# Enabling More Agile and Sustainable Business Through Carbon-Efficient Digital Transformations

**An IDC White Paper, Sponsored by VMware**

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## IDC OPINION

Enterprises worldwide, across geographies and industries, are pursuing the imperative of digital transformation (DX), which enables them to stay ahead of their competition through business agility and operational efficiency. This is becoming a nonnegotiable imperative as organizations face relentless competitive pressure from both traditional rivals and digital upstarts.

Successful DX journeys are built on the foundations of modern infrastructure paradigms such as virtualization, cloud computing, containers, serverless infrastructure, and innovations like artificial intelligence (AI)/ML technologies. Virtualization technologies have served as the bedrock on which organizations of all sizes have modernized their datacenter environments. By virtualizing compute, storage, and networks, organizations can transform to modern software-defined datacenters that employ a cloud operating model for better agility, flexibility, utilization, and scalability.

**Virtualization technologies have served as the bedrock on which organizations of all sizes have modernized their datacenter environments.** By virtualizing compute, storage, and networks, organizations can transform to modern software-defined datacenters that employ a cloud operating model for better agility, flexibility, utilization, and scalability.

Enterprises rely on virtualized environments for a wide variety of workloads, including mission-critical applications and new cloud-native containerized applications. While early virtualization deployments focused on server consolidation and increased server utilization, the concept and benefits of virtualization have been subsequently extended to storage and networking. VMware integrates its core virtualized infrastructure portfolio (vSphere for compute, vSAN for storage, and NSX for networking) in the form of VMware Cloud Foundation that enterprises can deploy in their own premises or access as a hybrid service offered by major cloud providers. VMware Cloud Foundation provides consistent hybrid and multicloud infrastructure that enables enterprises to build a software-defined datacenter spanning traditional IT on-premises, private cloud, and multiple public cloud environments. The same VMware Cloud Foundation platform natively supports the VMware Tanzu product portfolio, enabling development, deployment, management, and securing of modern containerized applications on Kubernetes clusters across on-premises, public cloud, and hybrid and multicloud environments.

IDC research finds that VMware, through its portfolio of infrastructure virtualization technologies, achieves a significant impact globally in reducing carbon emissions, which is quantified in this document in terms of net-avoided carbon emissions on a year-over-year basis.

Infrastructure virtualization technologies not only provide the architectural basis for enhanced operational and business agility in the cloud era but also increase the utilization and reduce the overall footprint of physical datacenter infrastructure. The result is reduced hardware and facilities-related costs, such as servers, power consumption, and cooling. The resource-saving contributions of storage virtualization, as represented by VMware's vSAN, and network virtualization, as represented by NSX, have grown significantly with the increased adoption of those product portfolios. vSAN has allowed customers to add storage capacity in modular increments, replace HDDs with more power-efficient SSDs, and replace Fibre Channel host bus adapters (FC-HBAs) and switch ports with more power-efficient Ethernet network interface cards (NICs) and ports. NSX has evolved as a network virtualization overlay to support both VMware and non-VMware application environments on premises and across multiple clouds. NSX provides a broad set of software-defined networking services for virtual machines (VMs) and Kubernetes containers including microsegmentation and firewalls, application delivery controllers (ADC), load balancers, and SD-WAN. Consequently, NSX is improving server utilization, improving power efficiency, and obviating the need for physical appliances and the resources they consume.

In turn, the overall reduced power consumption delivered by infrastructure virtualization results in lower carbon emissions (measured in terms of carbon dioxide, or CO2, emissions). IDC research finds that VMware, through its portfolio of infrastructure virtualization technologies, achieves a significant impact globally in reducing carbon emissions, which is quantified in this document in terms of net-avoided carbon emissions on a year-over-year basis. Furthermore, IDC research indicates that virtualized infrastructure has accounted for a consistently growing portion of the overall datacenter infrastructure deployed since its inception.

# Methodology

This is the fifth iteration of a VMware-sponsored IDC initiative to measure the impact of IT infrastructure growth in terms of carbon emissions and the influence infrastructure virtualization has had on curbing growth of these emissions.

Like prior studies, for this study, IDC used a conservative and defensible approach to calculate the server host infrastructure avoided and the associated power consumption and carbon dioxide emissions that were avoided because of enterprise use of VMware's virtualization infrastructure. The estimates include incremental virtualizations implemented in 2019 as well as contributions from the installed base of virtualized infrastructure still in operations as of 2015 providing ongoing avoided energy and carbon savings.

For storage and networking, the savings are twofold — savings associated with displacement of storage appliances and switches and using high-efficiency storage devices.

IDC used published data where possible, including IDC's Worldwide Quarterly Trackers covering enterprise servers and server virtualization. This data was used to establish the number of physical servers deployed, including the portions both with and without virtualization capabilities, from 2008 to 2019. IDC extended this data model back to 2003 to establish the total amount of servers deployed with VMware virtualization during the early years of adoption. Server virtualization data was estimated for 2016–2019 as IDC's Server Virtualization Tracker was discontinued after 2015.

For storage and networking, the savings are twofold — savings associated with displacement of storage appliances and switches and using high-efficiency storage devices.

IDC calculated the impact of vSAN and NSX on host server utilization and resultant storage appliance and switch displacement. The annual avoided infrastructure estimate was combined with avoided installed base estimates to determine the total avoided infrastructure counts for each year. For the installed base estimates, a useful life of 4.5 years was assumed. IDC used data on IT equipment avoidance from 2019 vSphere, vSAN, and NSX new deployments and existing installations, as well as weighted-average power data and annual runtimes to determine both annual and cumulative, since 2003, megawatt-hours (MWh) avoided. IDC also calculated energy and carbon emissions savings associated with the replacement of HDD-based storage with SSD-based storage devices.

The cumulative savings from storage virtualization were combined with compute virtualization savings. In addition to energy savings from avoided infrastructure during 2019, IDC also calculated power consumption avoided because of cooling and other non-IT equipment energy savings using a power usage effectiveness (PUE) of 1.6. This assumes approximately 37.5% of the total energy consumed by the datacenter is for operations such as cooling.

Equivalent power consumption avoidance data was then converted into metric tons of carbon dioxide (MT CO2) emissions avoided using the weighted-average annual U.S. electricity carbon emissions factor as published by the U.S. Energy Information Administration for the year 2019.

Equivalent power consumption avoidance data was then converted into metric tons of carbon dioxide (MT CO2) emissions avoided using the weighted-average annual U.S. electricity carbon emissions factor as published by the U.S. Energy Information Administration for the year 2019. An equivalent power consumption avoided for electric vehicles was calculated using miles per gallon gasoline equivalent (MPGe) rating published by the U.S. Environmental Protection Agency (EPA), and the carbon emissions avoided by Tesla electric vehicles were calculated using the carbon impact calculator published by Tesla.

A detailed methodology is included in the Appendix of this document.

These technologies, in addition to innovation accelerators such as Internet of Things (IoT) and cognitive computing/artificial intelligence (AI), can propel broader business transformation by creating value and competitive advantage through new offerings, business models, and relationships.

# Situation Overview

## Carbon-Efficient DX Strategies Start with a Foundation of Virtualized Infrastructure

Enterprises globally are putting DX and associated 3rd Platform technologies of cloud, mobile, social, and big data at the heart of their IT strategies. These technologies, in addition to innovation accelerators such as Internet of Things (IoT) and cognitive computing/artificial intelligence (AI), can propel broader business transformation by creating value and competitive advantage through new offerings, business models, and relationships. However, deployments of these next-generation technologies also create new challenges and requirements for IT departments.

Most enterprises undertaking DX initiatives continue to rely on legacy applications, often mission-critical workloads, for key pieces of their IT environments. This is unlikely to change for the foreseeable future, even as DX and IT transformation (ITX) remain long-term priorities for most organizations. In addition to these legacy apps, DX strategies encompass next-generation applications deployed using 3rd Platform and innovation accelerator technologies.

A key challenge for IT departments globally is how to effectively manage this evolving mix of legacy and modern infrastructure to effectively execute DX while keeping IT footprints secured and functioning properly. Furthermore, DX inevitably entails risks, including added complexity and security concerns.

Hybrid cloud environments — combinations of traditional virtualized, private cloud, and public cloud infrastructure — can provide enterprises with consistent, seamless, and interoperable environments to run their legacy and modern applications. Organizations starting with a foundation of virtualized IT environments using VMware technologies can benefit in several ways, as detailed in the sections that follow.

### *Consolidation*

- Elimination of IT sprawl and underutilized datacenter resources via improved utilization of servers, storage, and networking hardware
- Cost reduction via reduced infrastructure capex and opex due to lower power, cooling, and other datacenter overhead requirements, supporting the ability to reinvest in DX initiatives
- Improved infrastructure flexibility and business agility
- A focus on strategic initiatives enabled by faster provisioning and improved productivity that help IT staff

## *Modernization*

Through offerings such as VMware Cloud Foundation:

- An ability to implement a software-defined datacenter and bring cloud operating models and benefits to enterprise environments
- An ability to bridge siloed environments through a consistent and interoperable management layer
- Facilitation of partnerships with cloud providers that enable workload mobility and portability in hybrid, multicloud environments

Through offerings such as the VMware Tanzu portfolio:

- An ability to develop and run containerized and microservices-based applications on Kubernetes clusters
- An ability to declaratively manage, secure, and control microservices-based applications

## *Innovation*

- An ability to leverage technology innovations such as AI/ML technologies by running virtualized GPUs on vSphere to take advantage of the cost and carbon benefits of shared GPU infrastructure
- An ability to leverage higher-order services offered by cloud service providers through hybrid cloud infrastructure

## Measuring the Impact of VMware Virtualization on Physical Infrastructure Requirements

At the most basic level, infrastructure virtualization enables a net reduction in the amount of physical infrastructure deployed in any IT environment.

At the most basic level, infrastructure virtualization enables a net reduction in the amount of physical infrastructure deployed in any IT environment. The software (i.e., the hypervisor) virtualizes the hardware layers, presenting a unique hardware instance (virtual machines) to every operating system instance for compute, a built-in software-defined data persistent layer for these virtual machines (using server-based storage), and a networking subsystem (for east-west and north-south networking traffic). This enables IT to consolidate multiple server operating system instances as well as their associated storage and networking layers and the workloads hosted on them on to a smaller number of physical servers. VMware's virtualization software — the first commercially available software for x86 servers — enabled IT to accelerate the deployment of applications while sharply reducing spend on new servers.

IDC research suggests average VM densities, or the amount of VMs per host server, have steadily expanded over time due to incremental advances in computing technologies. In the early stages of virtualization, technological limitations held average VM densities for 2–3 VMs per host. Today, average VM densities have risen above 10 VMs per server. This trend has a direct correlation with the ability of IT departments to leverage virtualization to drive IT hardware consolidation at their organizations. VM sprawl refers to the phenomenon of using compute virtualization liberally, deploying more virtual server instances than required due to the relative ease and perceived low marginal cost.

Reducing the amount of physical IT infrastructure in use leads to an associated savings in datacenter floor space and power consumed by IT infrastructure deployments that have been avoided.

Reducing the amount of physical IT infrastructure in use leads to an associated savings in datacenter floor space and power consumed by IT infrastructure deployments that have been avoided. In addition, in aggregate, there is a commensurate reduction in cooling system power consumption and other ancillary datacenter services that is proportional to the datacenter's overall operational efficiency.

Within a few years, the role of a hypervisor has expanded beyond virtualizing compute to provide core infrastructure functions for data persistence (storage) and networking functions. On the storage side, IT can reduce spend on storage arrays by deploying server-based flash along with a software-defined hyperconverged storage stack such as VMware vSAN. Compared with proprietary storage, server-based storage makes it possible to add storage capacity in smaller increments for greater storage utilization. Contrarily, procurement of proprietary storage arrays typically involves planning cycles of several years that negatively impacts infrastructure utilization.

Organizations deploying vSAN can also realize energy savings by replacing HDD-based storage environments with SSD-based storage environments. SSDs consume less power on average compared with similar capacity HDDs. Further, all-flash storage requires fewer devices compared with HDD-based storage to meet performance needs, which can help organizations reduce datacenter floor space and cooling costs. While capacity needs can require that some more SSDs are added beyond what is dictated by performance requirements, storage efficiency technologies such as deduplication and compression enable organizations to store more data using less raw storage capacity compared with HDD-based systems.

vSAN also eliminates the need for FC-HBAs and Fibre Channel ports in favor of more efficient Ethernet network interface cards, which are found on nearly every x86 server platform. For hybrid configurations, each host requires a minimum of a single physical 1GB Ethernet NIC dedicated for vSAN use. For all-flash configurations, each host requires a minimum of a single physical 10GB Ethernet NIC available for vSAN use. Higher speeds, such as 25Gb, 40Gb, and even 100Gb NICs, are expected to become commonplace in the near future.

NSX can have a beneficial impact on the overall datacenter footprint in three ways. First, it can reduce compute overhead through better server utilization by performing network segmentation (microsegmentation) in the hypervisor rather than requiring physical server segmentation.

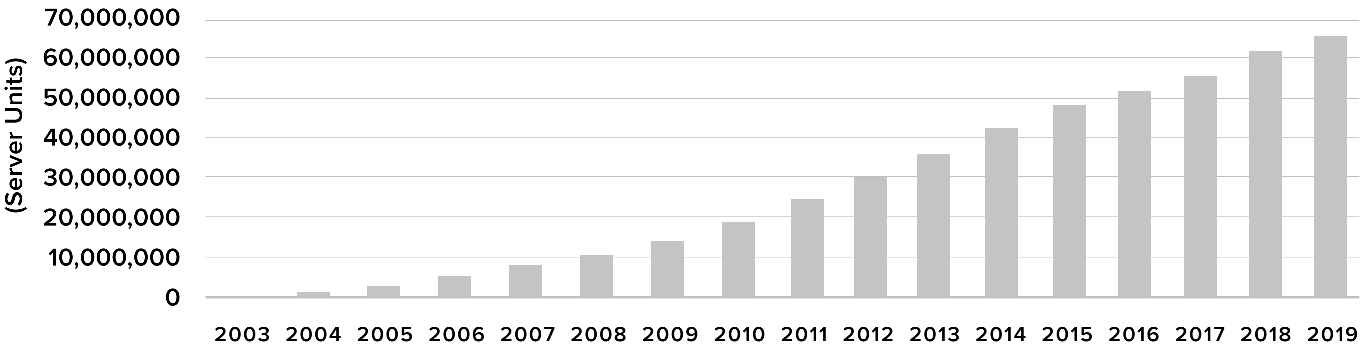
On the networking side, IT can reduce spend on physical network and security devices and appliances by deploying software-defined networking, such as VMware NSX's network virtualization overlay, which now extends from Layer 2 to Layer 7 of the OSI stack. Network traffic can be reduced because VM-to-VM traffic can remain within a physical server, and firewall traffic is reduced because NSX performs hypervisor-based distributed firewalling.

NSX can have a beneficial impact on the overall datacenter footprint in three ways. First, it can reduce compute overhead through better server utilization by performing network segmentation (microsegmentation) in the hypervisor rather than requiring physical server segmentation. Second, its ability to switch and route east-west (VM-to-VM) network traffic within the hypervisor, rather than having to traverse the physical datacenter network, reduces the number of physical networking devices that are required. Third, it minimizes the use of network and security appliances because NSX performs distributed firewalling within the hypervisor and now also provides load-balancing and ADC functionality in both virtualized and containerized environments. As a result, NSX typically reduces the number of physical and virtual hosts enterprises need to deploy, and that can have a beneficial impact on the overall datacenter footprint.

Figure 1 illustrates the avoided IT infrastructure benefits of virtualization resulting from the previously outlined factors. According to IDC estimates, over 66 million physical servers, storage appliances, and switches were not deployed in 2019 because of implementations of VMware's virtualization technologies, up from nearly 55 million infrastructure devices in 2017. These figures serve as the basis for calculating the amount of energy and $CO_2$ emissions avoided because of the use of VMware virtualization products. Because storage and network virtualization adoption is still relatively small compared with compute virtualization, the $CO_2$ impact from displaced storage and networking equipment has been combined with compute virtualization.

**FIGURE 1**

## Worldwide IT Infrastructure Avoided Because of the Use of VMware Virtualization Software, 2003–2019




Note: There are minor changes to historical data from the prior iteration to incorporate IDC's most up-to-date published data and other modeling refinements.
Source: IDC, 2020

## Measuring the Impact of Avoided IT Infrastructure on Power Consumption and Datacenter $CO_2$ Emissions

The power consumption avoided is directly proportional to the avoidance of physical servers and the corresponding workloads (and their associated storage and networking) being deployed on virtual machines hosted by a hypervisor running on existing physical servers.

Using the calculated number of servers (refer back to Figure 1) that were avoided because of the use of VMware's virtualization products, IDC calculated the power consumption avoided using the following formula:

$$P_s = N_s \times S_s \times H_s$$

$$P_T = \sum P_s$$

$$P_c = \sum P_T$$

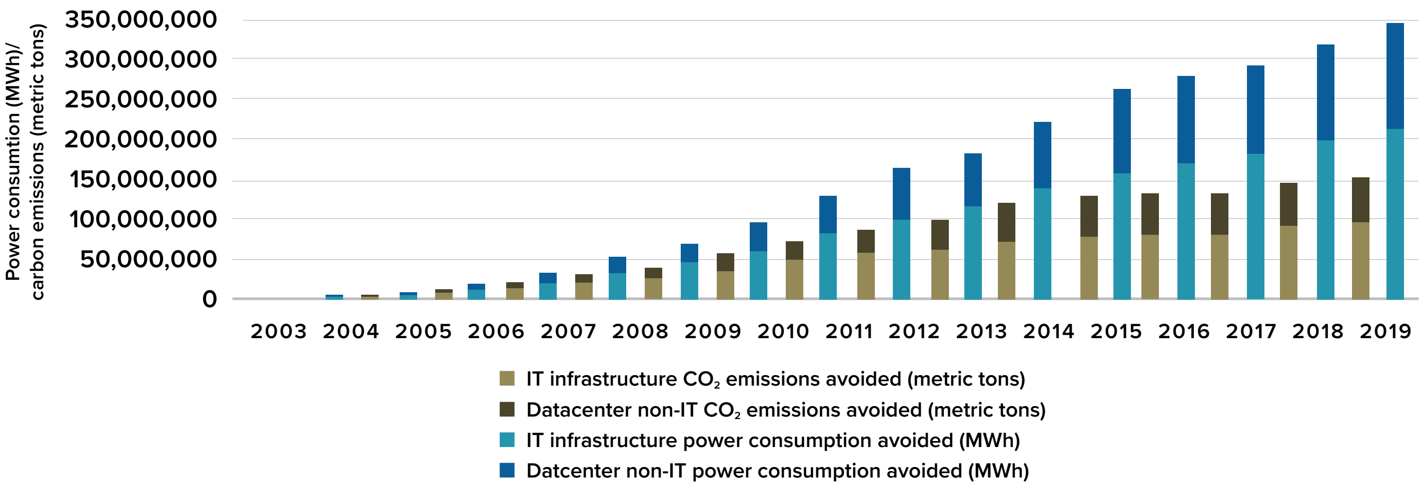
Where

- $P_s$ is the annual power consumption avoided (MWh) for a given type of displaced IT infrastructure
- $N_s$ is the estimated number of physical servers or storage arrays avoided in a given year, including installed base for each equipment type
- $S_s$ is the weighted-average power of each avoided physical server or storage array type (MW)
- $H_s$ is the total number of hours of use per year per server or storage array type
- $P_T$ is total power consumption avoided (MWh) across all displaced IT equipment in a given year
- $P_c$ is cumulative power consumption avoided (MWh) across all displaced IT equipment from 2003 to 2019

Figure 2 illustrates overall power consumption and carbon emissions avoided using VMware virtualization products.

**FIGURE 2**

## Worldwide Power Consumption and Carbon Savings Associated with Infrastructure Avoidance Because of the Use of VMware Products, 2003–2019




Note: There are minor changes to historical data from the prior iteration to incorporate IDC's most up-to-date published data and other modeling refinements.
Source: IDC, 2020

According to IDC estimates, more than 66 million physical servers were not deployed because of VMware virtualization technologies in 2019, which equated to more than 217,480,000MWh of incremental energy saved during the year. Assuming a PUE of 1.6, more than 130,488,000MWh of additional energy savings were achieved due to reduced cooling load and other datacenter resources from smaller IT deployments.

The impact of power consumption avoided using VMware's virtualization products can be visualized by this simple analogy. With the total power consumption avoided in 2019 by using VMware's virtualization, a 2019 Tesla Model S Long Range electric car could be driven back and forth to Mars more than 4,000 times. With the cumulative power consumption avoided since 2003, this electric car could be driven back and forth to Mars more than 28,000 times!

IDC calculated $CO_2$ emissions using the following formula:

$$V_t = CEF_{US} * P_t$$

$$V_c = \sum V_t$$

Where

- $V_t$ is the annual $CO_2$ emissions reduction (metric tons) across all VMware virtualization products in a given year
- $CEF_{US}$ is the weighted-average annual U.S. electricity carbon emissions factor (metric tons $CO_2$/MWh) for a given year
- $P_t$ is the total annual power consumption avoided (MWh) across all VMware products in a given year
- $V_c$ is the cumulative $CO_2$ emissions avoided (metric tons) across vSphere, vSAN, and NSX products from 2003 to 2019

The amount of IT infrastructure-related $CO_2$ emissions avoided because of the use of VMware virtualization products grew from approximately 84 million metric tons in 2017 to more than 95 million metric tons in 2019 (refer back to Figure 2). An additional 57 million metric tons of $CO_2$ emissions savings were achieved in 2019 due to non-IT datacenter savings, for a combined total of 152 million metric tons. The total $CO_2$ avoidance from VMware virtualization in 2019 is equivalent to removing nearly 33 million cars from the road and the avoidance of over 378 billion miles driven using averages for U.S. vehicles. It is also equivalent to more than 337 times (cumulatively) or 40 times (in the year 2019 alone) that of the carbon impact of all of Tesla's electric cars in the United States put together. These figures would likely be even larger in the European market, as research suggests European vehicles have higher average fuel efficiency.

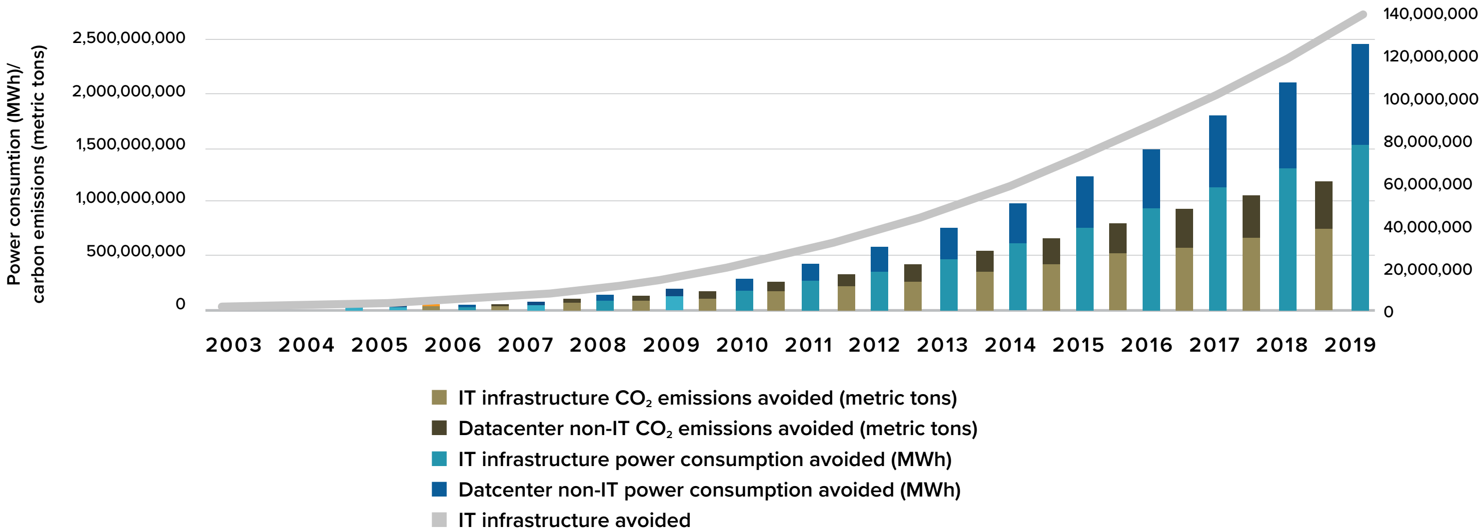
From a cumulative standpoint, IDC estimates over 142 million physical servers have not been deployed as a result of VMware virtualization since 2003.

From a cumulative standpoint, IDC estimates over 142 million physical servers have not been deployed as a result of VMware virtualization since 2003. This figure represents the sum of the annual net-new server instances running on servers equipped with VMware virtualization, discounted to account for VM sprawl, from 2003 to 2019.

Similarly, from a cumulative standpoint, IT infrastructure avoidance due to VMware virtualization equates to power consumption savings of over 1.5 billion MWh and $CO_2$ emissions avoidance of over 758 million metric tons from 2003 to 2019. An additional 455 million metric tons of $CO_2$ emissions savings were achieved over the period due to avoided non-IT datacenter energy for a combined total avoidance of 1.2 billion metric tons. Figure 3 shows the cumulative impact of VMware's virtualization solution.

**FIGURE 3**

## Worldwide Cumulative Infrastructure, Power Consumption, and Carbon Savings Because of the Use of VMware Products, 2003–2019




Note: Carbon emissions avoided includes IT equipment, as well as non-IT related datacenter power savings.
Source: IDC, 2020

# Conclusion

IDC has found that infrastructure virtualization software, the architectural foundation for cloud-era business agility, delivers a significant beneficial capex and opex impact by reducing the amount of hardware infrastructure required to support application workloads. Intensive infrastructure virtualization results in greater cost and energy savings on hardware and datacenter operations. As it turns out, however, the benefits do not end there.

The reduced cumulative and incremental power consumption provided by infrastructure virtualization also results in substantially lower carbon emissions (measured in terms of $CO_2$ emissions). This allows organizations that adopt infrastructure virtualization to achieve compelling reductions in carbon emissions on a cumulative and an incremental basis.

Through implementation of VMware's software-defined datacenter technologies such as vSphere, vSAN, and NSX, organizations can meaningfully pursue eco-conscious digital transformation initiatives. From 2003 to 2019, VMware's infrastructure virtualization software has produced a significantly reduced hardware infrastructure footprint that, in turn, has yielded a commensurate decline in power consumption savings and emissions avoidance. As a result, organizations that have deployed VMware's virtualization software have been able to combine greater IT efficiencies with salient contributions to the environment through the reduction of $CO_2$ emissions.

# Appendix

## Detailed Methodology

IDC used a conservative and defensible approach to calculate the incremental physical server infrastructure and the associated power consumption and carbon dioxide emissions avoided because of the industry's use of VMware virtualization software. Where possible, we used published IDC data as the basis for the secondary calculations.

The methodology applied is as follows:

1. IDC based this model on syndicated (published) IDC data including the following dimensions:
   - IDC's Worldwide Server Tracker data provided the basis for total worldwide server shipments. IDC used data from calendar years 2003 through 2019 as a starting point for this model.
   - IDC's Worldwide Quarterly Server Virtualization Tracker (discontinued in 2016) was the basis for new physical server shipments virtualized using VMware virtualization. IDC included the following VMware virtualization products: VMware GSX, VMware ESXi, VMware Server, and VMware vSphere. In addition, IDC included data for VMware vSAN and NSX to model the storage and networking impact. IDC's Worldwide Quarterly Server Virtualization Software Tracker provides data from 2008 through 2015, with more recent years being a modeled effort. Host servers running competitive hypervisors from Microsoft, Red Hat (acquired by IBM), Citrix, and others were specifically excluded from this analysis.
2. To bridge earlier historical years that predate IDC's Worldwide Quarterly Server Virtualization Tracker, IDC applied assumptions to solve for a complete historical view for the use of VMware hypervisor products on new server shipments virtualized (new servers shipped with a hypervisor installed before shipment, during shipment, or immediately after delivery). Assumptions applied for the period from 2007 back to 2003 were as follows:

- In 2003, the assumption applied is that VMware was the only viable x86 server virtualization technology in (relative) widespread use. IDC linearly scaled the overall worldwide penetration of virtualization deployments on new server shipments from 18% in 2008 (reported in IDC's Worldwide Quarterly Server Virtualization Tracker) to 2% in 2003.
- IDC scaled VMware's overall share of the worldwide total of new server shipments virtualized from 61% in 2008 to 100% in 2003. (In other words, VMware captured 100% of the 2% of new server shipments that were virtualized in 2003). In 2003, VMware was the only viable virtualization technology on x86 hardware.
- IDC's working models behind the top-level conclusions produced here were built using detailed dimensions including product type (blade, density optimized, rack optimized, and tower) and socket count (1 socket, 2 sockets, and 4+ sockets).

3. IDC applied the same assumption to bridge from 2007 back to 2003 to develop a complete historical view for the use of VMware hypervisor products on existing installed servers.
4. Virtual machine density (VM density), as reported in IDC's Worldwide Quarterly Server Virtualization Tracker for 2008–2015 (modeled for 2016–2019), was scaled back linearly to solve for historical data: The starting point for this model — 2003 — assumes two VMs/new server shipments virtualized. IDC estimates average VM density rates for servers running VMware's virtualization software surpassed 10 VMs per server in 2015 and 11 VMs per server in 2017.
5. Total instances for a given year were calculated by multiplying VM density for new virtualized server shipments and the existing virtualized installed base deployments (individually) by their respective unit volume.
6. At this point in the model, IDC applied a "discount" to reduce instances from the installed base that may have been the result of virtualization sprawl:
   - The discount applied ranged from 6% of instances in 2003 to over 25% of instances in more recent years. Virtualization sprawl is the presumption that virtualization software, in conjunction with today's datacenter-oriented virtualization-friendly licensing, makes it easy (and affordable) to spin up more instances than would have happened if a hardware and software purchase was necessary for each individual instance to be created.

7. To calculate the impact of improved server utilization from vSAN, the number of servers installed with vSAN was estimated using revenue data. vSAN environments were assumed to provide 50% greater server utilization compared with traditional storage approaches such as SAN. As discussed previously, VM density assumptions were used to calculate logical server instances running on these servers. The number of servers needed for a comparative non-virtualized storage environment was also calculated. The delta in the logical servers used for current vSAN deployments compared with what would be required in non-virtualized environments was added to the savings outlined previously.

8. IDC also examined the energy and $CO_2$ emissions savings from the replacement of existing HDD-based storage systems with all-flash vSAN deployments. IDC calculated the number of SSD drives installed in vSAN deployments and the associated number of HDD drives replaced. Power consumption and $CO_2$ emissions for SSDs and HDDs were calculated and compared. Key assumptions include:

   - IDC research suggests enterprises can meet storage performance requirements with 60–90% fewer SSDs compared with HDDs.
   - Capacity needs often require that some more SSDs are added beyond performance needs. Storage efficiency technologies enable enterprises to store more data using less raw capacity. For mixed workloads, average data reduction ratios in the 4:1 to 6:1 range are not unreasonable, and most workloads benefit from both compression and deduplication.
   - While it varies, on average, an SSD will consume roughly half the power of an HDD of similar capacity.

   In addition, IDC examined the degree to which VMware's NSX network virtualization overlay (NVO) yielded increased server utilization and led to server displacement. IDC estimated that NSX enhanced server utilization by approximately 20%, and it was in that area that NSX had its greatest impact on emissions reduction. Lesser emissions reduction contributions, not significantly material in the context of this study, resulted from potential displacement of top-of-rack (ToR) switches, physical firewalls, and other network and security devices.

9. Installed base of total server instances in use each year was determined by an installed base calculation on the discounted instance total, using a mathematical formula that replicates the calculations for physical server installed base totals produced in IDC's Worldwide Server Tracker database. This calculation is done individually for new server shipment virtualized instances and separately for instances aboard installed base servers that have had hypervisors installed and varied by form factor. Overall, the average life expectancy for servers included in this study was about 4.5 years:

- The presumption is that virtualized operating system/workload instances on a server newly deployed will have a life cycle much like that of an existing server installation (because the alternative would have been to install that instance on a dedicated server).
- Separately, IDC calculated the life expectancy/installed base for instances aboard installed servers that received a hypervisor through a redeployment midlife; instances running on these servers were assumed to have a considerably shorter life cycle than instances running on brand-new servers.
- These separate installed base calculations were combined to produce a total number of server instances that were avoided because of the use of VMware virtualization solutions.

10. The overall installed base servers in use were then multiplied by a weighted-average power consumption estimates based on server product types in proportion to sold quantities (blade, density optimized, rack optimized, and tower) and by socket count:

    - IDC used U.S. Department of Energy estimates to help shape the actual power consumed by servers, which tends to be roughly 70% of the rating of the power supply included with the server itself (source: Energy Technologies Area, Berkeley Lab).
    - Research indicates that rack servers consume the most power on average, while density-optimized servers consume the least power. Blade and tower servers consume approximately the same power. There is also a correlation between socket capability and power consumption, with more sockets requiring more power and vice versa.
    - For 2003, calculations assume that average rack server power consumption ranged from 275W (1-socket servers) to 575W (4+ sockets). Density-optimized servers range from 190W (1 socket) to 220W (4+ sockets) for the same year. Blade and tower servers fall between the other categories with a range of 220W (1 socket) to 370 W (4+ sockets).
    - Power consumption was assumed to increase in early product years, with very slight efficiency improvements each year up to 2019.

11. The results of Step 9 were then multiplied by the number of hours of utilization per day those servers experienced. Starting in 2014, it is assumed all servers across form factors have a continuous “on time” of 24 hours. “On time” was assumed to increase incrementally each year across form factors from 2003 to 2014. For 2003, IDC used the following server “on time” assumptions:

- Commercial servers commonly used in large-scale datacenters and cloud environments, including blade, density-optimized, and rack-optimized form factors, were assumed to have a high level of “on time” — from 20 hours to 22 hours — because the result of shutting down servers during low-use periods can be detrimental to the balancing of cooling systems counteracting the heat exhausted from datacenter infrastructure.
- Density-optimized form factors, commonly used in hyperscale datacenters, were assumed to have continuous uptime of 24 hours per day throughout the model period. However, density-optimized servers are not heavily used with VMware hypervisor products because most density-optimized servers tend to run bare metal workloads.
- Form factors more likely to have non-datacenter deployments were treated uniquely. Tower form factors are commonly used in small and medium-sized businesses (SMBs) and branch offices and were assumed to have a comparatively short daily “on time” of 12 hours per day (source: IDC estimates).
- The resulting data produced watt hours of power consumed per day and per year.

12. Avoided power consumption estimates were extended to factor in the impact of non-IT equipment datacenter operations as a result of IT infrastructure not deployed. This included avoided cooling and other non-IT equipment operations energy savings using a power usage effectiveness of 1.6. The PUE is a measure of a datacenter’s energy efficiency, exclusive of the IT equipment, and is calculated as the datacenter’s total energy consumption divided by the energy consumption of just the IT equipment. A value of 1.6 assumes 37.5% of the total energy is used for non-IT equipment operations such as cooling, lighting, and power conditioning.
13. IDC converted annual power consumption to megawatt-hours annually and in turn converted MWh to equivalent $CO_2$ emissions associated with that power consumption:

- Power consumption was converted to carbon emissions using the average annual $CO_2$ electricity emission factor for the United States as published by the U.S. Energy Information Agency (EIA). According to the U.S. EIA, average pounds of $CO_2$/MWh of electricity generated has generally improved over the model period. The annual emissions factor used for the calculation ranges from nearly 1,400lb of $CO_2$/MWh for 2003 to approximately 965.3lb of $CO_2$/MWh for 2019.

- The equivalent vehicle miles for electric cars were obtained from U.S. Environmental Protection Agency–published energy consumption ("MPGe" equivalent of 30KWh/100 miles) for the specific model used (Tesla Model S Long Range). The average distance between Earth and Mars (141,600,000 miles) used for the calculations was obtained from the NASA website.
- IDC recognizes that there are differences in country electricity emissions factors. Our assumption is that emerging geographies have higher $CO_2$ emission rates, and mature geographies (such as Western Europe) have lower $CO_2$ emission rates.
- The United States accounted for about 41% of new server shipments in 2019, while Western Europe accounted for 13% of new server shipments. Asia/Pacific accounted for 39% of new server shipments, and the rest of the world accounted for the remaining 7% of server shipments in 2019.
- IDC used the average U.S. $CO_2$ emission rate/MWh for the overall worldwide calculation, assuming higher emission rates (because of the use of inexpensive, high-emission fuels) in the fast-growing emerging market segments will more than offset the lower emission rates of Western Europe. Thus the U.S. average is a conservative conversion factor to use (source: U.S. Energy Information Agency).

14. The calculation for power consumption equivalency per vehicle is as follows:

- Annual $CO_2$ pounds avoided via the use of VMware virtualization was converted to gallons of gasoline consumed using a conversion metric of 19.64lb of $CO_2$ per gallon of gasoline based on published research by the U.S. Energy Information Agency.
- 153 billion pounds of $CO_2$ emissions (estimated net-new emissions avoided in 2019) equated to over 7.8 billion gallons of gasoline avoided during the year.
- The equivalent $CO_2$ emissions saved from all of Tesla electric vehicles were obtained from Tesla's published carbon impact calculator (available at www.tesla.com/carbonimpact).
- The equivalent vehicle miles for the total gallons of gasoline avoided annually was calculated using average miles per gallon data published by the U.S. Environmental Protection Agency. An estimate for the number of vehicles removed from the road was calculated using published data on the average number of miles driven per vehicle per year on average in the United States, which is also published by the U.S. EPA.

IDC worked with VMware to correlate these findings against internal historical data to arrive at a closer approximation of real-life savings.

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## About IDC

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