The carbon benefits of cloud computing

A study on the Microsoft Cloud in partnership with WSP

Updated 2020

This white paper is an update to "Cloud Computing and Sustainability: The Environmental Benefits of Moving to the Cloud," published in 2010. In this paper, we have expanded the older study to show how the Microsoft Cloud can accelerate energy savings and reduce carbon emissions.

Contents

Foreword

Today, a technology revolution is transforming virtually every aspect of life as we know it. The scale of its impact is on par with the discovery of electricity, such that some are calling this era the Fourth Industrial Revolution. Powering this revolution are cloud computing and the technological advancements that underpin it. With cloud computing, businesses, governments, institutions, and individuals are able to access nearly unlimited computing power at the push of a button, enabling them to gain insights and make discoveries previously not dreamed of in fields such as healthcare, agriculture, and retail. And yet, even as the cloud unlocks humanity's vast potential, the exponential expansion of IT infrastructure raises questions about the environmental impacts from this growth.

At Microsoft, we believe the science on climate change is clear, and that the world must reach "net zero" emissions, removing as much carbon as it emits each year. In support of this, in 2020 we reaffirmed our commitment to thread sustainability into everything we do, and announced an ambitious goal and new plan to reduce and ultimately remove Microsoft's carbon footprint. As part of that plan, we will shift to a 100 percent supply of renewable energy by 2025, and take action to remove more carbon than we emit by 2030—the same year by which we will reduce our carbon emissions more than 50 percent and electrify our fleet of global campus vehicles. By 2050, we will remove our historic carbon footprint. We are also deploying $1 billion from our climate innovation fund to accelerate the global development of carbon reduction, capture, and removal technologies, which will be required to enable us to achieve our goals.

We are equally committed to extending the benefits of the cloud beyond our operations to our customers, by working to deliver IT services with a smaller environmental footprint. Increasing demand for computing services is inevitable, and we aim to support this growth as responsibly as possible. We engaged external experts to conduct this study, comparing the Microsoft Cloud with traditional enterprise datacenter deployments. The results show that the Microsoft Cloud delivers impressive sustainability benefits, and point to the opportunity for business and society to reduce the carbon footprint associated with computing in support of a more sustainable future.

We invite you to read about the environmental advantages of deploying your applications in the Microsoft Cloud.

Noelle Walsh
Corporate Vice President, Cloud Operations + Innovation (CO+I)
Microsoft Corporation

Executive summary

Cloud computing makes it possible to collect, analyze, and store huge quantities of data, reduce the total cost of ownership of IT, and increase business agility. Today, datacenters supporting the cloud consume a significant, and growing, amount of energy.

Societally, moving from many on-premises servers to fewer large datacenters presents the opportunity to reduce overall IT consumption of energy and related carbon emissions. With this in mind, Microsoft commissioned a study to compare the energy consumption and carbon emissions[1] of four applications in the Microsoft Cloud with their on-premises equivalents:

- **Microsoft Azure Compute**
- **Microsoft Azure Storage**
- **Microsoft Exchange Online**
- **Microsoft SharePoint Online**

We selected these cloud applications as they together account for about half of the energy consumed in Microsoft datacenters. To gain as full and accurate a picture as possible, the study considered the full life cycle for the computing scenarios (from manufacturing to end-of-life).

The results show that the Microsoft Cloud is between 22 and 93 percent more energy efficient than traditional enterprise datacenters, depending on the specific comparison being made. When taking into account our renewable energy purchases, the Microsoft Cloud is between 72 and 98 percent more carbon efficient. These savings are attributable to four key features of the Microsoft Cloud (Figure 1): IT operational efficiency, IT equipment efficiency, datacenter infrastructure efficiency, and renewable electricity.

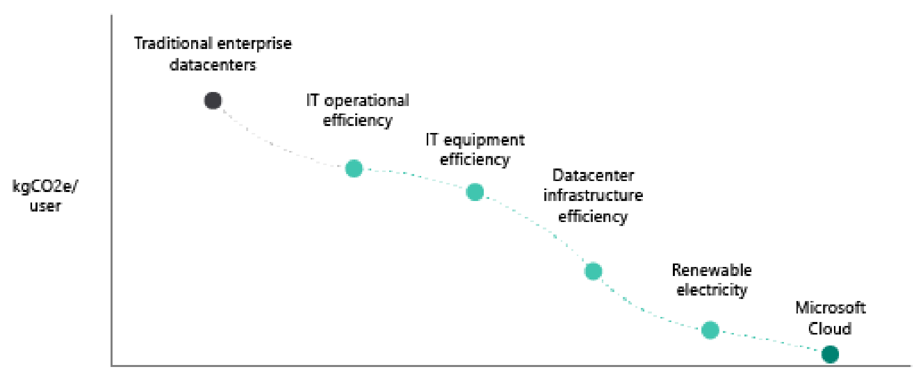


Figure 1*: The four features of the Microsoft Cloud that reduce environmental impact.
**kgCO2e = kilograms of carbon dioxide equivalent*

At Microsoft, our commitment is to create a cloud that is trustworthy, responsible, and inclusive. This study provides a current measurement of the potential energy efficiency and carbon savings that businesses can realize with the Microsoft Cloud. The impact of using our cloud services will improve even more as we continue to refine how we manage capacity, boost energy efficiency, reduce waste, and add new sources of renewable energy.

[1] Throughout this paper, “emissions” and “carbon” refer to all greenhouse gas (GHG) emissions.

Introduction:

Cloud computing and increasing energy consumption

The world is now entering the Fourth Industrial Revolution, which, as described by the World Economic Forum, will feature major technological advances in artificial intelligence, robotics, genomics, materials sciences, 3D printing, and more. Businesses, governments, and civic institutions can now collect, store, and analyze data at an unprecedented scale, speed, and depth. Big data and deep analytics unlock the potential to make a positive impact throughout the world, from conserving the world's freshwater supply to optimizing energy use in buildings. These improvements add up to financial savings and carbon reductions at a global scale.

Cloud computing—large-scale, shared IT infrastructure available over the internet—is the engine enabling these technology advancements. And these advancements, in turn, are driving cloud uptake. At the same time, the cloud can help businesses reduce their total cost of ownership[2] and realize greater business agility by delivering significant economies of scale and enabling access to data and applications anywhere.

But as the world's use of cloud computing accelerates, so too does the energy consumed in the cloud. In the United States alone, datacenters consume about 70 billion kilowatt-hours (kWh) of electricity each year, roughly 1.8 percent of the total electricity consumed in the country. This number is expected to grow to 73 billion kWh by 2020, about the same amount of energy that 6 million homes consume in one year.[3] This number would be higher if not for the efficiencies realized in many commercial cloud datacenters.

Following the Paris Agreement, as climate change gains public attention and as governments establish regulations to curtail carbon emissions, the environmental impact of computing is increasingly under scrutiny. At Microsoft, we embrace our responsibility to operate sustainably to reduce the climate impact of our business: we are committed to carbon neutral operations and purchasing renewable electricity. We are also committed to helping our customers understand and reduce the environmental impact of their computing.

As part of this commitment, we conducted a study to assess the environmental implications of cloud computing. Specifically, our objectives were to:

1. Assess the energy use and carbon emissions associated with key applications within the Microsoft Cloud in comparison with their on-premises equivalents.

---

[2] Total cost of ownership is the total cost of an IT solution or product over time. The metric considers direct and indirect costs, capital expenses (such as IT equipment), and operating expenses (such as equipment upkeep and software).

[3] Arman Shehabi, Sarah Josephine Smith, Dale A. Sartor, Richard E. Brown, Magnus Herrlin, Jonathan G. Koomey, Eric R. Masanet, Nathaniel Horner, Inês Lima Azevedo, and William Lintner. *United States Data Center Energy Usage Report*. Berkeley, CA: Lawrence Berkeley National Laboratory. LBNL-1005775. 2016.

2. Improve our understanding of the energy and carbon benefits of computing using Microsoft and other commercial cloud services in general compared with on-premises implementations.

The study builds on the 2010 Microsoft report *Cloud Computing and Sustainability: The Environmental Benefits of Moving to the Cloud*.[4] To conduct this updated study, Microsoft engaged WSP, a global consultancy with expertise in environmental and sustainability issues, to model the environmental impact of using Microsoft Cloud services instead of on-premises deployments. Stanford University IT sustainability and compute energy expert Dr. Jonathan Koomey served as an in-depth technical reviewer.

This paper presents the research approach and findings of the study, demonstrating that Microsoft Cloud computing offers significant advantages in energy consumption and carbon emissions over on-premises deployments, findings that are consistent with both the original study and other industry research[5].

---

[4] *Cloud computing and sustainability: The environmental benefits of moving to the cloud.* Accenture, WSP. 2010.
[5] P. Thomond. *The enabling technologies of a low-carbon economy: A focus on cloud computing.* Microsoft and GeSI. 2013.

Research approach:

Life cycle evaluation of on-premises and cloud IT services

This analysis uses a quantitative model to calculate and compare the energy consumption and carbon footprint of IT applications and compute and storage resources in the Microsoft Cloud with equivalent on-premises deployments (Figure 2). The model draws on greenhouse gas accounting principles from the World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD) Corporate Standard and Product Life Cycle Standard.

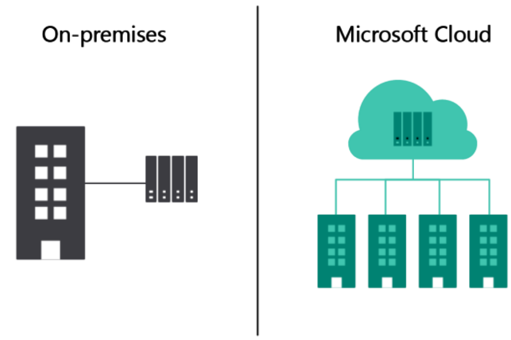


Figure 2: Study design: a quantitative evaluation of Microsoft Cloud services in comparison with on-premises deployment equivalents.

Cloud services

The study looks at four cloud services that account for nearly half of the energy consumed in Microsoft datacenters:

- Azure Compute
- Azure Storage
- Exchange Online
- SharePoint Online

Both Exchange Online and SharePoint Online were included in the original 2010 study.[6] However, in this study, the scope was expanded to include Azure services, which provide infrastructure as a service (IaaS), above and beyond software as a service (SaaS). Our aim was to generate a broader and more inclusive spectrum of data points to enable a more accurate assessment of the energy and carbon implications of different types of services used today.

On-premises deployment scenarios

The study considered a range of on-premises deployment scenarios relative to the four Microsoft Cloud services listed previously:

- Azure Compute comparisons:
    - Physical servers
    - Virtualized servers

[6] *Cloud computing and sustainability: The environmental benefits of moving to the cloud.* Accenture, WSP. 2010. *Note:* The original 2010 report focused on three business applications: Exchange Online, SharePoint Online, and Microsoft Dynamics CRM Online.

- Azure Storage comparisons:
    - Direct attached storage
    - Dedicated storage
- Exchange Online and SharePoint Online comparisons:
    - Small deployments: 1,000 users
    - Medium deployments: 10,000 users
    - Large deployments: 100,000 users

Functional units

We analyzed the cloud services and on-premises deployments based on the functional unit for each cloud service—that is, the "useful output" offered by a deployment. We defined these functional units based on the level of service offered by the Microsoft Cloud. This allowed for an apples-to-apples comparison between the Microsoft Cloud and on-premises alternatives. The functional unit for each service is listed in the following table:

Service	Unit	Quality and performance criteria[7]
Azure Compute	Core-hour	Net computational output
Azure Storage	Terabyte-year	Number of data replications
Exchange Online	Mailbox-year	Mailbox size and replications
SharePoint Online	User-year	Provisioned storage and replications

Life cycle phases

A life cycle assessment provides a full picture of the environmental impact of a product or service, from the raw material extraction for equipment manufacturing through the end-of-life treatment of equipment. Assessing the full life cycle helps to ensure inclusion of all major emission sources. In this study, we assessed each of the four cloud services and their on-premises equivalents for energy consumption and carbon emissions impacts across four life cycle phases, as illustrated in Figure 3 and described following.

Figure 3: The life cycle phases used to define the boundary of energy consumption and carbon emissions considered in the analysis.

[7] The quality and performance criteria are proprietary to Microsoft and therefore specific numbers are not shared.

1. **Raw material extraction and assembly**—includes the energy consumption and emissions associated with the use of the raw materials and the assembly of servers, networking equipment, and hard drives.
2. **Transportation**—represents the energy consumption and emissions associated with transporting the servers and other IT equipment from the manufacturer to Microsoft datacenters or on-premises datacenters.
3. **Use**—encompasses the energy consumption and emissions from electricity used to run the servers, networking equipment, hard drives, and datacenter infrastructure, such as lighting, cooling, and power conditioning. Where relevant, includes energy from data flows over the internet.
4. **End-of-life disposal**—includes end-of-life energy consumption and carbon emissions associated with landfilling and recycling, based on conservative assumptions about recycling rates.

Data sources and key parameters

Primary data from Microsoft datacenters and equipment were used wherever possible, and secondary data such as industry averages were used as necessary.

Key parameters considered in the analysis included:

- Equipment counts and specifications.
- Device utilization.
- Power draw of servers, storage devices, and networking equipment used within the datacenters.
- Power usage effectiveness (PUE) of datacenters hosting the services.
- Data flows over the internet.
- Carbon intensity of electricity supply.

Equipment counts, equipment specifications, and power draw for Exchange on-premises deployments were determined using the Exchange Server Role Requirements Calculator for Exchange 2016. On-premises Exchange, SharePoint, compute, and storage equipment counts and specifications were supplied by industry experts whose primary role is to deploy these solutions for enterprises. The Microsoft Cloud analysis was based on actual data collected from current Microsoft datacenter operations.

For a detailed description of each of these key parameters and model assumptions, please see Appendix I and Appendix II.

Findings:

Smaller footprint with the Microsoft Cloud

The results of this study reveal significant energy efficiency improvements—from 22 to 93 percent—when switching from traditional enterprise datacenters to the Microsoft Cloud for any of the four services. The specific savings achieved vary by service and deployment scenario. The greatest relative savings are realized when smaller enterprise deployments transition to the cloud. The features driving these reductions for the Microsoft Cloud include more efficient operational practices, IT equipment, and datacenter infrastructure. These efficiencies translate into both energy and carbon savings. When also accounting for our purchases of zero-carbon electricity, emissions savings with the Microsoft Cloud can be as great as 98 percent.

Energy and emissions results by service and deployment scenario

Microsoft Cloud services achieve energy and emissions reductions in comparison with every on-premises deployment scenario assessed. The primary driver for energy and emissions reductions in each comparison is decreased electricity consumption per useful output during the use phase in the datacenters that run the Microsoft Cloud. Figure 4 below, shows the range of savings by service based on deployment scenario as described in the

On-premises deployment scenarios

The study considered a range of on-premises deployment scenarios relative to the four Microsoft Cloud services listed previously:

- Azure Compute comparisons:
    - Physical servers
    - Virtualized servers

- Azure Storage comparisons:
    - Direct attached storage
    - Dedicated storage
- Exchange Online and SharePoint Online comparisons:
    - Small deployments: 1,000 users
    - Medium deployments: 10,000 users
    - Large deployments: 100,000 users

Functional units

We analyzed the cloud services and on-premises deployments based on the functional unit for each cloud service—that is, the "useful output" offered by a deployment. We defined these functional units based on the level of service offered by the Microsoft Cloud. This allowed for an apples-to-apples comparison between the Microsoft Cloud and on-premises alternatives. The functional unit for each service is listed in the following table:

Service	Unit	Quality and performance criteria
Azure Compute	Core-hour	Net computational output
Azure Storage	Terabyte-year	Number of data replications
Exchange Online	Mailbox-year	Mailbox size and replications
SharePoint Online	User-year	Provisioned storage and replications

Life cycle phases

A life cycle assessment provides a full picture of the environmental impact of a product or service, from the raw material extraction for equipment manufacturing through the end-of-life treatment of equipment. Assessing the full life cycle helps to ensure inclusion of all major emission sources. In this study, we assessed each of the four cloud services and their on-premises equivalents for energy consumption and carbon emissions impacts across four life cycle phases, as illustrated in Figure 3 and described following.

Figure 3: The life cycle phases used to define the boundary of energy consumption and carbon emissions considered in the analysis.

section earlier.

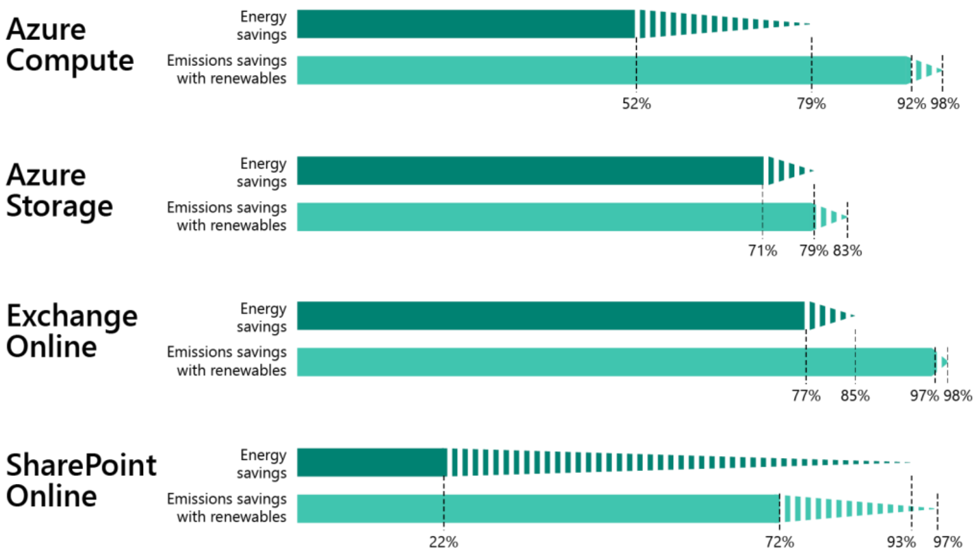


Figure 4: The range of energy and emissions savings by cloud service. "Energy savings" shows the energy savings of the datacenter electricity used in Microsoft Cloud services over the on-premises equivalents. "Emissions savings (with renewables)" shows the emissions savings of the Microsoft Cloud services over the on-premises equivalents, taking into account the purchase of zero-emission renewable electricity to power the Microsoft Cloud.

For detailed data sheets by service, see Appendix III.

Four energy- and carbon-reducing features of the Microsoft Cloud

Four main drivers contribute to the smaller energy and carbon footprint of the Microsoft Cloud (as illustrated in Figure 5). The first three—IT operational efficiency, IT equipment efficiency, and datacenter infrastructure efficiency—reduce the energy required to deliver the services. The fourth is the purchase of renewable electricity, which will power 100 percent of electricity consumed in Microsoft datacenters, buildings, and campuses by 2025. The remaining carbon emissions associated with the Microsoft Cloud are primarily from aspects of the life cycle outside Microsoft datacenters (that is, embedded carbon in the raw materials, equipment assembly, transportation, data flows, and end-of-life disposal).

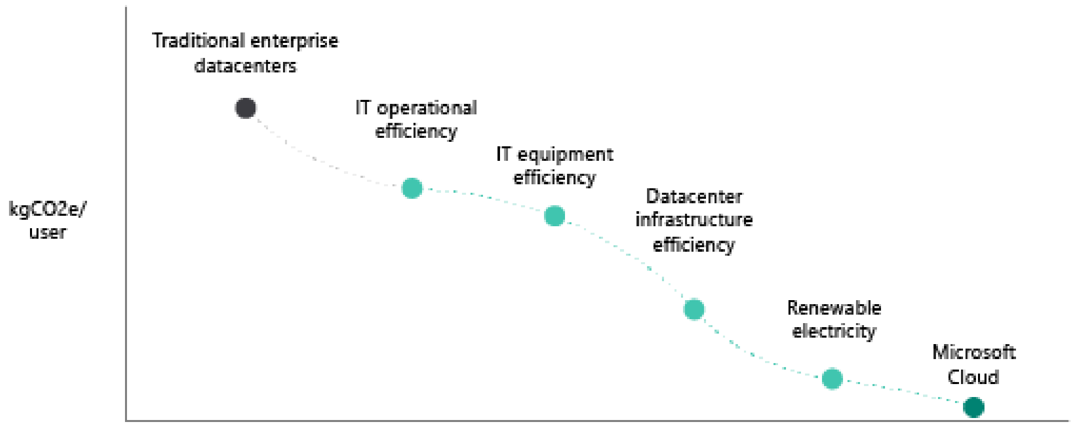


Figure 5*: The four features of the Microsoft Cloud that reduce environmental impact.
****kgCO2e*** *= kilograms of carbon dioxide equivalent*

The first three drivers of the reduced footprint (IT operational efficiency, IT equipment efficiency, and datacenter infrastructure efficiency) typically apply across all commercial cloud service providers, and even some on-premises scenarios, but will vary depending on factors such as the physical infrastructure and operational standards. Only cloud providers and private datacenters that purchase or use large volumes of renewable electricity will be able to achieve a carbon footprint comparable with the Microsoft Cloud.

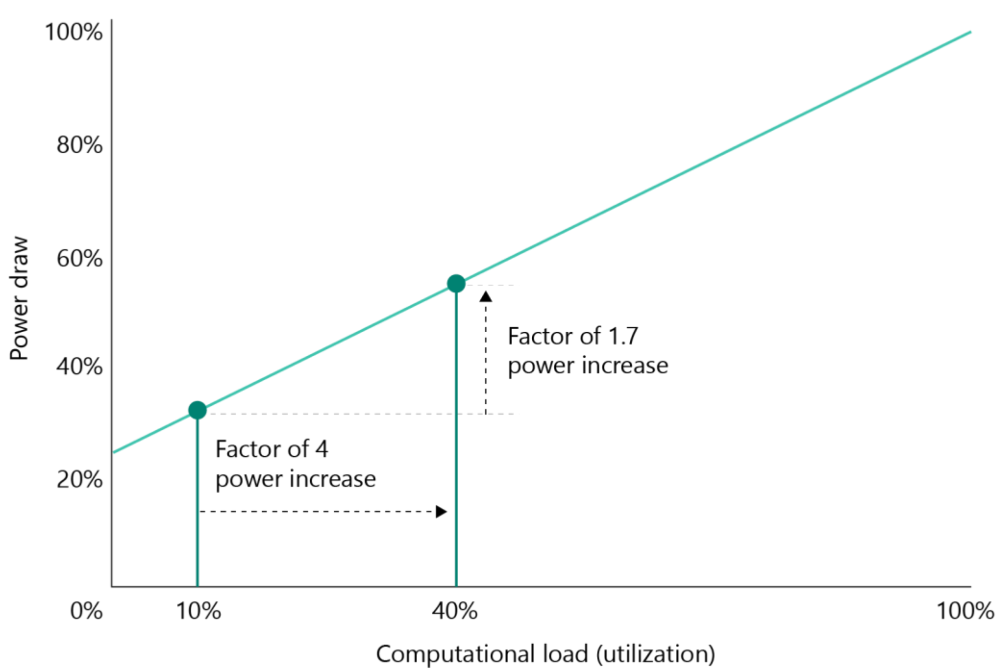
1. IT operational efficiency

The large economies of scale seen in cloud computing mean that commercial cloud services in general can operate with much greater IT operational efficiency than smaller, on-premises deployments.

- **Dynamic provisioning**—Emphasis on application availability can lead to overprovisioning of computing resources to avoid theoretical unmet demand. Improved matching of server capacity with actual demand minimizes waste. Microsoft manages capacity efficiently to avoid expensive overprovisioning, through monitoring and demand prediction that allow for continual capacity adjustment.
- **Multitenancy**—Microsoft uses multitenancy, occupying servers with multiple user types and a large user base with different demand patterns. Just as the electric grid interconnects thousands of users whose fluctuating power demands can balance one another, cloud infrastructure hosts thousands of companies and millions of users whose different use patterns can balance one another. This load diversity decreases overall fluctuations and makes loads more predictable. Generally, as the number of users increases, the ratio of the peak demand to the average demand for the user set decreases. Therefore, rather than sizing equipment to meet a single customer's peak load (for example, workers arriving at an office in the morning and immediately checking email), Microsoft sizes equipment to meet the time-coincident demand of the whole user set.

Server utilization—**Higher equipment utilization rates mean the same amount of work can be done with fewer servers, which in turn leads to less electricity consumed per useful output. While servers running at higher utilization rates consume more electricity, the overall performance gains more than offset the relative per-unit increase. As illustrated in**

- Figure 6, increasing the utilization rate from 10 percent to 40 percent will allow a server to process four times the previous load, while the power draw by the server may only increase 1.7 times.[8] Moreover, newer processors are continually driving towards a more attractive load curve where power draw is significantly reduced at idle or low utilization rates. The typically faster equipment replacement rates for commercial cloud service providers position them to take advantage of these improvements sooner than in on-premises deployments.



[8] Based on representative sampling of volume servers manufactured in the last two years, as measured using SPECpower_ssj2008 protocol from the Standard Performance Evaluation Corporation (SPEC).

Figure 6: As utilization increases, power per computational output decreases.

2. IT equipment efficiency

Because Microsoft spends a significant portion of operating expenses on electricity to run IT equipment, more so than the typical corporate IT department, we have a strong financial incentive to optimize IT efficiency. We take an active role in tailoring hardware components to the specific needs of the services we run, meaning the equipment runs leaner with a higher ratio of input energy going towards providing useful output than in traditional enterprise deployments. By collaborating with suppliers on the specification and design of servers and other equipment for maximum efficiency, Microsoft can realize benefits from scale that most corporate IT departments are unable to address. The results of this study suggest that more specialized, efficient IT equipment can reduce electricity consumption by 10 percent or more.

3. Datacenter infrastructure efficiency

Advanced infrastructure technologies in hyperscale datacenters reduce electricity requirements for overhead tasks such as lighting, cooling, and power conditioning. Power usage effectiveness (PUE)—the ratio of overall electricity consumption at the datacenter facility to the electricity delivered to the IT hardware—is a common measurement of how efficiently a datacenter uses electricity. The hyperscale datacenters that power the cloud are able to achieve better PUEs than typical enterprise datacenters. At Microsoft, we are committed to measuring PUE at each datacenter, and we are implementing better monitoring techniques and innovative design to continuously improve our PUE.

4. Renewable electricity

Consolidating distributed electricity demand from on-premises datacenters into the cloud unlocks the potential for large-scale purchases of green power that bring substantial renewable energy projects onto the grid that were not otherwise viable. We are committed to relying on a larger percentage of wind, solar, and hydropower electricity over time at our datacenters. By 2025, we will shift to 100 percent supply of renewable energy, meaning that we will have power purchase agreements for green energy contracted for 100 percent of carbon emitting electricity consumed by all our data centers, buildings, and campuses. When we’re not able to eliminate energy use or directly power our operations with green energy, we obtain zero carbon electricity through the purchase of renewable energy certificates. Counting these certificates, we purchase renewable electricity for more than 95 percent of our consumption, including electricity associated with services hosted in the Microsoft Cloud. For further discussion of how this is included in the calculations, see Appendix III.

Case study A:

A global engineering consulting firm

To assess the sustainability of the Microsoft Cloud in a real-world setting, this case study compared the energy and carbon footprint of a global engineering consulting firm that hosts roughly 10,000 users in Europe on Exchange 2016 on-premises with the equivalent footprint in the Microsoft Cloud.

The firm's implementation of Exchange was not as robust as the services offered by Exchange Online because the firm's deployment only had three copies of each database spread over two datacenters and a 5-gigabyte (GB) size limit for each mailbox. In contrast, even the most basic Exchange Online plan offers 50 GB of mailbox storage and, for most customers, four database copies spread across four geographically distinct datacenters to allow high levels of data redundancy and availability (as shown in Figure 7).

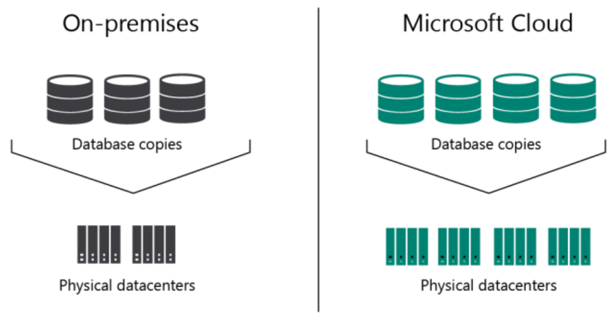


Figure 7: Contrasting the on-premises deployment of Exchange for a sample global engineering consulting firm (10,000 users) with the corresponding deployment in the Microsoft Cloud, which offers higher redundancy and availability.

Even while supporting a more robust Exchange environment than the on-premises deployment (with the additional infrastructure and energy demands that this entails), the Microsoft Cloud is estimated to reduce emissions by 93 percent compared with the on-premises environment (

Figure 8). These emissions reductions are a result of 6,000 kWh in energy savings and Microsoft renewable electricity purchases.

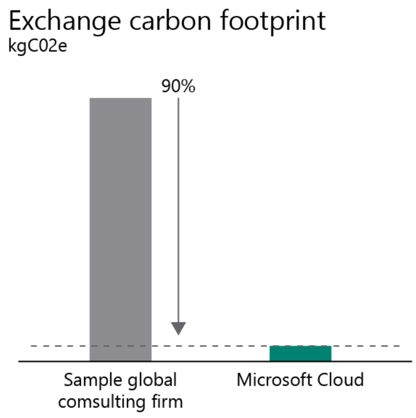


Figure 8*: Life cycle emissions results for an Exchange deployment for a sample global engineering consulting firm (10,000 users), showing emissions savings with the Microsoft Cloud versus on-premises.

****kgCO2e*** *= kilograms of carbon dioxide equivalent.*

Case study B:

A global apparel company

To assess the sustainability of the Microsoft Cloud in a real-world setting, this case study compared the energy and carbon footprint of a global apparel company's use of Azure virtual machines in 2016 with its on-premises alternative.

For solutions included in this study, the company chose to use Azure instead of deploying on-premises. Therefore, the footprint of the company's virtual machines in Azure was compared against the footprint had the same machines been deployed in the company's typical on-premises environment. The on-premises scenario was modeled on the deployments currently used by the company at a combination of both large and small owned datacenters in addition to co-located datacenters. Calculations considered the physical machine processing power, virtualization ratios, utilization, server power consumption, datacenter PUE, and carbon intensity of the electric grid.

The study found that the virtual machines deployed in Azure had a carbon footprint 70 percent smaller than the modeled on-premises equivalent (

Figure 9).

Azure provides both business and sustainability benefits by offering on-demand, global scalability in efficient, hyperscale, renewably powered datacenters.

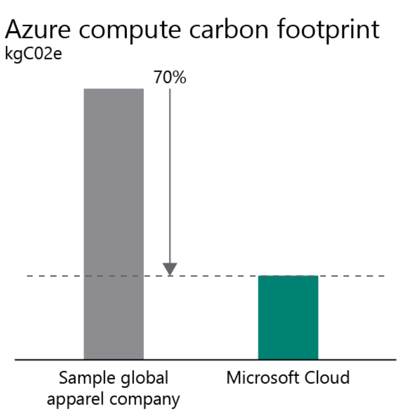


Figure 9*: Life cycle emissions results for an Azure compute deployment for a sample global apparel company, showing emissions savings with the Microsoft Cloud versus on-premises.

****kgCO2e** = kilograms of carbon dioxide equivalent.*

Looking ahead:

Becoming carbon negative by 2030

While the world will need to reach net zero, those of us who can afford to move faster and go further should do so. That's why we've committed to becoming carbon negative by 2030 and to ultimately remove Microsoft's carbon footprint from by the environment by 2050. We've concluded that seven principles will be vital as we continually innovate and take additional steps on an ongoing basis.

Grounding in science and math

It's vital that our work as a company to address carbon issues stay grounded in ongoing scientific advances and an accurate reliance on the basic but fundamental mathematical concepts involved. One aspect of this is relatively simple but quite important. Scientists account for carbon emissions by classifying them into three categories, or "scopes":

- Scope 1 emissions are the direct emissions that your activities create
- Scope 2 emissions are indirect emissions that come from the production of the electricity or heat you use
- Scope 3 emissions are the indirect emissions that come from all the other activities in which you're engaged. For a business, these emission sources can be extensive, and must be accounted for across its entire supply chain, the materials in its buildings, the business travel of its employees, and the full life cycle of its products, including the electricity customers may consume when using the product. Given this broad range, a company's scope 3 emissions are often far larger than its scope 1 and 2 emissions put together

Historically we've focused on reducing our scope 1 and 2 emissions, but we haven't calculated as thoroughly our scope 3 emissions. By 2030, we will be carbon negative for all three scopes.

Taking responsibility for our carbon footprint

We will drive down our scope 1 and 2 emissions to near zero by the middle of this decade with three steps.

- We will shift to 100 percent supply of renewable energy by 2025, electrify our global campus fleet by 2030, and pursue International Living Future Institute Zero Carbon certification and LEED Platinum certification for our Silicon Valley Campus and Puget Sound Campus modernization projects.
- In July 2020, we will start phasing in our internal carbon tax to cover scope 3 emissions.
- By 2030, we will remove more carbon than we emit, setting us on a path to remove by 2050 all the carbon we have ever emitted into the atmosphere since our founding in 1975.

Investing for new carbon reduction and removal technology

Our new Climate Innovation Fund will commit to invest $1 billion over the next four years into new technologies and expand access to capital around the world to people working to solve this problem. In addition to this new fund, we will continue to invest in carbon monitoring and modeling projects through our AI for Earth program, which has grown over the past two years to support more than 450 grantees across more than 70 countries.

Empowering customers around the world

We believe that Microsoft's most important contribution to carbon reduction will come not from our own work alone but by helping our customers around the world reduce their carbon footprints. We are also launching a new 24/7 matching solution with Vattenfall – a first-of-its-kind approach that gives customers the ability to choose the green energy they want and ensure their consumption matches that goal using Azure IoT.

Ensuring effective transparency

As we're doing today, Microsoft will continue to disclose the carbon footprint of our services and solutions. We will support strong industry-wide standards for transparency and reporting on carbon emissions and removal, and we will apply these ourselves. We have also signed the United Nations' 1.5-degree Business Ambition Pledge, and we hope many other companies will also join. We will publicly track our progress in our annual Environmental Sustainability Report.

Using our voice on carbon-related public policy issues

We will also use our voice to speak out on four public policy issues that we think can advance all of the world's carbon efforts:

- The need to expand global basic and applied research efforts on carbon, funded by governments, and reorient them towards targeted outcomes and enhanced cross-border collaboration to develop the breakthrough technologies needed to achieve net zero global emissions.
- The removal of regulatory barriers to help catalyze markets to enable carbon-reduction technologies to scale more quickly.
- The use of market and pricing mechanisms so people and businesses can make more informed carbon decisions.
- The empowerment of consumers through transparency based on universal standards to inform purchasers about the carbon content of goods and services

Enlisting our employees

Finally, we'll capitalize on the energy and intellect of our employees by inviting and encouraging them to participate in our carbon reduction and removal efforts. We will create more opportunities for our employees to become actively involved, both in company-wide activities and in the work of their individual teams. Each year this work will culminate during our annual weeklong hackathon event that will include a specific focus and call for proposals on carbon reduction and removal.

Appendix I:
Key parameters

The analysis considered the following key parameters:

- **Equipment counts:** the number of devices (servers, networking equipment, and storage devices) required to provision a given deployment. This includes excess capacity in both the cloud and on-premises scenarios to account for equipment required to meet peak loads or planned future growth.
- **Equipment specifications:** the specifications of servers, storage equipment, and networking devices used for the analysis. This includes number of cores, processor power, storage capacity, and power draw at different utilizations. Actual equipment specifications were used to model the Microsoft Cloud scenarios. Specifications for representative equipment, as determined by industry experts, were used to model on-premises deployment scenarios.
- **Device utilization:** the load that a device (server, networking switch, or storage device) handles relative to the peak load the device can handle. This number is expressed as a percentage.
- **Device power consumption:** the power consumed by a device, either measured directly, or extrapolated based on manufacturer specifications and device utilization.
- **Networking equipment power consumption:** the power consumed by networking equipment in the datacenter that is not directly measured or included explicitly in the deployment (for example, aggregation and core switches).
- **Datacenter PUE:** an efficiency metric that is the ratio of the total amount of electricity consumed by a datacenter to the amount of electricity delivered to the IT equipment. By definition, PUE is equal to 1 or greater, and the closer PUE is to 1, the more efficient the datacenter. PUE accounts for electricity used in the datacenter for lighting, cooling, power conditioning, and other support services.
- **Electricity from data flows over the internet:** the additional electricity use incurred in cloud computing and large on-premises deployments from sending data over the internet that would not occur in smaller deployments where IT resources are co-located with the users. This electricity use was considered for the Microsoft Cloud and for large-scale deployments based on assumed typical usage patterns of each service.
- **Electricity carbon intensity:** the average emission rate for the regionally specific mix of primary energy (such as hydro, natural gas, coal, and wind) used to generate electricity provided to the electric grid. In order to convert electricity into carbon emissions, the electricity consumption data is multiplied by the carbon intensity of the electric grid where the electricity is consumed.[9] As discussed in the Renewable electricity section earlier, we purchase renewable electricity for more than 95 percent of our consumption.

---

[9] Electricity carbon intensities are obtained from the US Environmental Protection Agency (EPA)'s eGRID for the United States and the International Energy Agency (IEA) or national environmental agencies for all other countries.

To demonstrate the carbon and energy savings possible with the Microsoft Cloud, we performed two separate analyses in this study:

1. One that did *not* take into account Microsoft's renewable electricity purchases. For this analysis, the emissions related to electricity consumption during the use phase were calculated using the carbon intensity from the local electric grid where Microsoft datacenters operate.

2. One that *did* take into account the zero emissions associated with our renewable electricity purchases.

The cloud service-specific results of these analyses are presented in Appendix III. Note that for the purposes of discussion in this paper, the study assumes on-premises deployments are located in the United States, whereas the Microsoft Cloud emissions are based on the average carbon intensity of the electric grid in the locations where Microsoft datacenters host a given service.

Appendix II:

Model assumptions

Embedded emissions

- Embedded emissions include the emissions associated with the raw material extraction and processing of the IT equipment required for the service. These factors are sourced from the article "Characteristics of Low-Carbon Data Centers" by Masanet et al.[10]
- Embedded emissions are amortized over the expected lifetime of each device.

Transportation

- The model considers the emissions from transporting IT equipment from tier 1 suppliers to the datacenter. Shipment is assumed to be via truck and marine freight. Transportation for the equipment used in Microsoft datacenters is based on the actual location of the datacenters and Microsoft tier 1 suppliers. Emission factors for trucks and cargo ships are from the GaBi databases.[11]
- Transportation emissions are amortized over the expected lifetime of each device.

Use phase energy

- Device utilization is either measured directly or based on expected values provided by industry experts.
- The expected power consumption for equipment at different utilization rates is based on equipment specifications provided by Microsoft engineers or manufacturer-specified values. Where possible, manufacturer-specified values were validated against published test results performed using the SPECpower_ssj 2008 methodology.
- PUE is based on measured values for Microsoft datacenters and industry values, by datacenter type, for on-premises deployments.[12] The datacenter type for on-premises implementations was matched to the deployment size and architecture (that is, larger deployments are housed in larger, more efficient datacenters).
- Energy use and emissions from data flows over the internet were estimated based on assumed typical data flow rates by application type. A kWh/gigabyte (GB) factor was used to estimate

[10] Eric Masanet, Arman Shehabi, and Jonathan Koomey. "Characteristics of Low-Carbon Data Centers." *Nature Climate Change* 3 (2013): 627-630.

[11] thinkstep. GaBi Software-System and Database for Life Cycle Engineering, 1992-2017. thinkstep AG. Accessed February 24, 2017.

[12] Arman Shehabi, Sarah Josephine Smith, Dale A. Sartor, Richard E. Brown, Magnus Herrlin, Jonathan G. Koomey, Eric R. Masanet, Nathaniel Horner, Inês Lima Azevedo, and William Lintner. *United States Data Center Energy Usage Report*. Berkeley, CA: Lawrence Berkeley National Laboratory. LBNL-1005775. 2016.

electricity consumption,[13] and emissions were calculated based on the carbon intensity of the electric grid where the datacenter is located.

End-of-life disposal

- End-of-life disposal includes emissions associated with landfill and recycling for servers, hard disk drives, and network switches.[14]
- The model assumes a conservative recycling rate of 20 percent. Even with a low assumed recycling rate, these emissions are negative due to the credit based on avoided use of virgin material from recycling.
- End-of-life emissions are amortized over the assumed lifetime of the device.

Model exclusions

Unless otherwise noted, the following are excluded given their negligible impact:

- Embedded carbon in the building, including cooling and air conditioning equipment.
- Microsoft corporate overhead, including administration and software development.
- Upstream emissions from extracting the fuel used to power the electric grid.
- Embedded emissions for certain IT equipment not exclusively used by the modeled service, such as datacenter switches not located in the server racks.

[13] Joshua Aslan, Kieren Mayers, Jonathan G. Koomey, and Chris France. "Electricity intensity of Internet data transmission: Untangling the estimates." *Journal of Industrial Ecology*. doi:10.1111/jiec.12630. August 1, 2017.
[14] E. Masanet, et al. *Optimization of product life cycles to reduce greenhouse gas emissions in California*. California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2005-110-F. August 5, 2005.

Appendix III:

Energy and carbon benefits of Microsoft Cloud services

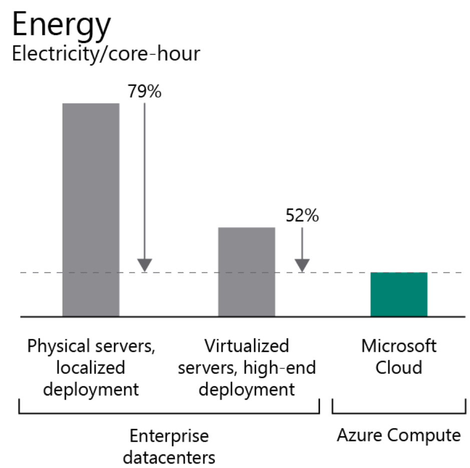
The following pages provide standalone datasheets that summarize the energy and carbon benefits of using each of the Microsoft Cloud services covered in this paper: Azure Compute, Azure Storage, Exchange Online, and SharePoint Online.

Azure Compute

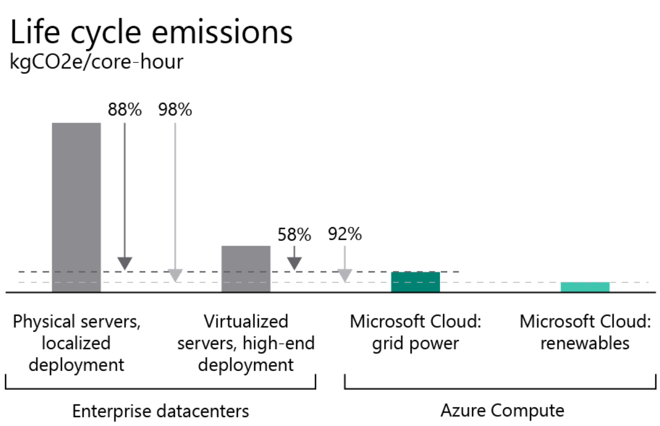
We conducted a study with industry experts to determine the energy use and carbon emissions associated with Azure Compute compared with compute equivalents deployed in traditional enterprise datacenters. Our methodology considered the impact of the IT equipment and operations, datacenter infrastructure, and information flows over the internet required to provide a cloud service and its traditional on-premises equivalent.

The results show that **Azure Compute is 52–79 percent more energy efficient** than compute equivalents deployed in traditional enterprise datacenters *(right)*, depending on the type of enterprise deployment.

In addition to providing greater energy efficiency through the Microsoft Cloud, we purchase renewable electricity for more than 95 percent of our consumption, which includes the datacenters that power Azure Compute. **When renewable energy is taken into account, carbon emissions from Azure Compute are 92–98 percent lower** than traditional enterprise datacenter deployments of compute equivalents *(below)*.



The graph below shows the emissions savings of transitioning compute functions from traditional enterprise datacenters to the Microsoft Cloud, using two approaches: (1) reflecting emissions associated with standard grid power for the Microsoft Cloud datacenters; and (2) taking into account zero carbon emissions associated with renewable electricity purchased for the Microsoft Cloud datacenters.



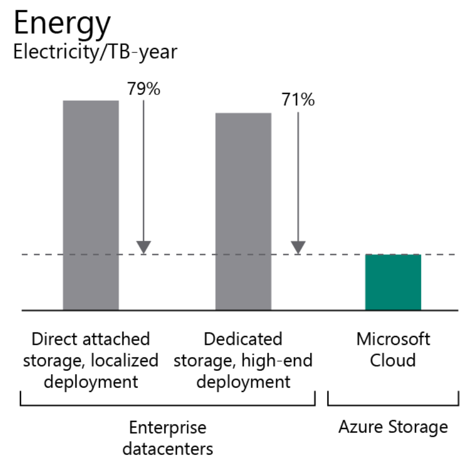
kgCO2e *= kilograms of carbon dioxide equivalent.*
Microsoft Cloud: grid power *includes emissions associated with datacenter electricity consumption before taking into account the purchase of renewable electricity.*
Microsoft Cloud: renewables *reflects zero emissions for renewable electricity purchased for datacenters. The residual emissions are primarily from life cycle emissions not associated with datacenter operations.*

Azure Storage

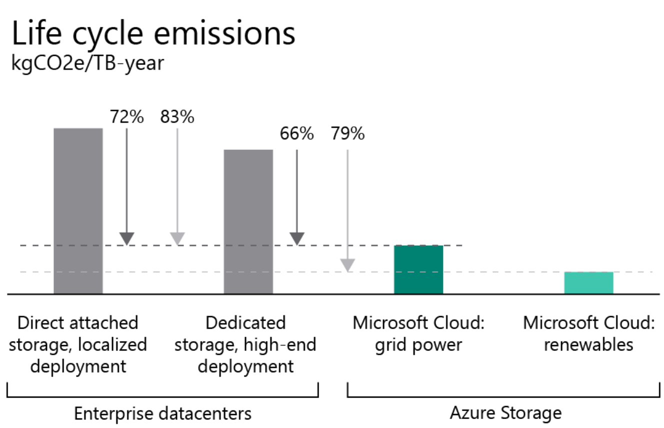
We conducted a study with industry experts to determine the energy use and carbon emissions associated with Azure Storage compared with storage equivalents deployed in traditional enterprise datacenters. Our methodology considered the impact of the IT equipment and operations, datacenter infrastructure, and information flows over the internet required to provide a cloud service and its traditional on-premises equivalent.

The results show that **Azure Storage is 71–79 percent more energy efficient** than storage equivalents deployed in traditional enterprise datacenters *(right)*, depending on the type of enterprise deployment.

In addition to providing greater energy efficiency through the Microsoft Cloud, we purchase renewable electricity for more than 95 percent of our consumption, which includes the datacenters that power Azure Storage. **When renewable energy is taken into account, carbon emissions from Azure Storage are 79–83 percent lower** than traditional enterprise datacenter deployments of storage equivalents *(below)*.



The graph below shows the emissions savings of transitioning storage from traditional enterprise datacenters to the Microsoft Cloud using two approaches: (1) reflecting emissions associated with standard grid power for the Microsoft Cloud datacenters; and (2) taking into account zero carbon emissions associated with renewable electricity purchased for the Microsoft Cloud datacenters.

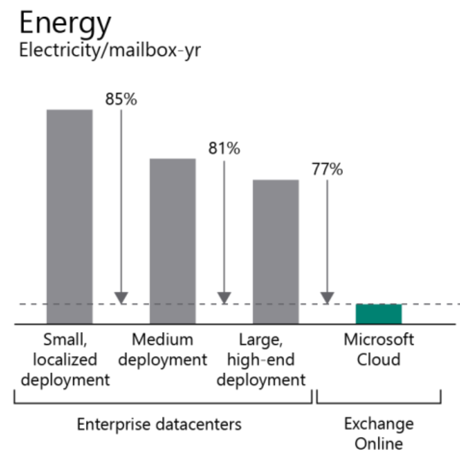


***kgCO2e** = kilograms of carbon dioxide equivalent.*
***Microsoft Cloud: grid power** includes emissions associated with datacenter electricity consumption before taking into account the purchase of renewable electricity.*
***Microsoft Cloud: renewables** reflects zero emissions for renewable electricity purchased for datacenters. The residual emissions are primarily from life cycle emissions not associated with datacenter operations.*

Exchange Online

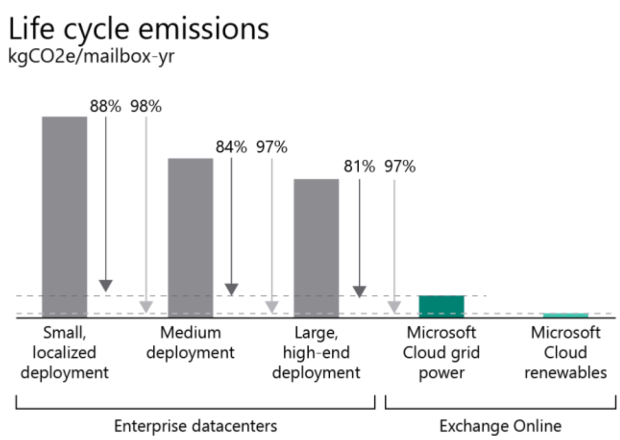
We conducted a study with industry experts to determine the energy use and carbon emissions associated with Exchange Online compared with Microsoft Exchange deployed in traditional enterprise datacenters. Our methodology considers the impact of the IT equipment and operations, datacenter infrastructure, and information flows over the internet required to provide a cloud service and its traditional on-premises equivalent.

The results show that **Exchange Online is 77–85 percent more energy efficient** than Microsoft Exchange deployed in traditional enterprise datacenters *(right)*, depending on the size of the enterprise deployment.



In addition to providing greater energy efficiency through the Microsoft Cloud, we purchase renewable electricity for more than 95 percent of our consumption, which includes the datacenters that power Exchange Online. **When renewable energy is taken into account, carbon emissions from Exchange Online are 97-98 percent lower** than traditional enterprise datacenter deployments of Exchange *(below)*.

The graph below shows the emissions savings of transitioning Exchange from traditional enterprise datacenters to the Microsoft Cloud using two approaches: (1) reflecting emissions associated with standard grid power for the Microsoft Cloud datacenters; and (2) taking into account zero carbon emissions associated with renewable electricity purchased for the Microsoft Cloud datacenters.

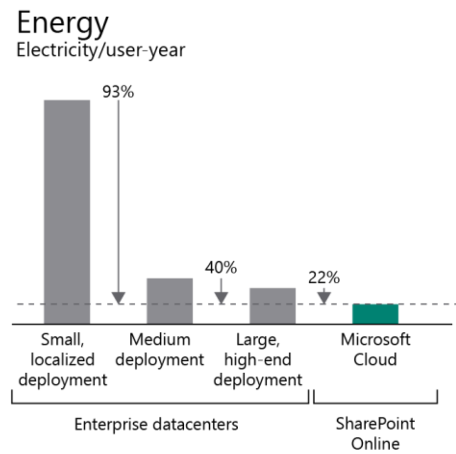


***kgCO2e** = kilograms of carbon dioxide equivalent.*
***Microsoft Cloud: grid power** includes emissions associated with datacenter electricity consumption before taking into account the purchase of renewable electricity.*
***Microsoft Cloud: renewables** reflects zero emissions for renewable electricity purchased for datacenters. The residual emissions are primarily from life cycle emissions not associated with datacenter operations.*

SharePoint Online

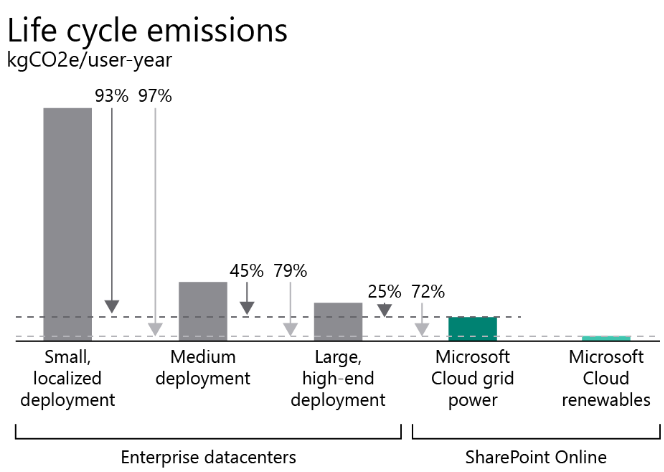
We conducted a study with industry experts to determine the energy use and carbon emissions associated with SharePoint Online compared with SharePoint deployed in traditional enterprise datacenters. Our methodology considers the impact of the IT equipment and operations, datacenter infrastructure, and information flows over the internet required to provide a cloud service and its traditional on-premises equivalent.

The results show that **SharePoint Online is 22–93 percent more energy efficient** than SharePoint deployed in traditional enterprise datacenters *(right)*, depending on the size of the deployment in the enterprise datacenter (small, medium, or large).



In addition to providing greater energy efficiency through the Microsoft Cloud, we purchase renewable electricity for more than 95 percent of our consumption, which includes the datacenters that power SharePoint Online. **When renewable energy is taken into account, carbon emissions from SharePoint Online are 72–97 percent lower** than traditional enterprise datacenter deployments of SharePoint *(below)*.

The graph below shows the emissions savings of transitioning SharePoint from traditional enterprise datacenters to the Microsoft Cloud using two approaches: (1) taking into account emissions associated with standard grid power for the Microsoft Cloud datacenters; and (2) taking into account zero carbon emissions associated with renewable electricity purchased for the Microsoft Cloud datacenters.



kgCO2e *= kilograms of carbon dioxide equivalent.*
Microsoft Cloud: grid power *includes emissions associated with datacenter electricity consumption before taking into account the purchase of renewable electricity.*
Microsoft Cloud: renewables *reflects zero emissions for renewable electricity purchased for datacenters. The residual emissions are primarily from life cycle emissions not associated with datacenter operations.*