

Digital Transformation and a Net Zero Emissions Europe

The role of cloud computing and data centres in achieving power sector emissions reductions in Europe

An Aurora Energy Research white paper, sponsored by VMware

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Contents

Contents.....	2
Foreword by VMware.....	3
1. Executive Summary	4
2. Introduction	5
3. Embracing virtualisation leads to carbon emissions reductions in the IT sector.....	7
3.1 <i>The growth of computing demand and emergence of the cloud</i>	7
3.2 <i>The energy and emissions impact of computing demand</i>	8
3.3 <i>The potential for further carbon emissions savings in computing demand</i>	11
4. Data centre best practices for supporting the integration of renewables into power grids across Europe.....	14
4.1 <i>Challenges facing a high-renewables Europe</i>	15
4.2 <i>Data centres' potential in supporting the integration of renewables on the grid</i>	16
5. Methodology.....	18
6. Further information.....	23



Foreword by VMware

In 2020, life seemed to change overnight. With the world in the grips of the Covid-19 pandemic, everyday tasks—going to work, connecting with family, attending school—were suddenly ushered into a new era. For many organisations, the pandemic has proven to be a watershed moment for the way they do business, accelerating ongoing digital transformations to ensure continuity of their work—and driving greater dependence on the data centre as a result. This “new normal” has led to tremendous decreases in carbon emissions from commuting. But this increasing reliance on digital technologies such as mobile, edge and private/public cloud computing has further accelerated the enormous energy consumption by data centres, and therefore, the urgency to act to decarbonise.

Despite the pandemic, business leaders and policy makers have not lost sight of aggressive sustainability and carbon emissions goals to help mitigate climate change. These twin missions—accelerating digital transformation and reducing carbon emissions—can go hand-in-hand. Technologies like data centre virtualisation and an embrace of a hybrid cloud model can help organisations track, manage, and reduce their carbon emissions as their digital transformation proceeds.

At VMware, our goal is to empower our customers with the resources and tools they need to ultimately reduce environmental impact across our vast partner ecosystem.

Sustainability has long been a core value for VMware, which powers the world’s complex digital infrastructure. The company has set standards for itself internally, having achieved 100% renewable energy and carbon neutrality goals ahead of schedule. Beyond these ambitious goals for its own business practices, VMware also aims to incorporate sustainability features into its products, to offer solutions that help customers positively impact the environment and society, as well as provide customers and partners with data that enable informed choices around cleaner technology. Since 2003, our product portfolio has helped our customers avoid over 1.2 billion tonnes of CO₂.

The total emissions avoided through VMware virtualisation in 2019 are 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. With the total power consumption avoided in 2019 by using VMware’s virtualisation, 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 times¹.

This report demonstrates how VMware’s transformative software can enable partners to reduce their carbon emissions and intends to make recommendations to policy makers on how they can incentivise sustainable digital transformations as they work towards climate change and green policy goals.

¹ VMware Global Impact Report 2020

<https://www.vmware.com/content/dam/digitalmarketing/vmware/en/pdf/microsites/vmware-global-impact-report.pdf>

VMware is committed to investing in the health of our environment and our communities, which are critical for the long-term sustainability of our business, and we hope that this report will serve as a valuable resource to our partners who are committed to doing the same.

1. Executive Summary

Virtualisation software allows for substantially more computation to be done with significantly less IT hardware. Its use, along with improved management and optimisation of operations and hardware upgrades, enables productivity and energy efficiency improvements in IT operations. Coupled with the increased usage of renewable energy to fulfil electricity requirements, these energy efficiency gains can help IT operations in Europe to substantially decrease their carbon footprint. This is especially important as more and more enterprises are engaging with digitised information to transform their business operations, leading to continued exponential growth in computing demand.

This report examines future scenarios of European computing demand and its impact on European electricity consumption and emissions. A 'Zero Progress' scenario has been developed to understand what computing emissions level would result in a world where current technological progress surrounding virtualisation software and its penetration remains stagnant through to the year 2040. This is then compared to a 'Continual Improvement' scenario that applies reasonable trends to these factors to assess the potential impact of virtualisation in abating future emissions from European computing demand.

Our analysis suggests European computing emissions would grow 250% over the next 20 years in a Zero Progress scenario. But continued improvements in virtualisation technology and its penetration, underlying the Continual Improvement scenario, can enable a cumulative energy efficiency-sourced CO₂ reduction of 454 million tonnes by 2040, a 55% reduction compared to the baseline. While a Zero Progress scenario is improbable, this scenario highlights the importance of continued innovation in computing and its impact on carbon emissions. Consequently, policy initiatives that stifle a continuation of the pace of innovation seen historically in the sector can have a direct impact on emissions.

Further, this report assesses two possible levers to further mitigate the carbon footprint of European computing demand: 1) increasing the virtualisation rate of public cloud data centres and on-premises IT operations and 2) increasing the number of renewable-energy powered data centres and shifting computing demand to locations of lower power grid carbon intensity.

Lastly, this report provides an overview of how data centres can play a role in helping integrate renewable grids across Europe. The intermittency of renewable energy sources like wind or solar present some challenges to increasing their penetration on power grids. Addressing these challenges requires sources of flexibility to help balance the grid. Data centres can help integrate renewables into the grid by:

- Utilising their backup/emergency battery storage to help balance supply and demand on the grid;
- Optimising the cooling of IT infrastructure to provide flexibility to the grid; and

- Engaging in demand response by reducing data centre power consumption to better match the current local supply of renewables.

While this report quantifies the possible impact of technical developments in both the computing and electricity sectors in Europe, a standardised and coherent policy on data centre operations and computing procurement policies would enable the industry to identify and implement critical initiatives to support the decarbonisation of the sector.

The new European Commission (EC), the EU's Executive Branch which took office in November 2019, indicated two of its main priorities are to lead on the digital and green transformation of the European Union.² Included in this effort is the EC's intention to implement a "Green Public Procurement policy"—a voluntary instrument intended to nudge purchasing power towards environmentally friendly goods, services and works.³ Additionally, the EC identified the need to reduce the digital sector's carbon emissions. In particular, data centres will need to become more energy efficient, reuse waste energy and use more renewable energy sources with the aim of becoming climate neutral by 2030.⁴

2. Introduction

Many countries have recently legislated net zero carbon emissions targets by 2050 or before.⁵ In fact, in the European Union, only a handful of countries were reluctant to pass net zero laws. The European Commission has recently proposed legislation for the 27 member states to become climate-neutral by 2050 as part of the European Green Deal.⁶

A key component of achieving climate neutrality involves greening the electricity system. Today, the 27 European Union Member States (and the United Kingdom), account for almost 10% of global energy-related CO₂ emissions.⁷ Considering the magnitude of EU emissions, it is imperative that the EU works diligently to reduce its electricity emissions intensity. This challenge will become increasingly important as more and more aspects of the economy and life are electrified and digitised.

As many enterprises are undergoing their digital transformation to upgrade their business operations, including through the adoption of computing-intensive revolutionary technologies such as blockchain, virtual reality, edge computing, machine learning and artificial intelligence, their requisite computing demand is expected to grow exponentially over the next couple of decades. Without further investment in technology and climate stewardship, this increase in

² European Commission, "6 Commission priorities for 2019-24", Accessed 26 June 2020. URL: https://ec.europa.eu/info/strategy/priorities-2019-2024_en

³ European Commission, "Green Public Procurement", 11 June 2020. URL: https://ec.europa.eu/environment/gpp/index_en.htm

⁴ European Commission, "Shaping EU's Digital Future", 19 February 2020. URL: https://ec.europa.eu/info/sites/info/files/communication-shaping-europes-digital-future-feb2020_en_4.pdf

⁵ Megan Darby, *Climate Home News*, "Which countries have a net zero carbon goal?", 14 June 2019. URL: <https://www.climatechangenews.com/2019/06/14/countries-net-zero-climate-goal/>

⁶ Mehreen Khan, *Financial Times*, "EU begins arduous path to net zero climate emissions", 3 May 2020. URL: <https://www.ft.com/content/ff7094e0-5dcb-11ea-b0ab-339c2307bcd4>

⁷ IEA, "Net-zero carbon or GHG emissions reduction announcements", 10 March 2020. URL: [https://www.iea.org/data-and-statistics/charts/net-zero-carbon-or-ghg-emissions-reduction-announcements-\(10-Mar-2020\)](https://www.iea.org/data-and-statistics/charts/net-zero-carbon-or-ghg-emissions-reduction-announcements-(10-Mar-2020))

computing demand would result in a similarly significant rise in electricity consumption and emissions. However, this need not be the case. Providers of computing services have an opportunity to assist in building a net zero emissions Europe with the goal to support the EU's productive computing while decarbonising that activity through energy and infrastructure efficiencies and renewable energy.

Virtualisation software allows for much more computation to be done with significantly less IT hardware. Combined with improved management and optimisation of operations and hardware upgrades, its use enables substantial productivity and energy efficiency improvements in IT operations. Coupled with the increased usage of renewable energy to fulfil electricity requirements, these energy efficiency gains can help IT operations in Europe to substantially decrease their carbon footprint. In addition, the computation of digitised information is being increasingly moved to the cloud where, among other things:

- 1) energy efficiency is generally higher than for on-premises operations;
- 2) the physical location of computing infrastructure can be optimised to cooler and/or less carbon-intensive electricity regions; and
- 3) electricity demand flexibility can be provided to help integrate higher percentages of renewables into power grids across Europe.

Underpinning the capabilities of many cloud-based services is a technological process called virtualisation. Virtualisation is the utilisation of software to simulate hardware functionality and create multiple virtual computer systems, or virtual machines, on a single physical server. This technology, in aggregate, allows for much more computation to be done with significantly less IT hardware and commensurately less data centre infrastructure, and consequently, less energy. Among the dozen major players in the virtualisation product market, VMware holds the highest market share, followed by IBM and Huawei.⁸

A previous VMware-sponsored white paper by IDC estimated that VMware's virtualisation products have led to the avoidance of over 142 million physical servers, 2,500 TWh of electricity usage, and the emission of 1.2 billion tonnes of CO₂ worldwide from 2003–2019.⁹ While it has been previously argued that virtualisation has led to significant CO₂ reduction in the past several years, this paper will explore a probable future trajectory of emissions from European computing demand and how virtualisation, cloud computing and data centres can further reduce emissions.

⁸ Gary Chen, *IDC*, "Worldwide Virtual Machine Software Market Shares, 2017: Virtualization Still Showing Positive Growth", December 2018. URL: <https://www.vmware.com/content/dam/digitalmarketing/vmware/en/pdf/products/vmware-idc-virtual-machine-market-shares-2017.pdf>

⁹ Sriram Subramanian, Brad Casemore, *IDC*, "Enabling More Agile and Sustainable Business Through Carbon-Efficient Digital Transformations", August 2020. URL: <https://www.vmware.com/content/dam/digitalmarketing/vmware/en/pdf/company/vmware-idc-whitepaper-2020.pdf>

3. Embracing virtualisation leads to carbon emissions reductions in the IT sector

3.1 The growth of computing demand and emergence of the cloud

Computing demand, including data processing, storage and networking, has grown tremendously over the past couple of decades. This growth has been driven predominantly by the digital transformation of businesses and processes, as well as the emergence of online entertainment, the Internet-of-Things, fog/edge computing, blockchain, AI/ML, virtual reality and the rising demand for anytime, anywhere access to information.

The form of this computing demand has also changed drastically. At first, European computing demand was met by servers and storage arrays distributed about an individual company's premises. Enterprises then began realising efficiency gains and cost reductions by consolidating their IT infrastructure into data centres. The advent of cloud computing enabled further consolidation of computing resources, even enabling enterprises to shed some of their traditional capital expenditures in maintaining on-premises IT systems and software purchases.

By 2010, the digital transformation was well underway with Amazon Web Services and Elastic Cloud providing early, virtualised, shared public ("multi-tenant") cloud services (2002, 2006), followed by Google App Engine (2008), and Microsoft Azure (2010), among others. This revolution in the digital age has enabled many innovative software-as-a-service (SaaS) businesses to be created like Spotify, Netflix, Microsoft 365, Salesforce, Zoom and Uber.

Currently, 75% of European computing demand is handled in cloud data centres.¹⁰ These cloud data centres include private (dedicated, virtualised hosts either in private enterprise or public cloud environments), public, both hyperscaler and non-hyperscaler (multi-tenant, virtualised hosts in public cloud environments), and hybrid (primarily using private cloud infrastructure, and relying on public cloud to handle additional demand during peak periods). The progression of increasing energy and infrastructure efficiency is shown in **Figure 1**.

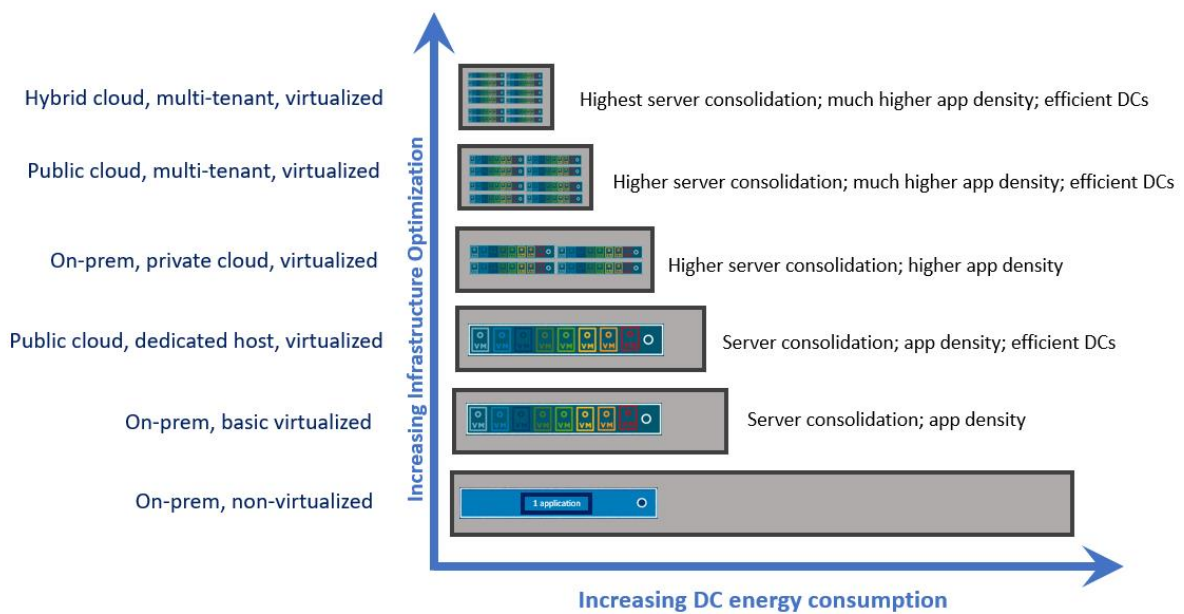


Figure 1: Illustrative progression of energy and data centre infrastructure efficiency across data centre environments

VMware has been at the centre of this transition, leading the way in helping its customers transform their IT infrastructure to capitalise on the flexibility, scalability and performance of private and hybrid clouds. Its technologies help to bring together previously isolated infrastructure silos to manage them as a single entity and bring cloud-like capabilities back to an on-premises environment. By combining these once disparate elements into a holistic, software-defined and integrated platform, customers realise a wide range of benefits, including reduced complexity, cost control, agility and notably, the ability to monitor and manage carbon emissions.

3.2 The energy and emissions impact of computing demand

The impact of virtualisation on computing emissions

To construct a forecast for European computing emissions, it is necessary to quantify the likely evolution of key computing demand and emissions drivers. Given the inherent uncertainty of how this fast-moving sector will evolve, it makes sense to explore multiple scenarios. Our approach to constructing these projections, including assumptions and supporting data, is outlined in the methodology section, but the section below outlines our key findings.

Our analysis shows that the extent to which virtualisation technologies advance and penetrate the market is one of the key determinants of the expected carbon footprint of European computing. Consider the 'Zero Progress' scenario and 'Continual Improvement' scenario presented in **Figure 2**.

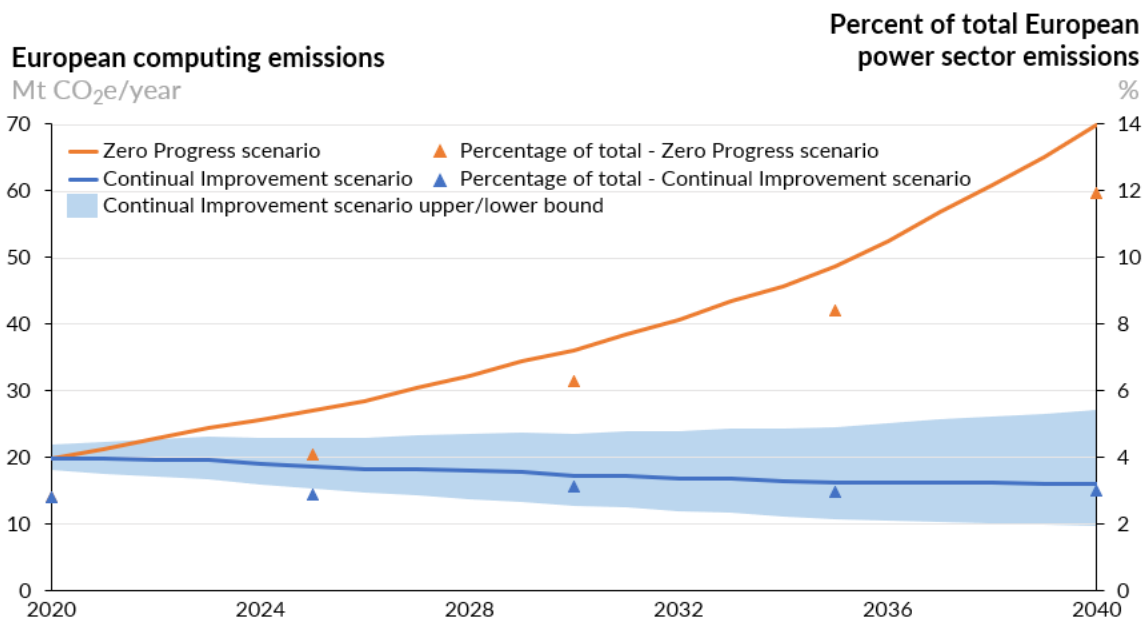


Figure 2: Projected emissions from European computing demand (2020–2040)

Our analysis shows that with the expected exponential growth of computing demand (measured in terms of computing workloads), and no further increase in the current virtualisation rate¹¹ and VM density¹², European computing emissions could grow 250% over the next 20 years. This is shown as the Zero Progress scenario.

However, virtualisation rates and VM densities have been increasing steadily over the past decade, and that trend is expected to continue. Assuming the same Zero Progress scenario computing demand projection but with a 0.5% and 5.7% CAGR in virtualisation rates for public cloud and on-premise data centres, respectively, and 7.6% CAGR in VM densities (consistent with historic trends), European computing emissions could decrease moderately, 19%, by 2040 in the Continual Improvement scenario.¹³ This is because increasing VM density and virtualisation rates lead to a higher number of workloads per physical server, which in turn leads to much lower power consumption and associated emissions per unit of physical IT infrastructure.

It is important to note that while the Continual Improvement scenario is based on expected growth rates in virtualisation and VM densities based on the technical and economic potential of these technologies, market forces and public policy will dictate their deployment and widespread adoption. In addition to this, future emissions are also sensitive to other factors, such as computing demand and expected hardware efficiency gains. These sensitivities provide an upper and lower bound for the Continual Improvement scenario, as shown in **Figure 2**.

¹¹ Virtualisation Rate refers to the percentage of physical servers that are virtualised across Europe.

¹² Virtual Machine Density gives the average number of virtual machines in a virtualised server (host). Typically, each application runs in its own VM. So, the higher the density the more applications are running on host.

¹³ Our assumptions and approach are detailed in the Methodology Section.

By 2040, based on the growth trajectories in virtualisation rates and VM density assumed in the Continual Improvement scenario, European computing emissions could represent between 2% and 5% of total European power sector emissions.¹⁴ This compares to 12% of total European power sector emissions in the Zero Progress scenario and amounts to 54 million fewer tonnes of CO₂ being emitted annually by 2040.

Carbon intensity of European power grids

Computing demand and its associated electricity consumption is geographically dispersed throughout Europe, where power grids have varying levels of carbon intensity (shown in Figure 3).

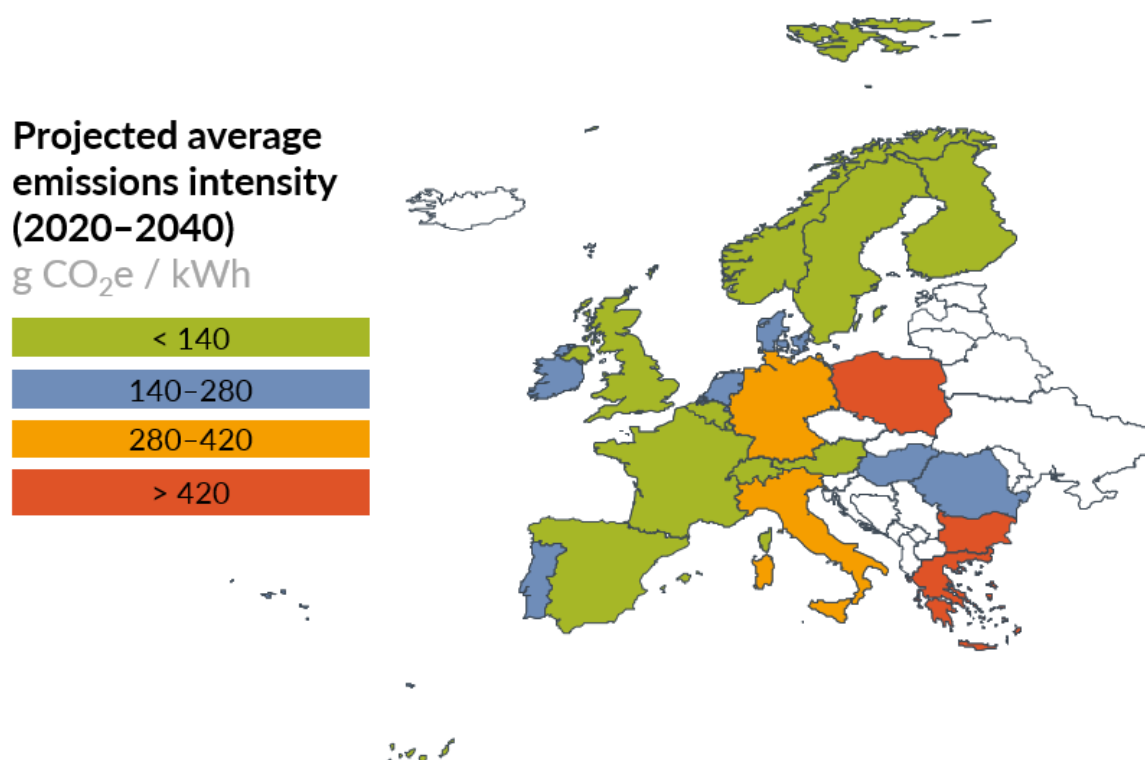


Figure 3: Projected Average Emissions Intensity (2020–2040) in g CO₂ / kWh (excluding Turkey, Monaco, Malta, and Gibraltar).

As the share of renewables in the power system grows and coal generation is phased out, the CO₂ emissions intensity of power grids across Europe is expected to fall. This trend is highlighted by an expected 43% reduction in emissions intensity in the UK over the next two decades, as well as a 64% reduction in Ireland, 56% reduction in Germany, and 60% reduction in Spain.¹⁵

The effect of declining power sector emissions is important; even as total European electricity consumption increases, net CO₂ emissions are expected to fall over time. In both the Zero Progress and the Continual Improvement scenarios, we assumed the total electricity consumption from European computing demand in 2020 was about 81 TWh, which accounts

¹⁴ European Commission, “Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market”, 9 November 2020.

¹⁵ Based on Aurora’s long-term forecasts of these power markets.

for almost 2.5% of Europe's total electricity consumption.¹⁶ In the Continual Improvement scenario this grows to almost 115 TWh in 2040. However, in the same scenario, total projected carbon emissions from increased computation demand and commensurate data centre infrastructure growth are estimated to be about 20 million tonnes in 2020, and 16 million tonnes in 2040 (shown in **Figure 2**). This equates to 2.8% of Europe's carbon emissions in 2020 and 3% in 2040. Thus, although we estimate a 40% increase in the electricity consumption of European IT over the next twenty years, we expect emissions to decrease by 19%. This is due to the increasingly less carbon-intensive outlook for European power systems.

Minimising the impact of computing demand on carbon emissions will, therefore, also depend on the ability to optimise the location of data centres. The impact of the geographic optimisation of computing demand is explored further in the next section.

3.3 The potential for further carbon emissions savings in computing demand

Some larger changes in computing macro-trends could further reduce the emissions impact of European computing demand. For instance, as illustrated in **Figure 4** and explained in further detail in the sub-sections below, a 10-percentage point increase in the penetration of virtualisation technology could lead to a cumulative 37 million tonne decrease in emissions over the next two decades. Further, the geographic optimisation of 14% off-premises data centres based on computing emissions intensity could lead to a cumulative 35 million tonne decrease in emissions over the same period.

Accelerated adoption of recent innovations in virtualisation of storage, networking, load balancing, GPU (e.g., AI, ML, blockchain, virtual reality) technologies further expand the scope of workloads that can be virtualised with commensurate reductions in data centre infrastructure and energy consumption.

It should be noted that these results represent our assessment of what is technically feasible in the industry. Greater public policy and regulatory efforts may be needed to help overcome market failures to achieve these positive benefits on CO₂ emissions.

¹⁶ European Commission, "Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market", 9 November 2020.

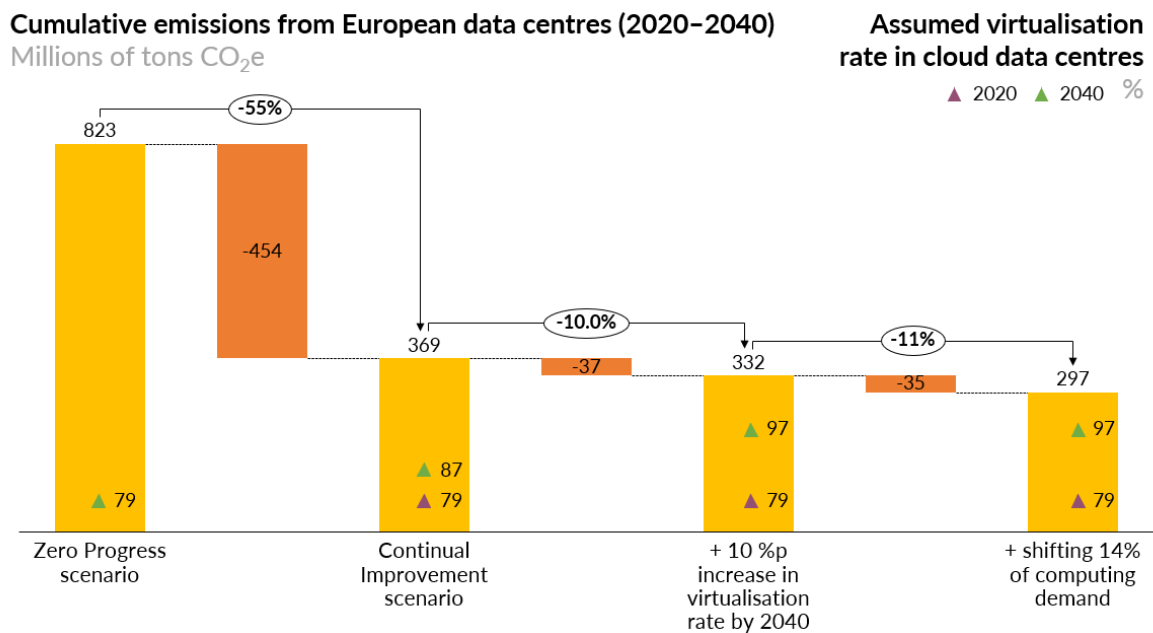


Figure 4: Possible reductions in cumulative emissions from European Data Centres from 2020 to 2040

Carbon savings from increasing data centre virtualisation

As previously mentioned, by increasing the utilisation of IT infrastructure, virtualisation allows for the same amount of computation to be done on less hardware. The impact of this on cumulative emissions is highlighted by the 55% drop between the Zero Progress and Continual Improvement scenarios. In the Continual Improvement scenario, we have assumed that the percentage of servers in public, private and hybrid cloud data centres that are virtualised across Europe increases from about 79% in 2020 to about 87% in 2040, and on-premises server virtualisation increases from 17% in 2020 to about 53% by 2040.

In other words, the Continual Improvement scenario assumes that 13% of cloud data centres and 47% of on-premises operations are expected to not be virtualised by 2040, leaving greater emissions reductions potential by increasing the penetration of virtualisation in data centres. A further 10-percentage point increase in the virtualisation of servers in cloud data centres and on-premises operations (97% and 63% virtualisation by 2040, respectively) would further reduce total electricity consumption, reducing cumulative emissions 10% by 2040.

While there are various reasons why a cloud services provider may not completely virtualise their servers (e.g., certain workloads may need to run directly on a physical server for performance reasons or the overhead costs of virtualisation may not justify the benefit of virtualisation), policy incentives to virtualise and a favourable European regulatory framework are needed to support the sector's ability to limit CO₂ emissions.¹⁷

¹⁷ Ingram Micro, "The Impact of Virtualization on a Data Center's Infrastructure", 09 June 2017. URL: <https://imagine.next.ingrammicro.com/data-center/the-impact-of-virtualization-on-a-data-center-s-infrastructure>

Carbon savings from shifting computing demand to different locations

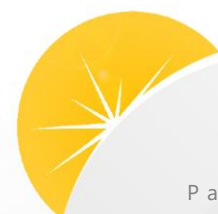
Many European nations including the UK, Germany, Spain and France are pursuing high renewable energy penetration by 2040 (this is changing very rapidly, however, with the UK and Germany having already seen 80+% renewable energy peak generation at times). This increase in renewables will lead to massive decarbonisation of their electric grids relative to other countries with less ambitious targets. Thus, shifting cloud data centre computing demand to countries with lower average carbon intensity can be pivotal in achieving emissions reductions. Gradually shifting even 14% of total off-premises computing demand from countries with high grid emissions intensity like Poland, Greece, Turkey and Bulgaria to countries with low electricity emissions intensity like Norway, Sweden and Switzerland can result in an additional 11% decrease in cumulative emissions from computing demand by 2040. This act could also provide a strong incentive for those low-renewable penetration countries to develop renewable energy strategies.

Of course, the entire computing demand of a country will not be shifted to other countries for many reasons, including data security, application latency and logistics restrictions. But enabling this locational flexibility can allow for similar intra-country shifts to areas with excess renewable generation, providing a benefit for renewables (by ensuring their cost-effective utilisation) but also for emission intensity of computing demand.

This shift may occur naturally, considering off-premises data centre operators will be increasingly incentivised to locate in countries with low emissions intensity due to increasing carbon prices and reduced electricity prices from high renewables penetration. However, this incentive signal is often distorted by a patchwork of regulatory structures, taxes, and tax exemptions. For example, in the Scandinavian countries, Ireland, the Netherlands and France, data centres are categorised as “energy-intensive” industries, thus qualifying for minimum taxes and levies in the EU minimum energy tax. The difference can mean paying as much as 73% less for energy.¹⁸ To the extent that regulatory or financial incentives do not align with the environmental impact, the environmentally optimal solution will be distorted.

A pan-European approach to incentivising reductions in carbon emissions is therefore much needed since measures to promote both the location of data centres in more energy-efficient locations, as well the use of technologies that enable management of data centre energy usage, can only be effective and successful if done at EU level. Green public procurement policy, which the EU is planning to implement soon as part of the “Greening ICT” initiative, can help to lead the way. Cloud procurement regulations in many countries already incorporate cost-control, flexibility, and security requirements; the addition of sustainability and carbon-emissions requirements can help drive broader adoption of carbon-emissions management as a key factor in digital transformation and hybrid cloud adoption.

¹⁸ Koronen, C., Åhman, M. & Nilsson, L.J. “Data centres in future European energy systems—energy efficiency, integration and policy”. *Energy Efficiency* **13**, 129–144 (2020). URL: <https://doi.org/10.1007/s12053-019-09833-8>



4. Data centre best practices for supporting the integration of renewables into power grids across Europe

An integral component of Europe’s climate targets involves a future energy grid system predominantly powered by renewable and low-carbon technologies. This has become apparent as the average cost of wind power has declined by 70% and solar PV by 86% over the past decade. In some countries, solar and wind power are already cost-competitive with conventional fossil fuel generation sources without subsidies.¹⁹ Also, considering expected trends, these renewables will similarly become cost-competitive in many other countries in the near future.²⁰ However, to accommodate these renewables, the power system needs to be completely transformed in order to maintain the levels of resource adequacy and reliability in the electricity system to which we all have grown accustomed.

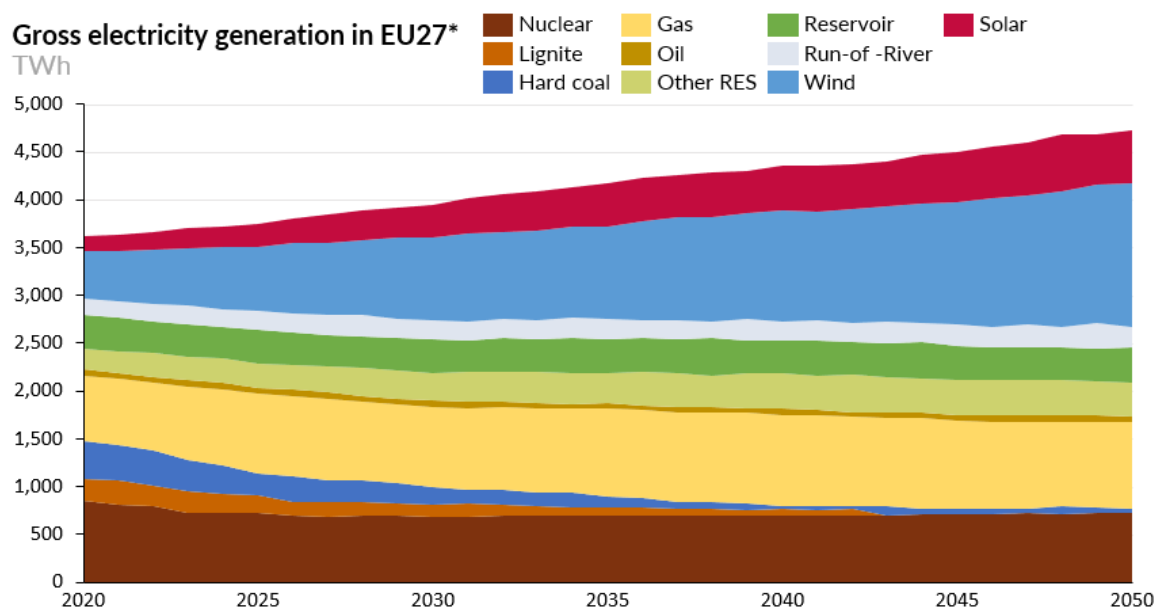


Figure 5: Gross electricity generation by technology in EU 27 (incl. Norway, Switzerland and the United Kingdom) (Source: Energy Brainpool, “Energy, transport and GHG emissions Trends to 2050 – Reference Scenario 2016” [1], “TYNDP 2018” [4])

¹⁹ William Mathis, *Bloomberg*, “Offshore wind prices plunge in latest UK auction”, 09 December 2019. URL: <https://www.renewableenergyworld.com/2019/09/12/offshore-wind-prices-plunge-in-latest-uk-auction/>

²⁰ Lazard, “Lazard’s Levelized Cost of Energy Analysis—Version 13. 0”, November 2019. URL: <https://www.lazard.com/media/451086/lazards-levelized-cost-of-energy-version-130-vf.pdf>

4.1 Challenges facing a high-renewables Europe

The emergence of renewable energies like wind or solar present some challenges. Wind and solar power are intermittent. Solar energy is only available during daylight and can be easily dampened by cloud cover, and wind generation can swing rapidly from one hour to the next.

Addressing these challenges requires different forms of flexibility to fulfil residual demand requirements²¹. The primary need is the shifting of renewable energy from times when more is being generated than can be consumed to periods to where there is not enough low-cost renewable generation to meet demand, requiring higher-cost, typically fossil-based generation to fill the gap. This can be achieved through grid-level technologies like storage and flexible demand.

Illustrative power demand in two typical weeks,
GW

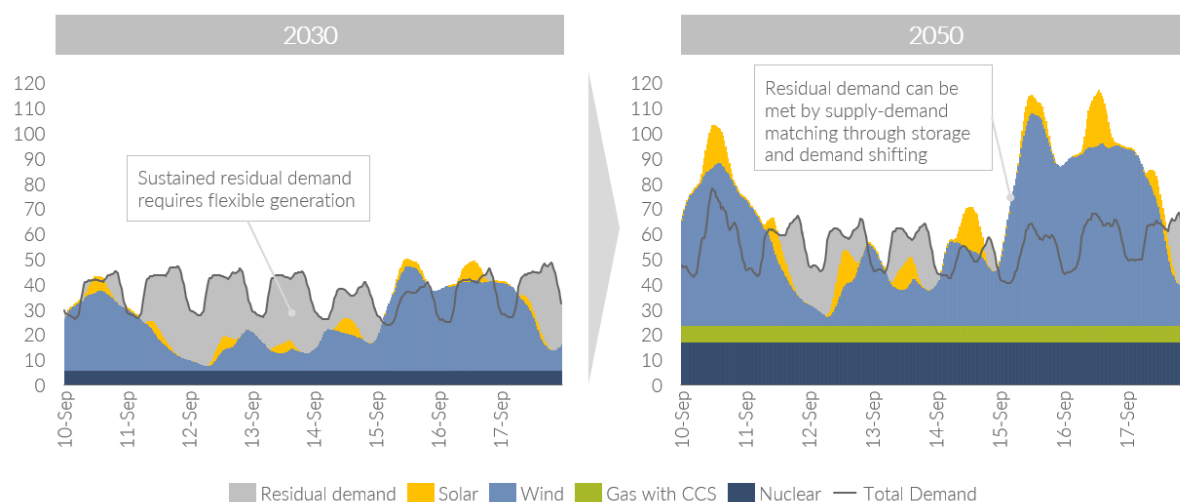


Figure 6: Demand-supply matching: as we approach 2050, flexibility and storage becomes necessary for the proper utilisation of renewables. (Source: Aurora Energy Research)

When storing excess generation is not possible because of limited storage availability, increasing demand when renewable generation rises and responding conversely when it falls can support the integration of renewables into the grid. This demand and supply balancing increases revenues for renewable generators by reducing curtailment—turning off generation due to a glut on the system or grid constraints prohibiting supply to reach demand centres. This strategy not only improves the overall economics of renewables and resiliency of electricity supply, but also can economically provide other crucial grid services like inertia, frequency response, voltage support, etc.

²¹ Residual demand is the amount of electricity demand unmet by low marginal cost resources such as wind and solar power. This demand must be met by other sources in order to meet consumer demand and maintain grid stability.

4.2 Data centres' potential in supporting the integration of renewables on the grid

Data centres can engage in demand response by reducing their power consumption to better match the current local supply of renewables

Data centres are suitable candidates for demand response with minimal infrastructure investments since they are fitted with components that already monitor and respond to control signals. Some immediate opportunities include:

- Workload scheduling to run low priority/batchable workloads when renewable energy is high; and
- Moving a fraction of workloads to a different power grid location.

A previous study by Koronen et al estimated the maximum theoretical potential for demand response for data centres to be in the range of 38 to 80% of the installed power demand in 2030.²² Of course, there are limits to the degree of demand response data centres can contribute. Depending on the type of workload handled by the data centre, the duration of applicable demand response is typically in the range of minutes to hours. However, it may only require small amounts of workload curtailment or shifting across regional data centres to achieve the needed demand response. VMware vSphere, industry-leading compute virtualisation platform, enables companies to easily and dynamically manage workload placement and run times, and even power cycle hosts machines where workloads have been vacated to maximise low-risk curtailment capacity.

Exciting early work is underway to leverage geographically disparate cloud environments and virtualised workload management capabilities to enable carbon-aware and carbon-efficient computing,^{23,24,25} facilitating time- and/or geographic-shifting of workloads to periods or locations of low electricity carbon-intensity.

If able to provide all this flexibility, data centres could become an important component of future European energy systems. Many jurisdictions are procuring a wide array of specific services to help integrate renewables and build a net zero emissions Europe. This includes an increasingly large capacity of batteries and demand side response from individual commercial and industrial entities, as well as aggregators. Data centres are in a unique position to provide these services as an add-on to their main functionality without having to make costly investments in search of high returns. This brings not only a financial benefit to data centres, but also valuable support to the integration of renewables in European power grids.

²² Koronen, C., Åhman, M. & Nilsson, L.J. "Data centres in future European energy systems—energy efficiency, integration and policy". *Energy Efficiency* **13**, 129–144 (2020). URL: <https://doi.org/10.1007/s12053-019-09833-8>

²³ Zoha Usmani, Shailendra Singh, "A Survey of Virtual Machine Placement Techniques in a Cloud Data Centre", *Procedia Computer Science*, Vol 78, 2016, pp 491-498.

²⁴ Girish Ghatikar, Venkata Ganti, Nance Matson, Mary Ann Piette, "Demand Response Opportunities and Enabling Technologies for Data Centers: Findings From Field Studies"; 2012.

²⁵ <https://www.zdnet.com/article/green-tech-google-shifts-data-center-workloads-to-follow-the-sun-and-the-wind/>

Data centres can utilise their backup/emergency battery storage to help provide flexibility to the grid

Typically, data centres have battery energy storage systems (BESS) to assist in securing an uninterruptible power supply sized to the peak power demand of the data centre. If a data centre requires 5 MW of electricity during its peak over the course of an average day, the site will also have a 5 MW BESS. These systems typically do not have much energy capacity though, providing power to the data centre for 5–30 minutes, long enough for back-up generators to become fully operational.²⁶

This storage can be utilised to charge when renewable generation on the grid is high and discharge when it is not. Operating the BESS in such a way can provide benefits to the data centre operators beyond altruistically helping the business case for renewables. Operators can actively shave their peak electricity consumption from the grid by using energy from their battery. This enables operators to reduce the portion of their energy bill, often referred to as the peak demand charge, which is based on the highest grid electricity demand of the data centre over a 15 to 30 minute period. Depending on the structure of the respective electricity market, this flexibility could enable a data centre to take advantage of time-of-use electricity price tariffs—using energy from a battery charged when electricity prices were lower instead of buying electricity from the grid during high-price periods.

If the battery storage system is managed with enough reserve to serve its emergency purpose as well, it may also provide useful grid services and balancing. However, the more a data centre operator uses its BESS in energy markets, the faster the system will degrade, requiring replacement. Thus, an operator will have to optimise the operation of the BESS to maximise the financial benefit.

Data centre operators can also optimise the cooling of the data centre to provide flexibility to the grid

The use of pre-cooling, within limits, can also be utilised to temporally shift demand for server cooling without damaging equipment. According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers, the recommended operating temperature for data centres is between 15° C and 40° C, depending on the configuration of the data centre and the workload demand. Data centre operators can look to pre-cool the data centres even by 0.5° C during periods of high renewable generation (likely responding to time-of-use tariffs). This virtually creates a thermal buffer, allowing for cooling demand to be reduced during periods of low renewables generation.

Depending on the data centre's size and architecture, it could take as little as five minutes to pre-cool a facility.²⁷ Similarly to the use of BESS to provide flexibility, peak demand charge reduction potential and time-of-use tariffs can adequately incentivise data centres to be operated to financially benefit while also helping to integrate renewables into the grid.

²⁶ Y. Shi, B. Xu, D. Wang and B. Zhang, "Using Battery Storage for Peak Shaving and Frequency Regulation: Joint Optimization for Superlinear Gains," in *IEEE Transactions on Power Systems*, vol. 33, no. 3, pp. 2882-2894, May 2018, doi: 10.1109/TPWRS.2017.2749512.

²⁷ Basmdjian, Robert. (2019). "Flexibility-Based Energy and Demand Management in Data Centers: A Case Study for Cloud Computing". *Energies*. 12. 3301. 10.3390/en12173301.

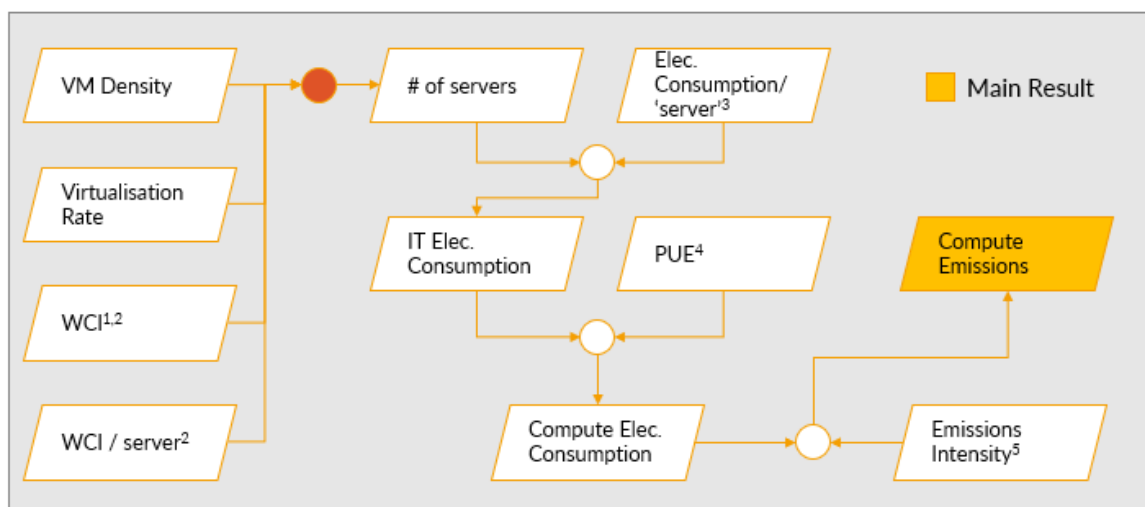
5. Methodology

In Section 4 of this report, we provide projections for energy consumption and resulting CO₂ emissions from the European Computing sector out to 2040. The assumptions used in the analysis are estimates based on publicly available data. Forecasting trends in European-wide computing is a challenge, as the computing industry is rapidly evolving, opaque and highly heterogeneous. In this methodology section, we break down the steps taken to arrive at our final projections, highlighting the key areas of uncertainty in our assumptions.

We will begin with the assumptions and calculations underlying the Continual Improvement scenario for European Computing Emissions, followed by a brief explanation of the differing factors behind the Zero Progress scenario, then an explanation of the additional waterfall steps in **Figure 4**, and then finally we will outline the sensitivities explored to reach the 'high' and 'low' scenario projections (i.e. Continual Improvement scenario upper and lower bound).

Computing Emissions Projections – Continual Improvement scenario

The overall logical flow of calculations is summarised in **Figure M1**. Throughout the process, we maintain the distinction between on-premises and off-premises (cloud) computing. We begin on the left-hand side with metrics for computing demand and virtualisation that are combined to produce a forecast of the number of servers. We then factor in data on energy consumption related to IT and cooling to obtain total electricity consumption, which then leads to final forecast of emissions from the European computing sector.



$$\bullet \frac{WCI}{server^1} = \frac{(Physical\ Servers \times Virtualisation\ Rate \times VM\ Density) + [Physical\ Servers \times (1 - Virtualisation\ Rate)]}{Physical\ Servers}$$

1. Workload and Compute Instance. 2. Total European WCI/density figures for 2016-2021 came from Cisco Global Cloud Index. For 2016-2021, we calibrated sensible VM Density and Virtualisation assumptions to Cisco's WCI / server and WCI estimates. Post 2021 we used projected VM Density, Virtualisation, and WCI to formulate the number of projected servers. 3. Including declining efficiency gains. 4. Region-specific PUE 5. Country-specific emissions intensity

Figure M1: Flow chart outlining overall methodology.

Computing Demand: The starting point for our calculations is our forecast of European computing workloads, based on the Cisco Global Cloud Index (GCI)²⁸. Cisco defines the workload & compute instance (WCI) as a “a virtual or physical set of computer resources, including storage, that are assigned to run a specific application or provide computing services for one to many users”. It serves as a “general measurement used to describe many different applications”. Cisco published WCI estimates for both on-premises traditional computing and off-premises cloud computing for the years 2016-2021. Cisco’s estimates indicate that while cloud computing workloads will grow exponentially, the demand for traditional computing is dropping. We projected these trends out to 2040 using a linearly decreasing compound annual growth rate (CAGR), to reflect a likely slowing down of the boom in off-premises cloud computing adoption and the retention of on-premises computing for large players in the digital technology industry. The final Continual Improvement scenario for WCIs goes from 96.5 million in 2020 to 2.4 billion in 2040 for off-premises computing and from 8.8 million to 5.6 million for on-premises. Total WCI projections for the Continual Improvement scenario are shown in **Figure M3**.

Virtualisation metrics: The next step in our analysis is forecasting trends of virtual machine (VM) density and virtualisation rate. VM density is the average number of virtual machines per virtualised server and is a measure of the sophistication of virtualisation technology,²⁹ whereas virtualisation rate is the percentage of physical servers that are virtualised and is related to the penetration of virtualisation technology. The final assumed trajectories for VM density and virtualisation rate were given a sigmoidal (following along the exponential growth phase) and exponential (CAGR) shape, respectively. They were calibrated using WCI Density data (number of WCIs per server) and the formula below from Cisco, whilst being anchored to values independently published in literature³⁰ and anecdotal views from industry experts.

$$\frac{WCI}{\text{'server'}} = \text{Virtualisation Rate} \times (\text{VM Density} - 1) + 1$$

We assumed the same VM density trajectory for both off-premises and on-premises computing, growing from 15.5 in 2020 to 67.0 in 2040, while the Virtualisation Rates for on-premises and off-premises computing increase from 79% to 87% and 18% to 53%, respectively.

These quantities are difficult to estimate, both at present and looking forward, due to industry practices being both technically and strategically opaque. Therefore, these assumed

²⁸ Cisco, “Global Cloud Index: Forecast and Methodology, 2016–2021 White Paper”, 19 November 2018

²⁹ Evidence suggest that “VM density” to increase dramatically in the future with the rise of containerisation. For this analysis, we suggest containers to be a continuation of virtual machines rather than a separate entity. In application, containers and virtual machines are two different entities. Each virtual machine requires that a virtual server be run on a physical server, running its own operating system along with the various libraries required to host an application. Containers avoid the need for this duplication by running applications directly on the physical server on a single shared instance of the operating system. This frees up a lot of memory, bandwidth, and storage, leading to an increased number of workloads possible to run on a physical server.

³⁰ For example, Stephan Belanger, Brad Casemore, *IDC*, “Exploring the Impact of Infrastructure Virtualization on Digital Transformation Strategies and Carbon Emissions”, August 2019. URL: <https://www.vmware.com/content/dam/digitalmarketing/vmware/en/pdf/company/vmware-exploring-impact-of-infrastructure-virtualization-on-digital-transformation-strategies-and-carbon-emissions-whitepaper.pdf>

trajectories serve as estimations of European-wide averages and are not necessarily representative of the virtualisation rate and VM density of a particular data centre/cloud provider operation, due to the wide range in possible operational configurations.

Projecting physical infrastructure: Using our forecasts for VM density and virtualisation rate, we projected WCI densities for cloud and on-premises computing. We then divided our projection for the number of WCI by the WCI density to obtain the number of physical servers required to sustain future computing demand.

IT Energy Use per server: A recent estimate of total data centre energy usage in 2020 (81 TWh) from the European Commission³¹ was divided by their quoted average PUE³² of 2 and Cisco's³³ estimated number of physical servers for that year, giving an average IT energy usage of approximately 4.9 MWh per "server" per year. This metric includes power used by an average server and its accompanying storage and network infrastructure but does not include cooling. Using a linearly decreasing CAGR, informed by literature on year-on-year efficiency gains due to technology advancements, we project this to decrease year-on-year from 4.9 in 2020 to 2.2 MWh per "server" per year in 2040. Multiplying this projection for IT energy usage with our projection for the number of servers yields a timeline of annual data centre IT energy usage out to 2040.

Geographic distribution of servers: Our projected number of physical servers were distributed amongst European countries based on a directory of off-premises and on-premises data centres³⁴ for the application of country specific average PUE³⁵ and emissions intensity timelines. The geographic distribution of data centres is assumed not to change over time. Aurora Energy Research used proprietary models to forecast the power market evolution and grid emissions intensity of several European countries. Where not available, CAGR-based projections of historical emissions intensity data are used.³⁶ A selection of these grid emissions intensity projections are shown in **Figure M2**. Multiplying projections for IT energy usage by these PUE and emissions intensity forecasts yields country-specific CO₂ emission timelines, which are aggregated to give total European computing emissions, presented in **Figure 2: Projected emissions from European computing demand (2020–2040)** of the report.

³¹ European Commission, "Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market", 9 November 2020.

³² The PUE of a data centre is defined as the ratio of total energy usage to IT energy usage. Avgerinou, M.; Bertoldi, P.; Castellazzi, L. "Trends in Data Centre Energy Consumption under the European Code of Conduct for Data Centre Energy Efficiency". *Energies* 2017, *10*, 1470.

³³ Cisco, "Global Cloud Index: Forecast and Methodology, 2016–2021 White Paper", 19 November 2018

³⁴ Data Center Research. URL: <https://www.datacentermap.com/cloud.html>

³⁵ Avgerinou, M.; Bertoldi, P.; Castellazzi, L. "Trends in Data Centre Energy Consumption under the European Code of Conduct for Data Centre Energy Efficiency". *Energies* 2017, *10*, 1470.

³⁶ European Environment Agency, "CO₂ emission intensity", 17 September 2018. URL: [https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-5#tab-googlechartid_chart_11_filters=%7B%22rowFilters%22%3A%7B%7D%3B%22columnFilters%22%3A%7B%22pre_config_ueo%22%3A%5B%22European%20Union%20\(current%20composition\)%22%5D%7D%7D](https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-5#tab-googlechartid_chart_11_filters=%7B%22rowFilters%22%3A%7B%7D%3B%22columnFilters%22%3A%7B%22pre_config_ueo%22%3A%5B%22European%20Union%20(current%20composition)%22%5D%7D%7D)

Emissions intensity for select countries

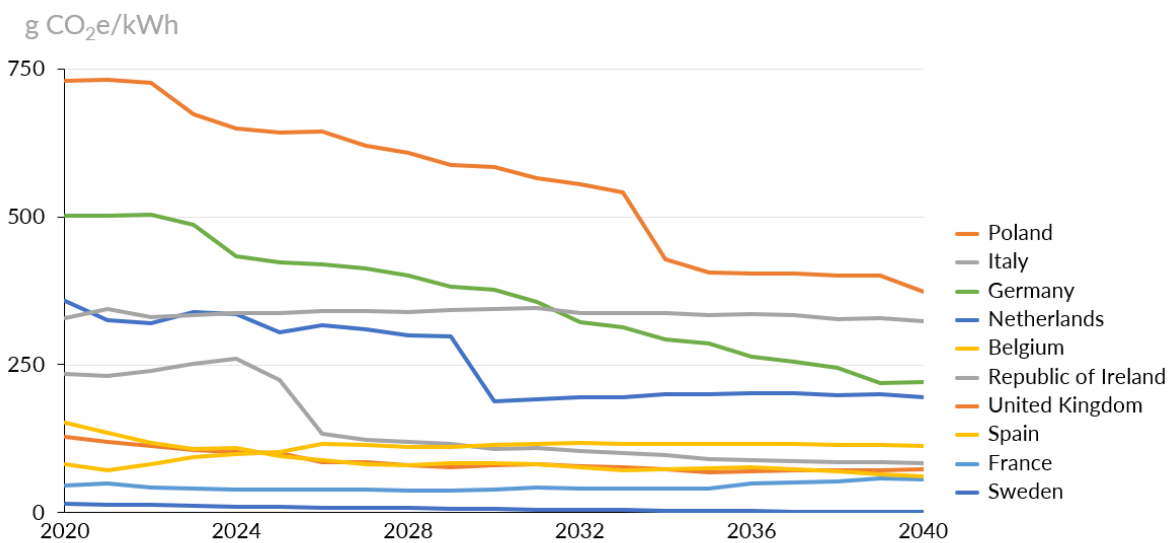


Figure M2: Emissions intensity timelines for select modelled European countries (2020–2040)

Zero Progress scenario—changes to assumptions

The Zero Progress scenario follows the same approach as the Continual Improvement scenario except the assumed virtualisation rate and VM density are constant throughout the projection, maintaining 2020 levels.

Continual Improvement scenario—adjustments for the waterfall chart

The steps in **Figure 4** of the main report are calculated by cumulatively altering the certain inputs of the workflow outlined above.

The first step results from assuming an increase in our virtualisation rate projections for both on-premises and off-premises computing. The change builds up linearly from +0 %p in 2020 to +10 %p in 2040.

The third step comes from revising the timeline of off-premises data centre distribution based on a ranking of countries in terms of their average forecasted carbon emissions intensity per server. All the off-premises computing demand from the worst ranked countries (Bulgaria, Malta, Greece, Turkey and Poland) is gradually shifted to the three best ranked countries (Norway, Sweden and Switzerland). This is meant to capture the potential effect of data centres being strategically located away from computing demand centres to minimise emissions.

High and Low scenarios—changes to assumptions

We acknowledge our forecasts are based on assumptions that carry significant uncertainty; this reflects the lack of transparency and inherent unpredictability of the rapidly advancing computing industry. Of these assumptions, our results are particularly sensitive to projections for WCI and IT energy usage efficiency gains. We flexed these inputs to provide reasonable upper and lower bounds for our forecasted computing emissions. The assumed projections for WCI are shown in **Figure M3**. The high scenario is characterised by high computing demand and low efficiency gains and the converse applies to the low scenario.

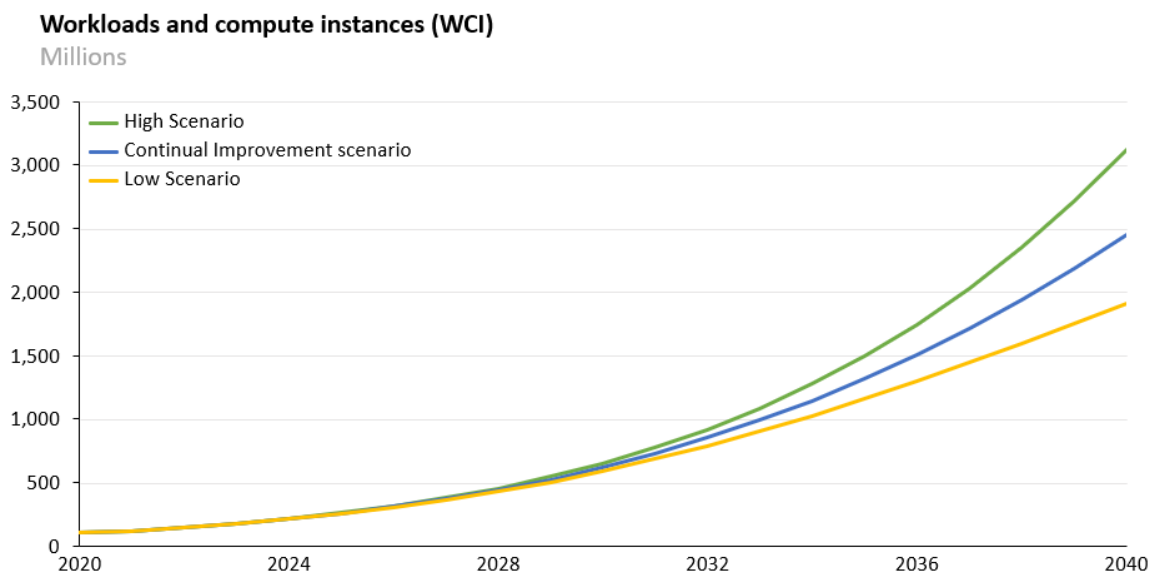


Figure M3: Projected European computing demand (WCI) for the Central (Continual Improvement scenario), High, and Low scenarios (2020–2040)

6. Further information

For any questions related to the analysis in this report, please contact ana.barillas@auroraer.com, christian.miller@auroraer.com or sahasrajit.ramesh@auroraer.com.

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