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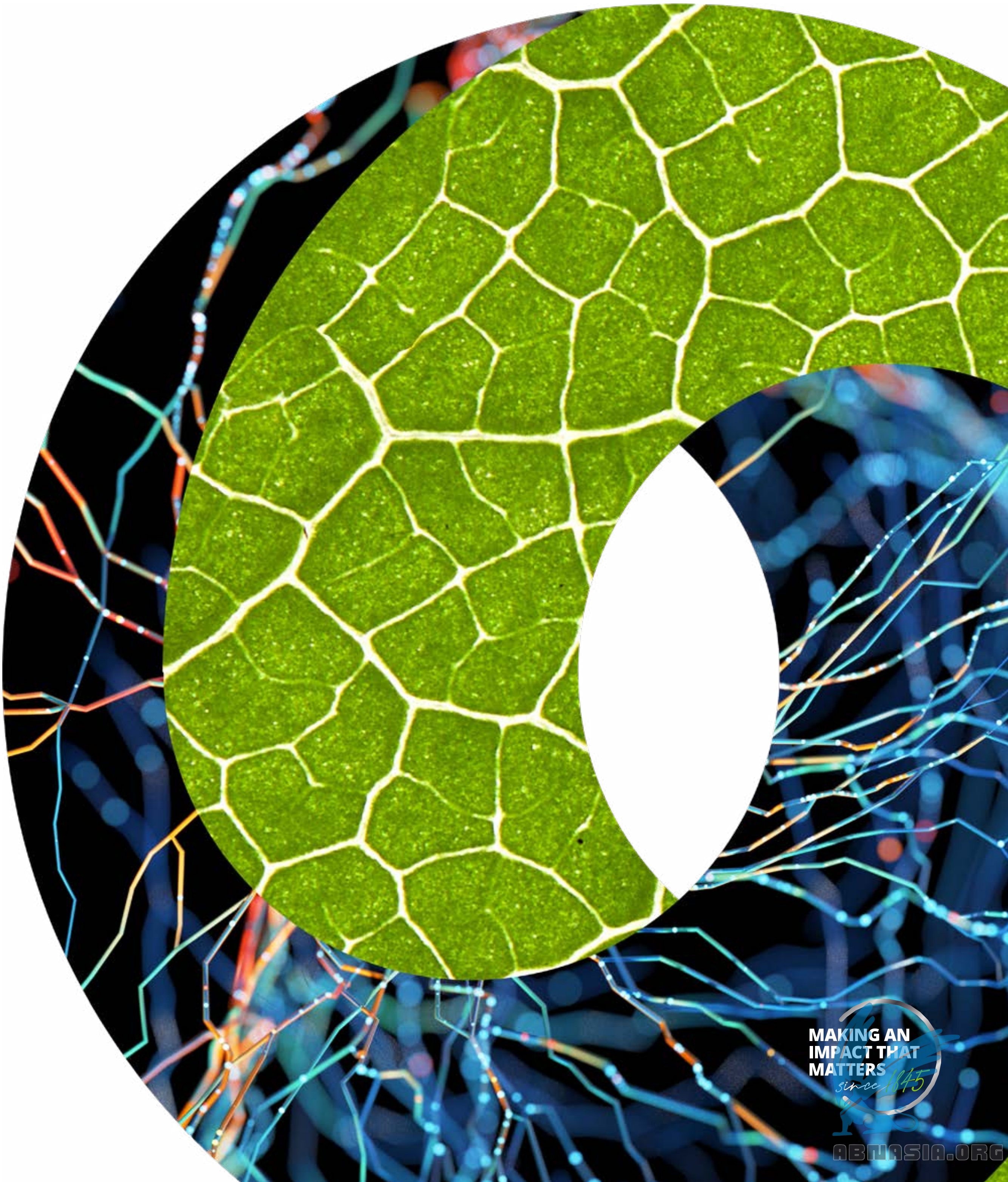
Powering artificial intelligence

A study of AI's environmental footprint—today and tomorrow

November 2024



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Glossary of terms

Term	Definition
AI	Artificial intelligence
CPU	Central processing unit
CAGR	Compound annual growth rate
DC	Data center
EACs	Energy attribute certificates
EMS	Energy management system
EV	Electric vehicle
GHG	Greenhouse gases
GPU	Graphics processing unit
HPC	High performance computing
IEA	International Energy Agency
LCA	Life cycle analysis
LPU	Language processing unit
ML	Machine learning
PPA	Power purchase agreement
PUE	Power usage effectiveness
PV	Photovoltaics
RES	Renewable energy sources
SDGs	Sustainable Development Goals
TCO	Total cost of ownership
TPU	Tensor processing unit
WUE	Water usage effectiveness

Definitions

Term	Definition
Additionality	Principle ensuring that the additional electricity demand of a new project is met by additional renewable electricity production rather than existing renewable sources
Artificial intelligence (AI)	Machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations, or decisions influencing real or virtual environments
AI for Green	Use of artificial intelligence to support environmental sustainability and address climate change by optimizing resource and energy use, and helping reduce emissions
Big Tech	Major technology companies that have significant influence on the industry
Central processing unit (CPU)	Primary chip that performs primary computing tasks
Colocation data center	Data centers rented out to multiples clients concurrently, utilizing common power and cooling
Compound annual growth rate (CAGR)	Average annual growth rate over a given period
Data center	Facility used to house servers and other related computer systems to store and manage data
Energy attribute certificates (EACs)	Contractual instruments that certify one megawatt hour of electricity as being generated by renewable energy sources
Energy Efficiency Directive	European Union (EU) legislative framework designed to enhance energy efficiency across member states through, among others, energy-saving schemes and the improvement of energy performance in buildings and technologies[1]
Energy management system (EMS)	A comprehensive framework used to monitor, control, and optimize energy usage in data centers. It incorporates various processes and technologies, including Service Level Management (SLM) and Resource Allocation Graphs (RAG), dynamic workload management, and real-time monitoring, to improve efficiency, reduce costs, and minimize environmental impact
European Code of Conduct for Data Centers	EU initiative designed to promote energy efficiency and best practices in data center operations through, among others, guidelines on energy management, cooling systems, and IT equipment usage[2]
Greenhouse Gas (GHG) Protocol	Internationally recognized framework designed to standardize the measurement and management of greenhouse gas emissions across organizations[3]
Graphics processing unit (GPU)	High performance computing chip tailored for parallel operations well-suited for large-scale data processing
Green AI	Development of AI technologies with a focus on minimizing the environmental impact associated with the underlying infrastructure, i.e. the servers, storage and chips used for AI
Greenhouse gases (GHG)	Gases contributing to climate change (e.g., CO_2, CH_4, Nox, etc.)
High performance computing (HPC)	Use of powerful servers and parallel processing techniques to solve complex computational problems
Hyperscale data center	The largest kind of data center, often designed for automation, scalability and efficiency, used to support large-scale extensive cloud services and online applications
Immersed liquid cooling	Technology used for reducing heat in electronic systems by submerging components in a thermally conductive but electrically insulating liquid coolant
Inference phase (for AI)	Stage in an AI model's lifecycle where it answers queries and prompts for the end user by applying its learned knowledge
Interconnection queues	List of power generation and energy projects that have requested to connect to the electric grid

Term	Definition
Jevons paradox	Principle stating that improvements in energy efficiency can lead to an increase in overall energy consumption, as reduced costs and increased efficiency often result in higher demand[4]
Language processing unit (LPU)	Specialized processing chip engineered for efficient natural language understanding and generation tasks. LPUs are known to be more energy-efficient than traditional AI technologies in specific applications such as real-time translation, speech recognition, or text analysis[5]
Leadership in Energy and Environmental Design (LEED) certification	Internationally recognized program designed to promote sustainability and leading practices in building construction and operation through, among others, guidelines on energy efficiency, water usage, and materials selection[6]
Life-cycle analysis (LCA)	Assessment of the environmental impacts of a technology from its creation to its use and end-of-life stages
Machine learning (ML)	An application of AI, whereby machines learn to identify patterns in datasets and perform tasks without explicit programming
Neuromorphic computing	Approach to computing that mimics the neural structure and functioning of the human brain in artificial neurons to improve computational efficiency
Power purchase agreement (PPA)	Contract to buy electricity from a specific source at a predetermined rate
Power usage effectiveness (PUE)	Ratio of total data center electricity use to IT equipment electricity use
Quantum computing	Use of quantum bits to perform complex calculations faster than classical computers by leveraging the principles of quantum mechanics
Regional energy hubs	Collaborative energy system where multiple parties, including energy producers, consumers, and storage providers, can coordinate to manage, distribute, and optimize energy resources
Renewable energy sources (RES)	Refers to bioenergy, geothermal, hydropower, solar photovoltaics, wind, and marine energy for electricity generation
Singapore Green Data Center Roadmap	Singaporean initiative designed to promote energy efficiency and best practices in data centers through guidelines on energy management, cooling systems, and IT equipment use[7]
Software carbon intensity	Global initiative designed to promote sustainability in software development with guidelines on measuring, reporting, and reducing the carbon footprint of software applications[8]
Tensor processing unit (TPU)	Specialized processing chip designed to accelerate tasks involving artificial neural networks. TPUs are known to be more energy-efficient than traditional AI technologies in specific applications such as neural network processing or large-scale deep learning tasks[9]
Total cost of ownership (TCO)	All direct and indirect costs associated with purchasing, operating, and maintaining a facility over its entire lifecycle
Training phase (for AI)	Process AI models undertake before their end use to learn from large data sets and calibrate their responses
United Nations Sustainable Development Goals (SDGs)	Set of 17 global objectives aimed at, among others, promoting sustainable development, eradicating poverty, protecting the environment, and ensuring peace by 2030[10]
Utilization rate	Ratio of a data center's actual power consumption to its total power capacity
Water usage effectiveness (WUE)	Ratio of data center water use to the IT equipment electricity use

Executive summary

Artificial Intelligence (AI) technologies are among some of the defining megatrends of this century, permeating various facets of economic and social activities and helping drive substantial growth in data and computational needs. However, this new digital age is also driving a significant increase in electricity consumption. This strong power demand growth is putting local strain on power utilities – who find themselves forced to dispatch fossil fuel power plants more often – and has given rise to concerns about the environmental footprint of AI. Soaring electricity consumption of data centers has challenged major technology companies in successfully achieving their climate goals due to increasing indirect emissions.

According to Deloitte Global analysis, global electricity use by data centers – the backbone of AI and modern computing – is estimated to be more than 380 Terawatt hours (TWh) in 2023, representing approximately 1.4% of global electricity consumption and around 0.3% of global greenhouse gas (GHG) emissions. This study offers a quantitative assessment of the environmental footprint of AI and data centers. Based on detailed bottom-up modeling, global data center electricity consumption is projected to nearly triple in the coming decade, reaching around 1,000 TWh by 2030 and accounting for approximately 3% of worldwide power use by then. Although data centers handle a wide range of computations, the primary growth driver for data centers in recent years, and likely in the future, has been AI applications.

The long-term impact of AI on carbon dioxide (CO_2) emissions remains highly uncertain. Several key factors contribute to this uncertainty:

- The pace and scale of AI technologies adoption across our economic activity, determining the computing power required for AI services;
- The potential advancements in data center efficiencies, which could affect the electricity consumption for AI-related activities;
- The availability and deployment of clean electricity to power data centers, determining the CO_2 emissions associated with AI services.

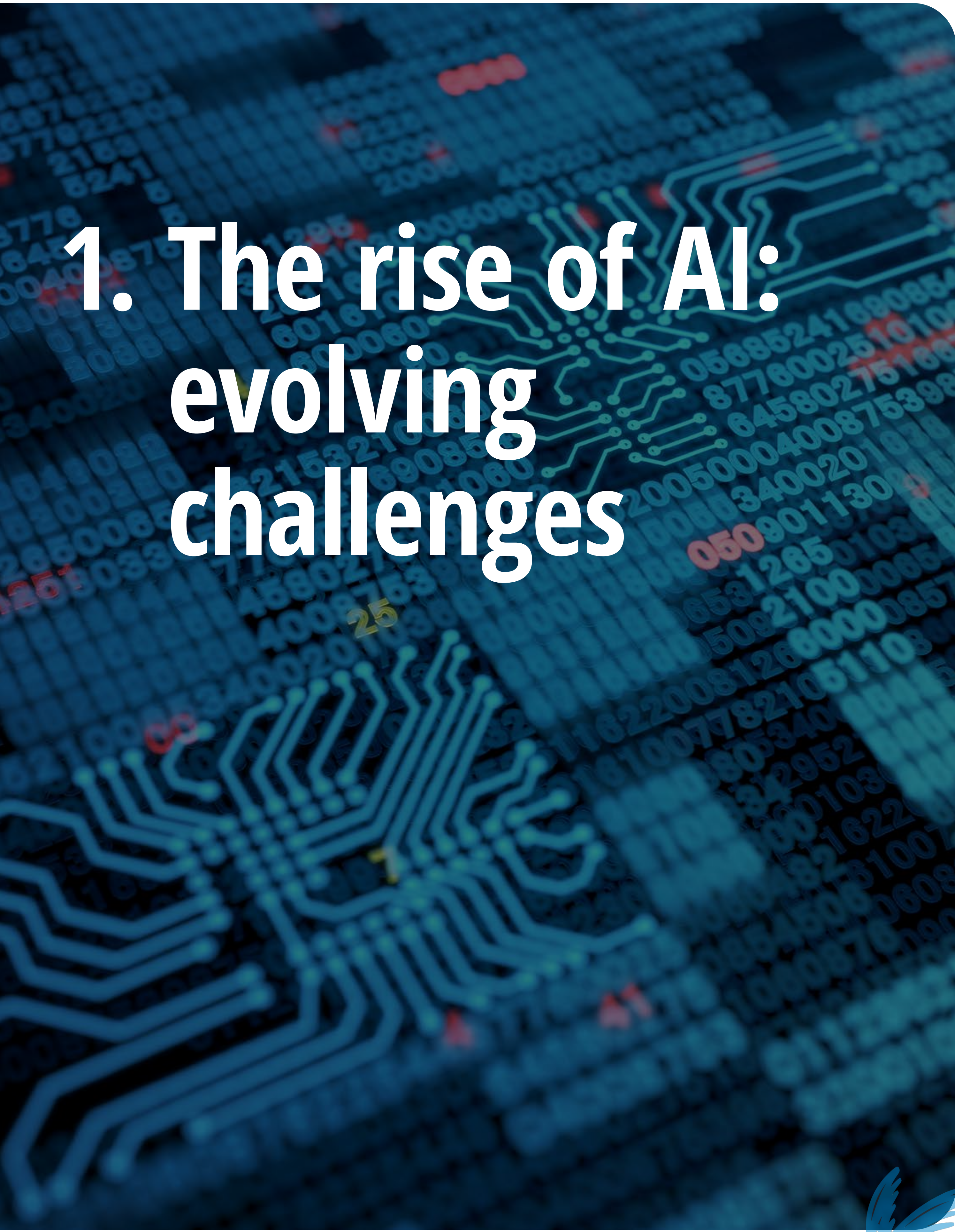
Deloitte Global's modeling suggests that a continuation of the current growth rate of AI data center capacity and hardware efficiency gains, coupled with the widespread adoption of leading technologies, would result in a power consumption of 2,000 TWh by 2050. To put this into perspective, this corresponds to around 3% of global electricity consumption by 2050 in a net zero emissions scenario, i.e., other electricity uses like e-mobility, electric heating, and green hydrogen by far outpace growth in data center power consumption. However, concerns have been raised that energy efficiency improvements will likely slow down over time. Should those improvements taper off by 2030, rising AI demand could push data center electricity demand beyond 3,500 TWh in the long-term. Conversely, an alternative perspective with a slower uptake of AI sees more moderate growth in electricity consumption, reaching around 1,700 TWh by 2050. This scenario would place considerably less pressure on technology companies to pursue cutting-edge server efficiency and breakthrough research. Despite the immediate challenges of accommodating more data centers in our power grids, the long-term outlook for data center demand growth is likely more moderate and far surpassed by the clean electricity needs from the decarbonization of industry, transport, and buildings.

The rise of AI and data centers needs to be accompanied by a commensurate increase in renewable energy to help avoid some of the negative implications for the climate. The rapid expansion of renewables can be key to achieving a peak in data center CO_2 emissions, ideally in the early 2030s, despite continued growth in electricity demand. To help achieve this outcome, it will likely require a concerted effort from both technology companies and policymakers to accelerate the expansion of renewable energy and enhance the power network infrastructure.

Additional levers include achieving "Green AI" enhancing reporting transparency through standardized, industry-wide efficiency metrics, spearheaded by policymakers and industry leaders. If well-designed, those metrics could be one basis for engaging the broader ecosystems in cleaner operations, from finance to research and development. The final lever is a commitment to efficient AI development and operation. If these four pillars – renewable expansion, transparency, ecosystems approach, and efficiency gains – are implemented in a timely manner, then the AI boom can happen without potentially jeopardizing its environmental footprint.

While there are undoubtedly challenges ahead to ensure its development, AI also has the potential to significantly aid in the transition to climate-neutral economies by aligning its usage with sustainable development goals – often referred to as "AI for Green". Weighing AI's energy consumption against its potential benefits is crucial to help ensure a net positive impact on climate goals. While historical energy-efficiency gains and current efforts are promising, continued efforts and firm commitments will be necessary to remain on the path toward a low-carbon economy.

1. The rise of AI: evolving challenges



1.1. Powering our digital age

Just two months after its release in November 2022, Open AI's ChatGPT had already reached 100 million monthly users,[11] making it the fastest-growing consumer software application ever. This rapid success highlights the current Generative AI (GenAI) boom, which has generated substantial investment and public interest, transforming AI into a US$200 billion dollar industry.[12] The rise of AI more broadly has the potential to become one of the megatrends of this decade, with other evolving digital technologies potentially extending into significant parts of our social life and economic activity.

In 2022, data centers already represented an estimated 350 TWh of electricity consumed globally, which is roughly equivalent to the electricity production of Saudi Arabia over the same period and accounts for about 1.3% of global electricity consumption.[13,14] However, since 2010, data center electricity use has remained relatively stable,[15] growing moderately despite a more than 17-fold increase in internet traffic worldwide,[16] thanks to significant efficiency improvements and the move from smaller localized enterprise data centers to larger hyperscale data centers.[17]

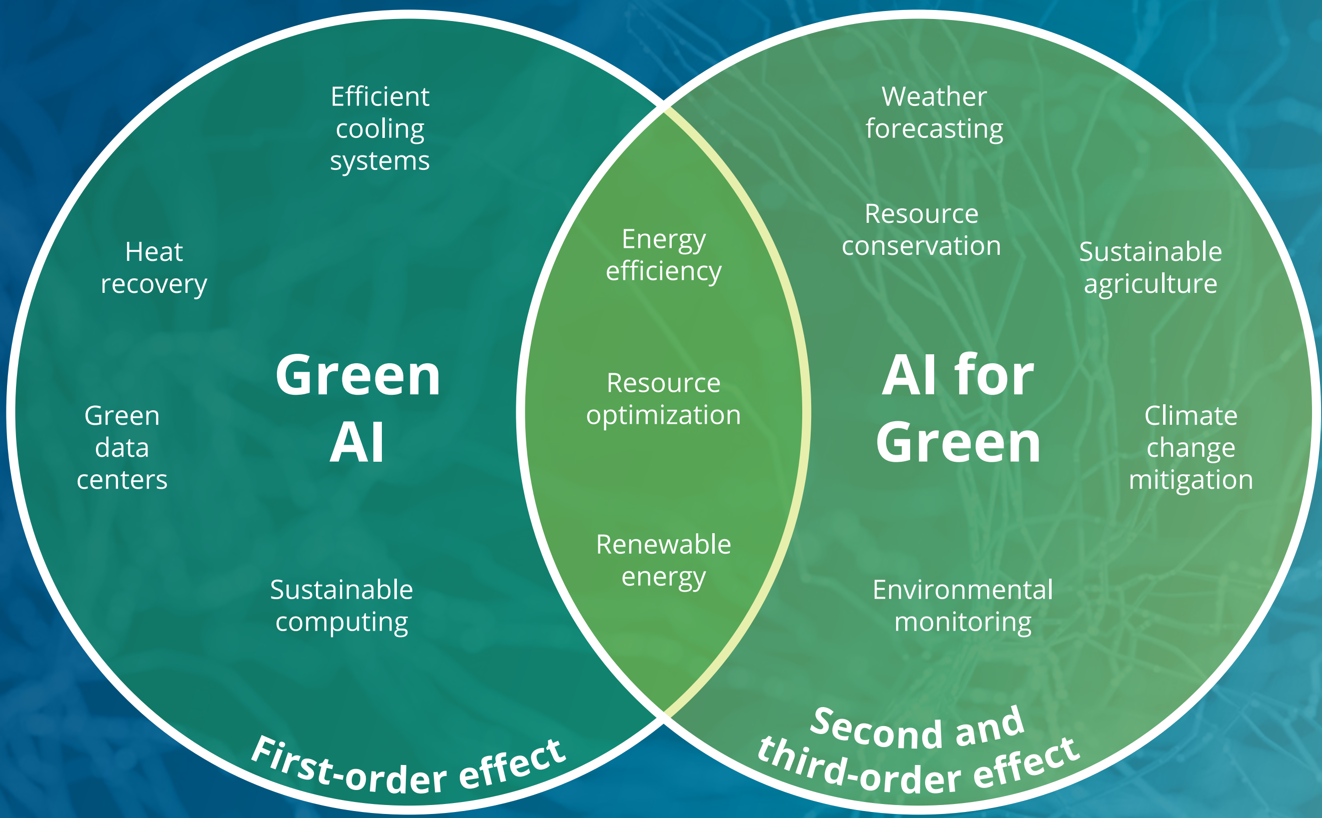
Projections for future years are raising concerns. The growing AI market is projected to be a key driver of additional electricity consumption, with some analysts expecting electricity consumption of data centers to double over the next two years.[18] As these technologies become more widespread, prioritizing energy efficiency and sustainable practices becomes increasingly important to help reduce their environmental impact. Although AI and related technologies hold the potential to accelerate the transition to climate-neutral economies, the growth in electricity demand from data centers risks offsetting these gains and delaying the energy transition if not appropriately managed.

In 2022, data centers already represented an estimated 350 TWh of electricity consumed globally, which is roughly equivalent to the electricity production of Saudi Arabia.

AI's potential to aid climate mitigation should be evaluated from two perspectives. The first, known as "Green AI," pertains to efforts to reduce AI's environmental footprint by adopting leading practices across the entire value chain—from clean energy supply purchases to hardware improvements. This aspect is typically assessed through life cycle analysis (LCA) and refers to "first-order effects" (Figure 1).[19]

As with any technology, second and third-order effects should also be assessed, in relation to the indirect and sometimes unintended consequences of deploying AI systems. Hence, the second perspective encompasses the "AI for Green" concept. Figure 1 outlines some of the potential benefits associated with AI. However, these induced complex effects can vary and should be anticipated by policymakers and businesses to mitigate potential negative impacts.

Figure 1. Conceptual vision of the "Green AI" and "AI for Green" concepts



Source: Deloitte Global illustration based on Hilty et al.[20]

1.2. Objective of this study

There is currently a lack of consensus on the impact of AI on both local and global power systems, along with the associated global GHG emissions. This study focuses on potential ways to achieve "Green AI" in the coming decades. While historical gains in energy efficiency are recognized[21,22] and continue to materialize,[23] some studies highlight the limited potential for further energy efficiency improvements[24,25,26] and the significant energy needs of AI compared to traditional computing.[27] Deloitte Global's study identifies key factors influencing AI development and provides a detailed quantitative analysis of the current and future energy usage of data centers. Importantly, it also outlines an industrial roadmap and a policy framework for developing a net-zero-compliant AI sector.

Concretely, the overarching aim of this study is to answer the critical questions emerging around the energy consumption and climate impacts of AI, notably:

01. What are the current trends, key drivers, and regulatory frameworks that will help shape the evolution of AI and the energy consumption of data centers?

02. How might the energy consumption of data centers evolve, and what would the resulting carbon footprint be?

03. What strategies can businesses and governments implement to help mitigate the environmental impact of AI-related energy consumption on climate?

The first step is to thoroughly understand the origin of AI's footprint concerns, establish "what-if" scenarios that integrate key uncertainties, and determine whether existing policies are sufficient to help address some of these challenges or if additional measures are required to ensure compliance with climate neutrality goals. These scenarios describe how the energy and environmental footprint of data centers might develop in future if a number of technological, economic, and regulatory drivers evolve in a certain way. They should not be interpreted as an attempt to predict the future as accurately as possible, but rather used as tools to test strategies and business plans.

2. The watts behind the wits

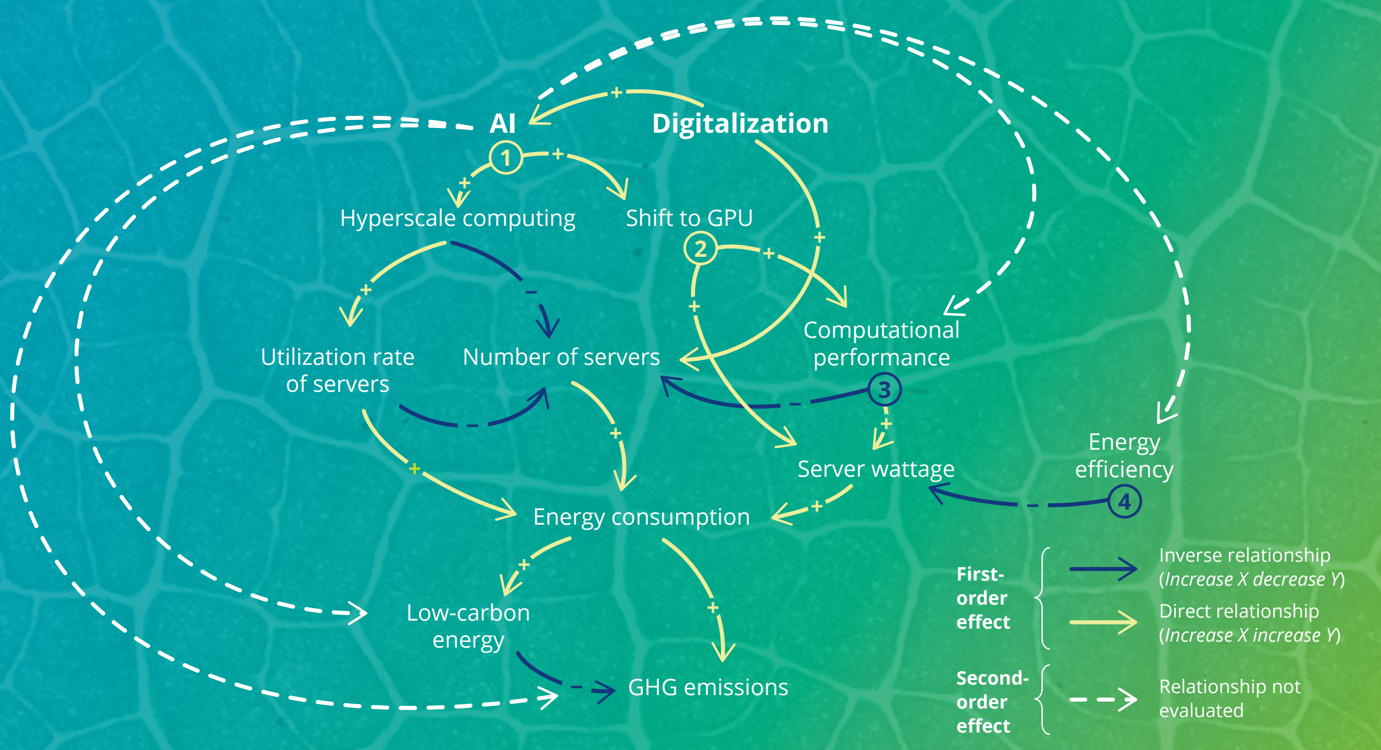
2.1. Understanding AI's power appetite

Data centers are the underlying infrastructure required for AI training and deployment. While often thought of as the cloud, data center operations rely on numerous physical components required for computing, processing, storing, and exchanging data. These components demand substantial amounts of power to operate, significantly contributing to the overall energy consumption of technology companies. For example, data centers accounted for 98% of Meta's additional electricity consumption between 2021 and 2022, and around 72% of Apple's between 2022 and 2023.[28]

While these components are key in understanding electricity consumption, distinguishing between different types of data centers is critical, as each serves specific needs and exhibits distinct electricity consumption characteristics. These range from basic computer rooms designed for simple computing tasks to mid-size and large-scale enterprise data centers.[29] Hyperscale data centers, which maximize hardware density and support extensive data computation (typically centralized and owned by technology companies) consume the most energy.[30] Within the hyperscale category, a new "AI hyperscale data center" segment stands out, specifically designed to support GenAI and machine learning (ML) workloads.

Figure 2 summarizes key factors and interactions that drive the electricity consumption of data centers. The first trend to consider in Figure 2 is the extent to which AI can drive the development of hyperscale data centers. Since smaller data centers are typically not equipped to handle the high rack densities and computational power required for AI adoption, most of the computations will likely be concentrated within AI hyperscale data centers. Those are equipped with high-performance computing resources, including the graphics processing units (GPUs) necessary for AI model training and inferencing. Using this specific equipment drives higher server wattage (Trend 2 and 3 in Figure 2) and the use of new cooling techniques.[31,32]

Figure 2. Four illustrative trends impacting the electricity consumption and GHG emissions of data centers



Source: Deloitte Global analysis.
Note 1: The "Hyperscale computing" trend highlights the relative importance of hyperscale data centers compared to edge data centers and edge AI solutions.
Note 2: The "Shift to GPU" trend also includes the transition towards specialized chips such as LPUs and TPUs, and the associated technological advancements.

As AI hyperscale data centers grow, their role will likely extend beyond AI-related tasks. These advanced facilities are set to take over functions traditionally handled by conventional data centers, especially for cloud high-performance computing (HPC) tasks such as large-scale data processing or scientific simulations. Indeed, GPUs offer superior performance for these specific applications and can be more energy-efficient for such workloads compared to traditional Central Processing Units (CPUs).[33] A transition to GPU-powered hyperscale data centers could, therefore, play a role in counterbalancing the increased energy consumption driven by a rising demand for cloud HPC. Similarly, specialized chips are emerging, such as Tensor Processing Units (TPUs) or Language Processing Units (LPUs), which could further enhance the energy efficiency and computational power of data centers. Their future integration can build a more versatile and powerful platform for handling AI and HPC tasks in the future.

However, there may be a partial reversal of the current trend, driven by edge AI, corresponding to in-device models and algorithms.[34] This approach facilitates real-time processing and decision-making directly on devices, thereby reducing latency and bandwidth usage. Additionally, as more governments look to prioritize data and AI sovereignty, smaller edge data centers could serve national markets rather than the current model of hyperscale data centers with an international reach.[35] While this trend helps to reduce latency and facilitates data center governance, it also negates some of the efficiency inherent to larger data centers, ranging from economies of scale in redundancy, cooling, or staffing. Furthermore, their location is constrained to be close to end-users, so edge data centers miss the opportunity to leverage the efficiencies offered by strategically located data centers where resources are not constrained.

The dynamic interplay between the growing demand for computational resources, advancements in computational performance, the types of servers deployed, and their utilization rates ultimately shape the overall electricity demand in data centers.

A concern arising from the growth in electricity consumption for data centers is the potential plateauing of energy-efficiency improvements (Trend 4 in Figure 2), which have been pivotal in containing the increase of data center electricity consumption since 2010. Recent observations indicate a deceleration in efficiency advancements for CPU-only computing.[36] According to Koomey's Law,[37,38] computing hardware efficiency doubles every 1.6 years, a trend that effectively held true from 1945 to 2000. However, this trend has slowed since 2000, with efficiency improvements doubling only every 2.6 years.[39] Despite this trend, the advancements achievable through accelerated computing architectures based on GPUs are promising and appear essential to continued scaling of AI, and for mitigating the rising electricity demand.

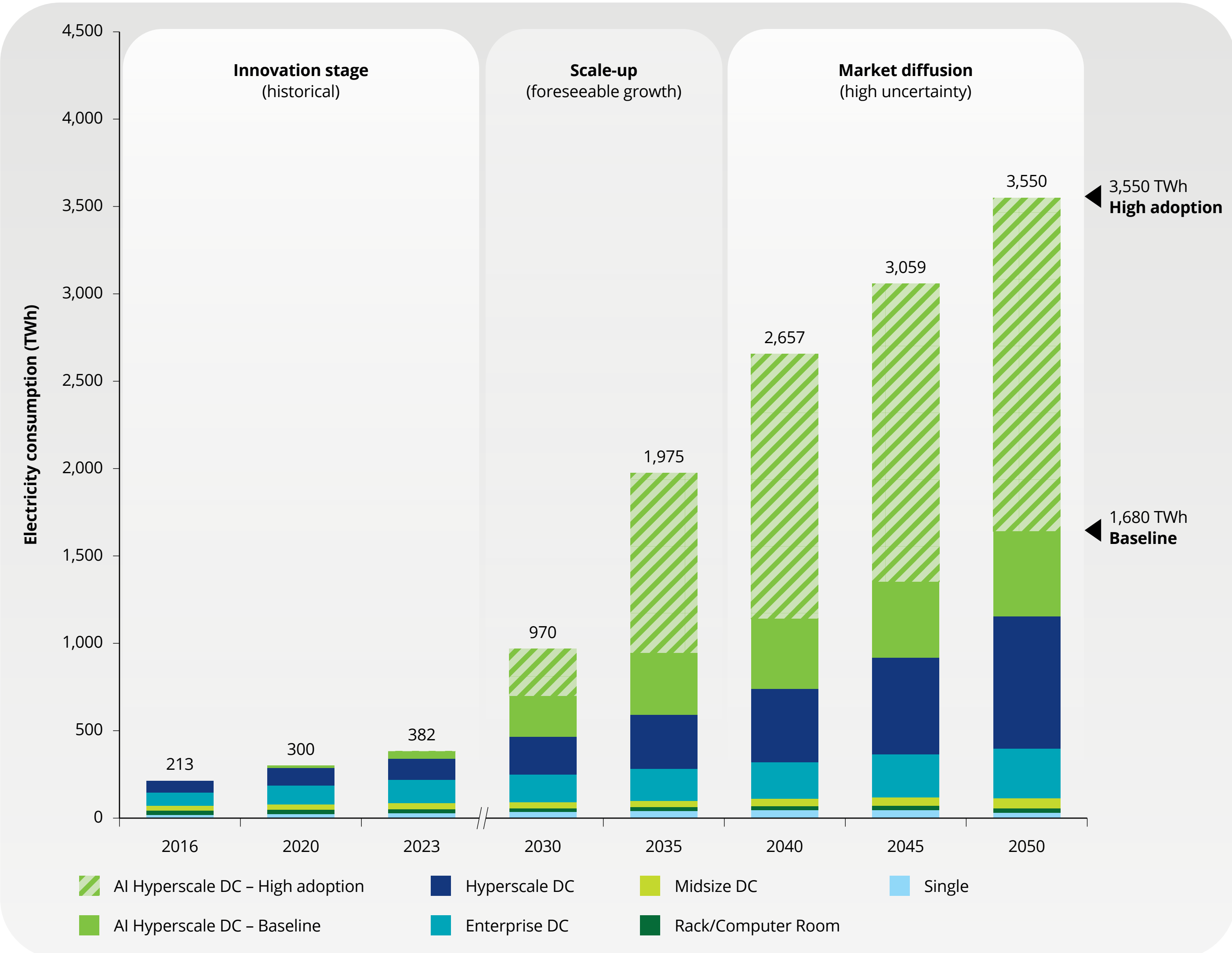
The dynamic interplay between the growing demand for computational resources, advancements in computational performance, the types of servers deployed, and their utilization rates ultimately shape the overall electricity demand in data centers. As technologies become more advanced and widely adopted, they can also contribute to increased energy efficiency through enhanced computational capabilities and optimized resource management.

2.2. Significant growth expected, contingent on AI adoption

The future electricity demand of data centers is assessed through a bottom-up approach that considers server types, IT equipment and energy efficiency trends. The period from 2024 to 2030 relies on a market-based assessment,[40] while 2030 to 2050 uses a diffusion model for new technology, following logistic growth or the S-curve.[41] As per Deloitte's analysis two distinct speeds of AI technology development and adoption are considered, acknowledging the challenges in estimating AI uptake across various sectors while accounting for currently announced investments.

The "Baseline" scenario assumes a gradual integration of AI capabilities into existing systems and industries, limiting AI deployment to the most straightforward and cost-efficient applications. This would result in a lower growth rate between 2024 and 2030 compared to the rapid installation pace observed between 2020 and 2023. Conversely, the "High adoption" scenario is based on the premise that current growth trends in AI servers will be sustained, fueled by increasing AI workloads and accelerated adoption of GenAI technologies.

Figure 3. Data centers' electricity consumption by server type and scenarios



Source: Deloitte Global analysis.

Based on Deloitte Global's assessment, the growing demand for AI, computing power, and storage needs will likely drive higher energy requirements in the two scenarios shown in Figure 3, even as data centers become more efficient. The expansion of hyperscale facilities could push consumption from 382 TWh in 2023 to 970 TWh by 2030 and up to 3,550 TWh by 2050 in the "High adoption" deployment scenario. Specifically, AI hyperscale data center consumption is projected to grow at a compound annual growth rate (CAGR) of 43% between 2023 and 2030, aligning with market expectations.[42,43] As the technology is already adopted across industries, the growth rate and associated electricity consumption are projected to slow between 2030 and 2050. The scenarios described in this study assume that no significant constraints will hinder the global expansion of data centers, aside from the scale of AI adoption on the demand side. The most likely limitation identified to date corresponds, indeed, to power[44] and grid availability.[45]

Overall, in the "High adoption" scenario AI hyperscale data centers account for 50% of the data center electricity demand by 2030 and nearly 68% by 2050, well above the current 11% attributed to AI hyperscale data centers.[46] These scenarios highlight the ongoing shift in the distribution of computing jobs, with new data center developments increasingly focusing on specialized AI-hyperscale data centers rather than smaller, traditional data centers.

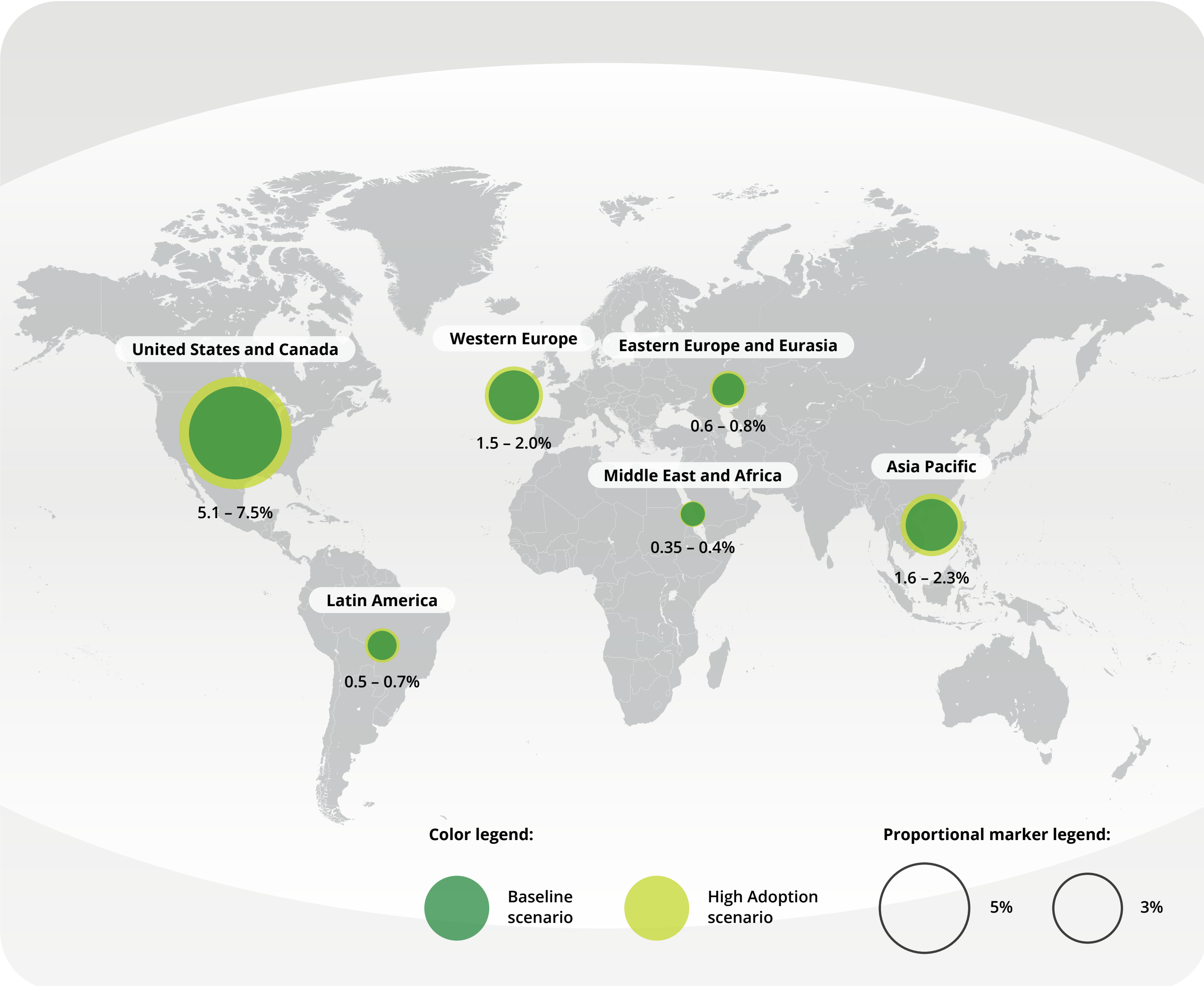
Conversely, in the "Baseline" AI deployment scenario, AI electricity consumption grows more slowly between 2023 and 2030 and further decelerates between 2030 and 2050. In this scenario, AI-related electricity demand reaches around 30% of overall data center electricity demand across the entire period.

This surge in electricity demand increases the share of electricity used by data centers globally, reaching 2.7% in 2030 and 5.0% in 2050[47] in the "High adoption" scenario. Regionally, the analysis estimates that Asia Pacific, the United States and Canada account for the highest share, respectively representing 42% and 36% of global data center electricity consumption in 2023 (Figure 4). Europe follows with 17%, while Latin America, the Middle East, and Africa collectively represent 5%. Despite this apparent market concentration, electricity demand is increasing across all regions. The fastest growth is expected in Asia Pacific, potentially reaching up to 435 TWh by 2030. This would represent approximately 2.3% of the region's total electricity consumption. The United States and Canada would also face a significant increase, with data centers' share of total electricity demand rising from approximately 3.9% in 2023 to 5.1-7.5% by 2030 and up to 6.6-10.3% by 2050 depending on AI adoption.

According to Deloitte's analysis, in contrast, the electricity demand from data centers in the Middle East and Africa is projected to reach 0.4% of total electricity consumption by 2030 and 0.3% by 2050. The deployment of data centers in these regions is likely to be constrained by high temperatures and water scarcity, which pose significant challenges for cooling and operations, despite significant potential for low-carbon power production.

Estimating the energy consumption of data centers in 2030 and beyond presents significant challenges due to the numerous variables involved. This assessment suggests that continuous improvements in AI and data center processing efficiency could yield an energy consumption level of approximately 1,000 TWh by 2030. However, if those anticipated improvements fail to materialize in the coming years, the energy consumption associated with data centers could rise to above 1,300 TWh, directly impacting electricity providers and challenging countries' climate-neutrality ambitions. Consequently, driving innovations in AI forward and optimizing data center efficiency over the next decade will be pivotal in helping to shape a sustainable energy landscape.

Figure 4. **Share of data centers' electricity demand in total electricity consumption, 2030**



Source: Deloitte Global analysis based on own calculations and IEA World Energy Outlook 2023, Net Zero scenarios.[48]

2.3. Achievable energy savings

Reducing the power demand from data centers can be achieved by increasing energy efficiency at various stages, from IT equipment to the overall site design.

At the IT equipment level, several measures can lead to more efficient use of resources and lower electricity demand. By improving the performance per watt of servers and reducing the server's idle power through innovations from chip manufacturers, data centers would be able to process more workloads with less energy. In particular, advancements in GPU technology would enable higher utilization rates and enhanced computing performance.[49] Similarly, implementing a comprehensive energy management system (EMS) is an important lever for optimizing energy efficiency, as it incorporates dynamic workload management and real-time monitoring, contributing to minimizing idle periods and maximizing energy use. Combined, these hardware innovations and systemic optimization strategies can significantly reduce overall power consumption in data centers.

At the infrastructure level, most of the achievable gains are captured by the power usage effectiveness (PUE), which corresponds to the ratio of the total power used by the data center (i.e., including lighting and cooling power demand) to the power used by the sole IT equipment (i.e., the servers, storages, and networks equipment) within it. By definition, a PUE value close to 1 corresponds to an efficient data center, where all the electricity is used by the IT equipment. In the last few decades, the average PUE has declined from 2.5 in 2007 to 1.58 in 2023.[50] Major United States technology companies managed to reduce the PUE of their hyperscale data centers further to around 1.1 in 2023, a 10% decrease compared to 2019, with top performers announcing 1.09 in 2024.[51,52]

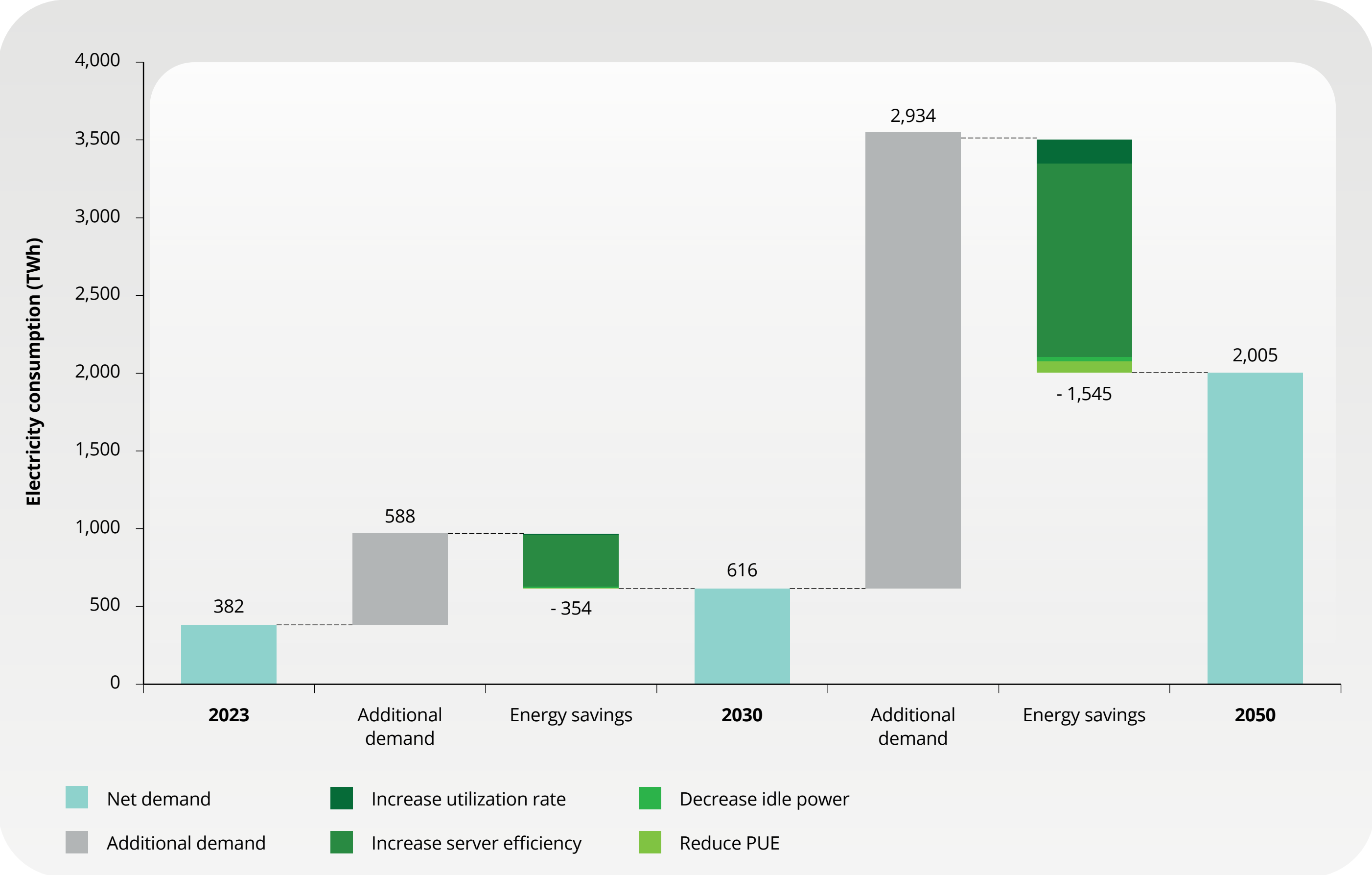
At the site level, facility design during the investment decision stage is a critical lever impacting electricity consumption. For example, minimizing unused space and ensuring adequate airflow are important levers to improve overall performance. In addition, the geographical location of a greenfield data center plays a crucial role in determining achievable energy efficiency. As mentioned earlier, data centers located in warmer or tropical climates require more power for cooling, directly translating into higher PUE.

While each factor is important to consider, some have more impact on reducing overall energy use than others. Based on the trends identified at the equipment levels, and due to the significant improvements and progress in data center facility design, the power consumption share for infrastructure equipment is expected to drop from 33% to 10% by 2050[53]. Consequently, the share attributed to servers is projected to rise slightly from 55% to 64% by 2050. With more servers deployed in line with the growing volume of data, the possible prevalence of "real-time" data—data that is created, processed and exchanged immediately— and the limitation of "dark" data — data that organizations collect but fail to use—hold the potential to tone down the growth of electricity consumption associated with long-term storage.[54]

Based on the levers identified at the equipment, infrastructure, and site level, the analysis estimates that broader adoption of the "leading available technologies" can help to reduce the electricity demand of data centers by more than 350 TWh in 2030 (36% less compared to the "High adoption" scenario). Looking ahead, more than 1,545 TWh (44% less compared to the "High adoption" scenario) could be saved in 2050 (as shown in Figure 5). The decreases are largely due to advancements in hardware and increased adoption of GPUs, which are expected to significantly boost computing performance.[55]

While some analysts predict that the performance gains of the current GPU paradigm may plateau between 2027 and 2035,[56] specialized processors and emerging paradigms such as quantum computing also hold promise for further enhancing the energy efficiency of AI and HPC. It is also important to note that a similar plateau may arise on the growth of AI workloads or the availability of data for model training, which could likewise result in lower energy consumption than anticipated.[57] Moreover, rapid advancements in model innovation and diversification of AI models could drive the creation of more efficient models, contributing to limiting energy consumption growth, provided that improved accuracy is balanced with similar improvements in energy efficiency.

Figure 5. Achievable electricity demand reduction through energy savings, "High adoption" scenario



Source: Deloitte Global analysis.

3. A broader view: what to expect

3.1. Peak emissions to be reached in the 2030s

The vast majority of emissions associated with data centers arise from their scope 2 emissions, i.e., the emissions associated with their electricity consumption (Box 1, p. 23). Consequently, major technology companies are increasingly securing low-carbon power purchase agreements (PPAs) to help mitigate these emissions, driven by commitments to reduce their carbon footprint and enhance their operations' sustainability. Technology companies have been the primary corporate off-takers of renewable PPAs over the past decade,[58,59] making significant efforts to align their electricity consumption with renewable energy on an hourly basis.[60,61] However, in the past two years, the electricity use by data centers has surged more rapidly than companies' ability to procure carbon-free energy, notably in the United States and the Asia Pacific region.[62] While this might be a short-term challenge given companies are already implementing measures to ensure long-term sustainability, the outcome will likely depend heavily on their capacity to secure a pipeline of clean energy projects in tandem with any data center expansion.

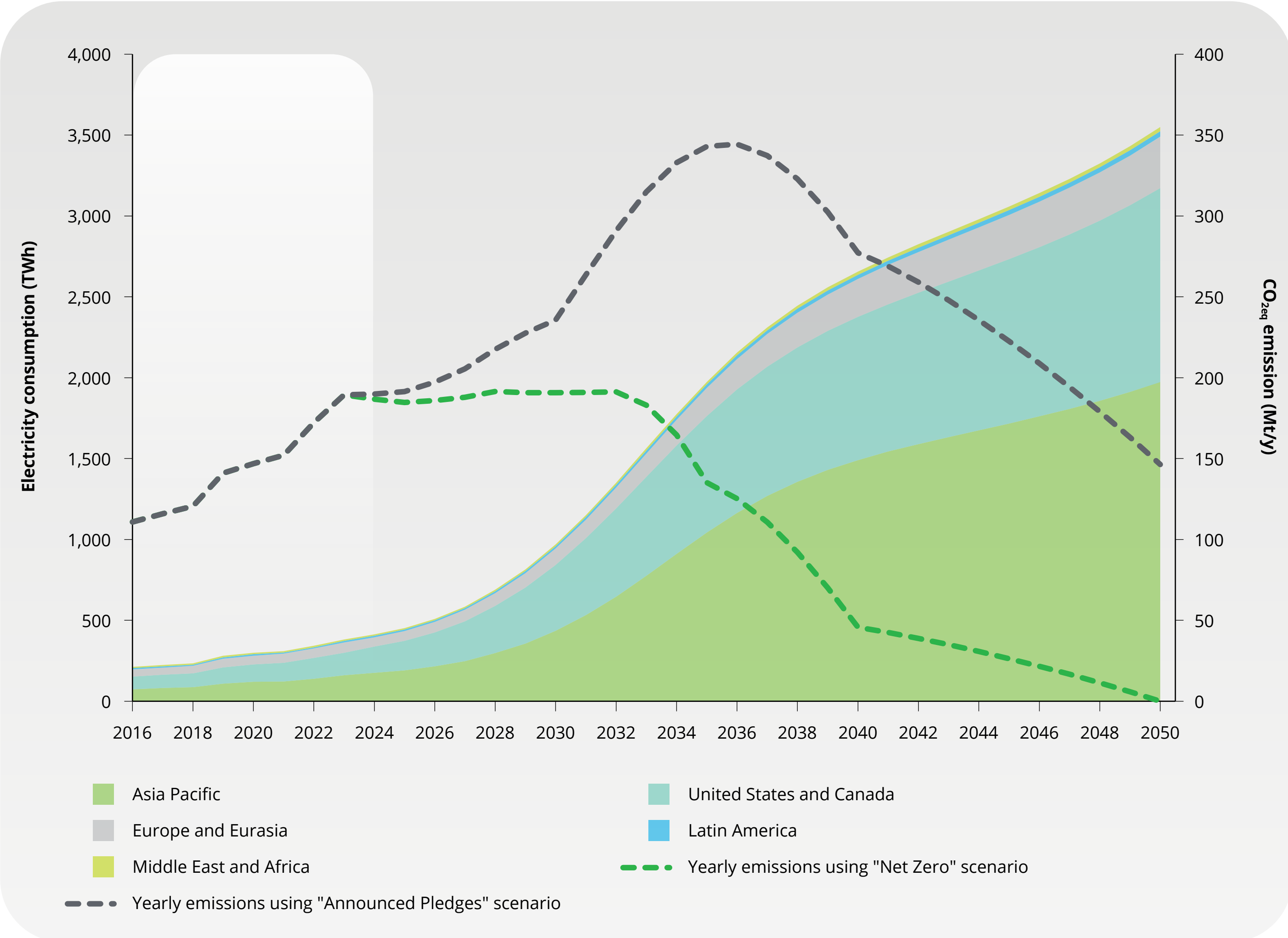
Based on the GHG Protocol, two standards are used to report scope 2 emissions. The market-based method reflects emissions from the electricity that companies specifically purchase through power purchase agreements or renewable energy certificates. In contrast, the location-based method captures the average carbon intensity of the grids where the electricity is consumed.[63]

Using a location-based approach, data centers' GHG emissions (including upstream emissions associated with power generation) are estimated at 189 $MtCO_{2eq}$ in 2023, representing just over 0.3% of GHG emissions. Under the 'Net-Zero by 2050' scenario from the International Energy Agency (IEA)[64], emissions can be expected to taper off through the mid-2030s despite growing electricity consumption (as shown in Figure 6). In contrast, under the IEA's "'Announced Pledges'" scenario[65], data center emissions are projected to rise to 235 $MtCO_{2eq}$ by 2030. Emissions in this scenario would continue to increase between 2030 and 2036 before gradually decreasing, ultimately returning to 146 $MtCO_{2eq}$ by 2050. Total cumulative emissions would amount to 6.7 $GtCO_{2eq}$ and represent 2.4% of the remaining allowed carbon budget[66] to stay below 1.5°C and 1.1% of the allowed carbon budget to stay below 1.7°C.[67] As the transition to cleaner energy sources accelerates, the carbon footprint of data centers is anticipated to decrease despite the growing demand for computational power.

According to Deloitte's analysis, committing to achieve net-zero emissions by 2050 could substantially reduce power sector emissions, resulting in cumulative emissions of only 3 $GtCO_{2eq}$ (a 56% reduction compared to the "Announced Pledges" scenario). Taking action to achieve climate-neutral power systems is now more crucial than ever, as it would significantly lower the environmental footprint of AI and data centers. Beyond considering grid carbon intensity, operators play a critical role by adopting best practices to lower power consumption. These measures could result in a cumulative CO_{2eq} reduction of 2% by 2030 and 9% by 2050.

Focusing on the regional assessment, notable variations exist due to differing speeds of decarbonization within the electricity sector. By 2030, the Asia Pacific region is projected to account for 59% of global emissions from data centers despite representing only 41% of the installed base. This discrepancy is mainly attributed to the higher carbon intensity of its electricity grid, estimated at nearly 320 gCO_{2eq}/kWh, more than double that of the United States and Canada region.[68] In contrast, Western Europe is expected to achieve the lowest grid emissions by 2030, at just over 100 gCO_{2eq}/kWh, thus contributing only to 4% of global GHG emissions from data centers. If Asia Pacific's average grid carbon intensity aligns with that of Western Europe, then its data center emissions would decrease by 70% compared to current projections. This underscores the significant impact that cleaner energy grids can have on reducing data center emissions, even with comparable energy consumption levels. However, it is also important to note that the Asia-Pacific region is diverse, with varying levels of commitment and advancements toward clean energy from policymakers. In this respect, joint initiatives between power producers and technology companies can better be captured with market-based emissions reporting, underlining the ongoing effort to supply data centers with clean energy sources globally, including in the Asia-Pacific region.[69]

Figure 6. Electricity consumption of data centers per region and associated CO_{2eq} emissions, "High adoption" scenario



Source: Deloitte Global analysis based on own calculations and IEA, Announced Pledges and Net Zero scenarios.[70]
Note: Future GHG emissions are subject to varying degrees of uncertainty, largely dependent on the speed and effectiveness of global decarbonization efforts.

As per Deloitte's analysis, focusing on market-based emissions reporting, it is estimated that the additional electricity demand from data centers between 2023 and 2024 represents 3% of the new renewable capacity built during this period.[71] Projecting further ahead, data centers will likely require an additional 150TWh from 2029 to 2030. If this increased demand be met entirely with renewable energy, it would account for 5.3% of the projected newly built renewable generation. The challenge is, therefore, to ensure sufficient additional renewable generation to meet the demand of new and electrifying sectors, while also phasing out unabated thermal power plants.[72] The effectiveness of market-based emissions reporting in meeting this challenge depends heavily on the additionality of the renewable energy sourced.

Box 1. Beyond power consumption: life-cycle emissions and water usage considerations

More than 75% of the life cycle emissions of data centers stem from the electricity used in the operations,[73,74] justifying the focus on energy efficiency. However, data center operators are encouraged to lower embedded emissions and disclose their broader environmental footprint. Among those, scrutiny on water consumption has increased as data centers consume significant amounts of water directly for cooling purposes, and indirectly through electricity generation. As data centers expand, managing water resources will remain a critical challenge, especially in areas where water supply is already under stress. Data centers' water usage is already leading to conflict with local communities,[75] a trend that could intensify if water management is not sufficiently monitored.

The standard metric for measuring the water usage intensity of a data center is the Water Usage Efficiency (WUE), calculated as the volume of water consumed per unit of IT energy usage, focusing solely on direct, on-site water consumption. For example, in Europe, yearly water consumption is projected to increase from the 2020 estimate of 145.2 to 546.7 million cubic meters by 2030.[76] There is increasing scrutiny on water usage in data centers, as demonstrated by Big Techs' commitment to being "water-positive" by 2030,[77] or by the release of frameworks to assess and manage water-relative risks.[78] Despite these efforts, transparency across the industry remains inconsistent, with standard metrics such as the WUE being still scarcely released by operators based on Deloitte's review.

3.2. The shifting paradigm in electricity demand forecasting

While the global impact remains generally moderate to date, data centers already account for a significant share of electricity consumption in some countries and jurisdictions. For example, in Ireland or Northern Virginia in the United States, data centers are responsible for 20% and 25%[79,80] of electricity use respectively. Therefore, an important factor to consider pertains to where the electricity demand growth will unfold. While electric vehicle (EV) charging stations are distributed relatively evenly across a geographic area to serve their purpose, hyperscale data centers are typically very concentrated and close to the region where data will be processed to help reduce latency and connection times.

One of the greatest challenges for these regions is to effectively anticipate and plan for long-term electricity demand growth. Ireland and Northern Virginia (as shown in Box 2) faced an important CAGR of the electricity demand in the last three years, between 4 and 8%. The first risk pertains to the average time required to deploy new power plants. Based on Deloitte's assessment, the average build time for new renewable projects does not exceed that of data centers. Nonetheless, building time reductions continue to be project developers' main focus. A similar decrease in renewable projects should be fostered to keep pace and co-develop data centers and clean energy sources.

However, power generation and security of supply are only part of the equation, as the electricity grid is emerging as one of the biggest looming bottlenecks.[81] There is already significant power capacity and many energy consumers are requesting to get connected to the grid, resulting in an interconnection queue that is more than twice the total installed capacity of the existing United States power plant fleet.[82] Similarly in Europe, some analysts predict that up to 205 GW of solar could encounter gridlock by 2030 because the grid planning process is lagging behind energy policy and market updates.[83] Based on that analysis, grid bottlenecks are likely to be one of the critical factors that prevent the joint development of data centers with renewable energy sources.

Box 2. Ireland and Northern Virginia's booming data center hubs

Ireland stands as Western Europe's premier destination for data centers. Since the 1960s, the Industrial Development Agency of Ireland has actively pursued a policy of attracting international investments through low corporate tax rates. This policy has successfully drawn in numerous large corporations, with most Big Tech choosing Ireland for their European headquarters. Beyond tax incentives, the country's cool climate, robust digital infrastructure, and strategic position as a gateway between Europe and North America further enhance its attractiveness to global technology companies.[84]

Similarly, Northern Virginia, and notably Loudoun County's Ashburn area, known as "Data Center Alley," is also a prime location due to its proximity to Washington, D.C., robust fiber optic network, and tax incentives for data centers that meet specific investment and employment creation thresholds.[85] These incentives have been a significant draw for data center providers, encouraging them to establish and expand their regional operations, now making Northern Virginia the largest data center market in the world.[86]

Local grid operators' forecasts in both geographies illustrate the difficulties in accurately estimating future load. Interestingly, after decades of overestimating future electricity demand, transmission operators have shifted to systematically undervaluing electricity growth over the past years, as illustrated in the following figure. These difficulties in estimating future electricity demand have profound implications regarding future infrastructure and power generation investments, as well as the carbon intensity of future electricity production.

Historical load forecast in Dominion, Northern Virginia (a) and Ireland (b)

Source: Deloitte Global analysis, based on PJM[87] and EirGrid[88]

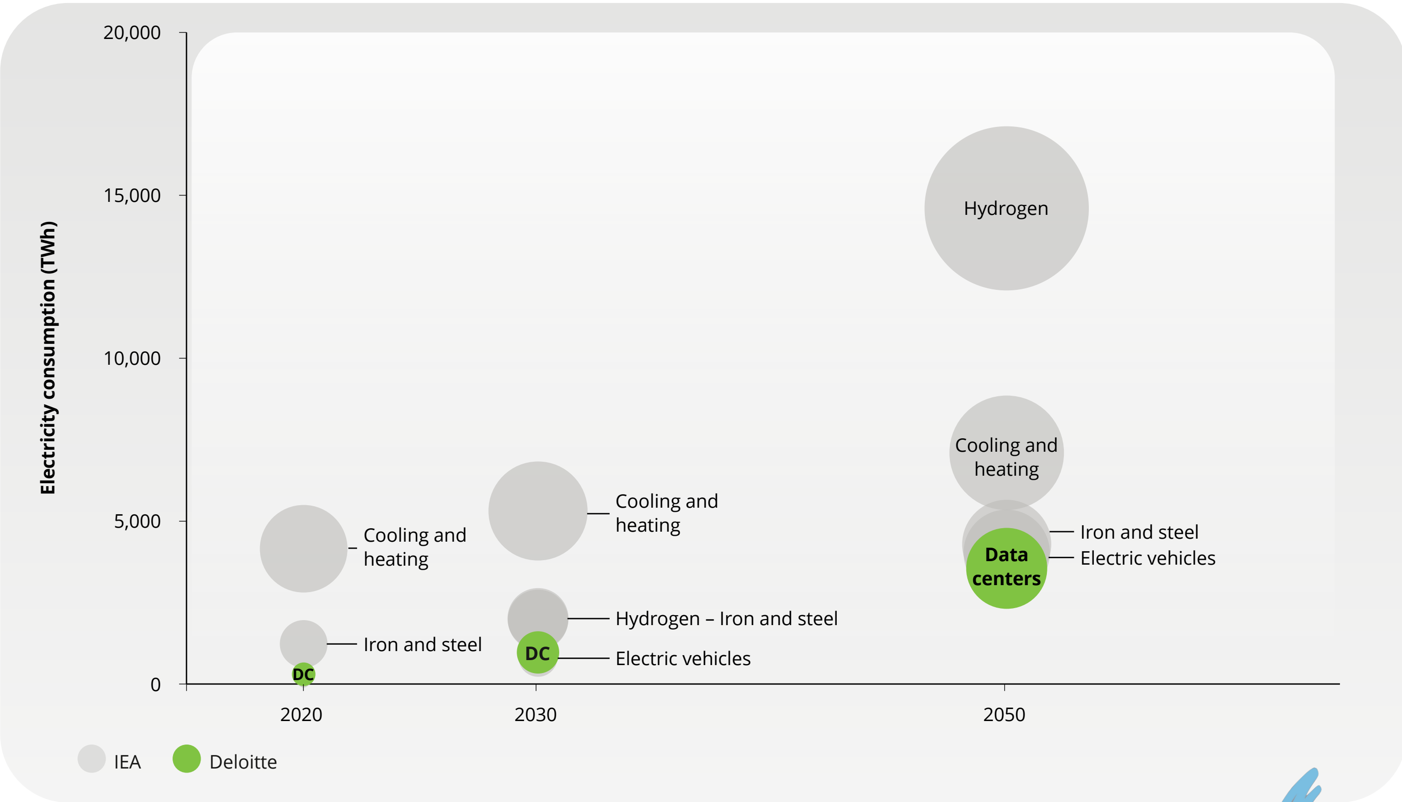
3.3. Digitalization's role in electricity demand growth

Finally, amidst the excitement around AI's deployment at scale and its potentially material economic impact, some observers are voicing more downbeat expectations. For instance, economists suggest that the GDP share of tasks impacted by AI will reach no more than 4.6% over the next ten years.[89] Similarly, Big Tech leaders underline that the additional demand from electric cars, heat pumps, and green steel manufacturing will become much more significant than data centers' demand by 2050.[90] While data centers are undoubtedly expected to contribute to future electricity consumption, they are likely to be just one of many factors, with others potentially playing a more significant role.

Based on the "Net Zero Emissions by 2050" scenario of the IEA's World Energy Outlook 2023 report, electric vehicles, green hydrogen, or an increase in electrified heat and cooling will each represent more critical growth drivers for electricity consumption globally,[91] as illustrated in Figure 7. From 2020 to 2050, the CAGR is expected to achieve 38% for green hydrogen and around 14% for electric vehicles, compared to a maximum of 9% for data centers. However, while other sectors are replacing fossil fuel usage with more sustainable energy sources, data centers are driving an increase in power consumption as a result of new usage.

More importantly, analysts remain ill-equipped to provide robust scenarios for estimating the energy consumption growth of data centers.[92] As a relatively new segment of the economy, predicting market size and performance gain over time is complex due to the lack of a transparent database. Additionally, the data centers' electricity consumption is heavily influenced by the extent of energy efficiency gains, which could lead to the Jevons paradox.[93] This concept indicates that while efficiency improvements are justified at the micro level, they can lead to higher energy consumption levels over time at the macro level. Despite significant energy efficiency strides—most notably with 'NVIDIA's recent Blackwell platform achieving a 25-fold reduction in costs and energy consumption[94]—the extent to which these advancements will curb energy consumption growth remains uncertain. The history of rebound effects suggests a need for caution.[95]

Figure 7. Prospective electricity consumption of selected applications



Source: Deloitte Global analysis based on own calculation ("High adoption" scenario) and the IEA ("Net Zero Emissions by 2050" scenario).[96,97,98]

4. Strategies for sustainable digital infrastructure

4.1. An industrial and policy roadmap toward "Green AI"

The United Nations Sustainable Development Goals (SDGs) set forth essential objectives to help foster a better and more sustainable future for all. Particularly, the goals "Affordable and Clean Energy" (Goal 7) and "Industry, Innovation, and Infrastructure" (Goal 9) are paving the way toward the development of "Green AI".[99] Stakeholders are taking meaningful actions aligned with these goals. By rethinking how data centers are built and managed, operators play an essential role in the global effort to curb data centers' energy consumption and environmental footprints. Thus far, "Green AI" has been primarily driven by industry leaders rather than policymakers, with many proactive efforts and self-imposed criteria on data center energy supply."

Nonetheless, several geographies have built on current leading practices to formulate policies that encourage the establishment of more sustainable data centers. Relevant policies differ depending on the severity of the challenges posed by data centers—ranging from low-impact scenarios requiring monitoring, to critical situations where data centers jeopardize grid stability, necessitating stringent interventions. Understanding the specific circumstances of each region allows policymakers to tailor strategies that help address local needs, thereby ensuring the growth of data centers while maintaining energy security and infrastructure integrity. Additionally, policymakers should aim to strike the right balance between legislating for sustainable operations and preventing a shift of operations toward locations with less stringent standards.

Landmark initiatives and regulations on data centers include the European Code of Conduct for Data Centers (EU DC CoC),[100] the Energy Efficiency Directive (EED),[101] and the Singapore Green Data Centre Roadmap and Standards.[102,103] In China, both local and national governments have passed comprehensive legislation aimed at reducing the environmental impact of data centers, notably the Three-Year Action Plan on New Data Centres[104] and the city of Beijing's Notice on Further Strengthening Energy Efficiency Review on Data Centers,[105] while the United States currently lacks comprehensive specific regulation on data centers at the federal level.

Four essential pillars have been identified to help achieve "Green AI". These pillars encompass each stage of a data center's lifecycle: data center facility design, clean electricity procurement strategies, ecosystem activation, and research and development activities. While most of the identified actions pertain to data operators (as shown in Figure 8), many initiatives can also be supported by policymakers, ensuring that the necessary instruments and markets are in place (as shown in Figure 9). Ensuring that standards and policies are co-developed, at least to some extent, would allow for a better strategic alignment across actors regarding climate imperatives.

4.2. Designing efficient infrastructure

Efficient data center design is critical to help foster "Green AI", whether by creating high-standard greenfield facilities or by modernizing existing brownfield sites. From the beginning, appropriately sizing data centers to meet actual market needs is challenging, but it offers substantial savings in total cost of ownership (TCO).[106] A right-sized facility not only results in reduced electricity costs, which account for 10% and 20% of TCO,[107] but can also alleviate the need for substantial investments driven by regulatory changes regarding data center standards.

From a regulatory perspective, encouraging transparent monitoring and harmonizing reporting standards is an important first step. Many jurisdictions are already mandating specific targets for data centers. Germany is among one of the most ambitious, requiring data centers that start operations after 2026 to achieve a PUE of less than or equal to 1.2.[108] In the United States, only federal data centers are targeted at present, with new facilities required to maintain a PUE no greater than 1.4.[109] China has also adopted stringent PUE standards for new data centers: newly built or renovated data centers must have a PUE of less than 1.5, a limit that drops to 1.3 for large-scale developments.[110]

However, while PUE is an important metric to monitor, solely relying on it could create unintended incentives and is insufficient to ensure "Green AI". For instance, moving away from mechanical cooling to favor water cooling decreases the PUE, but is likely to worsen the WUE metric, potentially exacerbating water stress. Moreover, PUE fails to capture many relevant aspects of energy efficiency. Specifically, it does not incentivize improvements in the energy efficiency of the computing performance of installed servers, as it only measures the ratio between IT equipment energy consumption and total electricity consumption. Consequently, some industrial leaders are moving toward more holistic frameworks to provide a thorough assessment of a data center's sustainability.

From an operator perspective, global standardization would allow operators to anticipate local regulatory changes. With the European Efficiency Directive's regulation targeting data centers[111] nearing implementation, operators outside the region should monitor its progression, as it may influence regulatory practices globally. Even smaller operators, who could potentially view the reporting requirements as burdensome, will likely also face increasing pressure to modernize their infrastructure or transition to more efficient colocation or cloud services. Standards such as the Energy Star[112] can be extended with additional certificates (e.g., LEED certification[113]) to adopt a broader set of metrics, such as water or carbon efficiency.

Nonetheless, standards should be tailored to the data center's geographical location, as cooling options widely differ depending on the geography.[114] In this respect, policymakers must acknowledge the limitations and trade-offs of designed metrics when establishing a comprehensive "Green AI" framework for the future.

4.3. Fostering clean energy supply

Transitioning to clean energy sources is essential for data center operators committed to sustainable operations with wind and solar power being favored due to their cost-efficiency, wide availability, and low carbon footprint. However, regional specificities and the necessity to ensure 24/7 clean energy for data center operations are prompting various stakeholders to consider alternative energy sources, like nuclear power in the United States[115] or geothermal energy, for example, in Kenya.[116]

Four essential pillars have been identified to help achieve "Green AI": data center facility design, clean electricity procurement strategies, ecosystem activation, and research and development activities.

Some jurisdictions have also started mandating data centers to be powered, partly or wholly, by renewable energy sources, most using a market-based approach. Germany, for example, currently mandates that at least 50% of a data center's electricity use must come from renewable sources, a number which will rise to 100% by 2027.[117] China will also require the share of renewable electricity used by data centers to increase by 10% per year starting in 2025.[118]

Going further, ensuring a high spatial and temporal correlation between energy consumption and energy purchase is emerging as a strong requirement. Energy Attribute Certificates (EACs)[119] have long served as market mechanisms for securing clean energy purchases. However, these often lack the spatial and temporal granularity required for making strong claims on the carbon content of the electricity effectively consumed. Consequently, power purchase agreements (PPAs) and 24/7 carbon-free energy (CFE) solutions have gained traction for their ability to enhance the traceability of electricity purchases while providing a natural hedge against electricity price spikes.

Data centers could also play a significant role in enhancing the flexibility of power systems by preventing the curtailment of renewable energy production, thanks to their modular and distributed features (Box 3). First, by favoring investment in fiber optic infrastructure over costly and time-consuming electricity grid reinforcements, operators can lay the groundwork for shifting computing jobs to where low-carbon electricity is produced. This approach would enable countries with under-developed electricity grids to create a sustainable data center sector.[120]

Moreover, the inherent characteristics of AI training present an additional flexibility opportunity. Unlike traditional data center operations or AI inference, AI training does not require immediate results and is therefore not as sensitive to latency. This allows AI training to be conducted in locations where resources such as renewable electricity and water are abundant and unconstrained. This flexibility not only enables more sustainable practices by optimizing the use of renewable resources but also minimizes the environmental impact of AI training activities.

To help foster the adoption of clean energy sources, policymakers should focus on addressing grid connection bottlenecks and reducing permitting times for renewable projects to facilitate their co-development with data centers. Policymakers can also take action by establishing standards and mandating a minimum share of renewable energy usage. However, achieving the highest standards will be more challenging to achieve for countries with little low-carbon electricity production. Once again, standards should be set regionally to encourage operators to pressure their power suppliers to provide clean electricity rather than incentivizing them to develop new data centers only in locations already well-engaged in the energy transition.

Box 3. The unique flexibility of cloud computing

Load shifting in cloud computing has emerged as an influential feature of distributed data centers, enabling operators to optimize the timing and location of computing tasks.[121] By reallocating computing jobs based on electricity prices or the availability of renewable energy, data center operators can reduce their carbon footprint while curbing operational costs. Industry leaders, like Google, are at the forefront of this approach, often referred to as "carbon-aware computing",[122] and are working toward minimizing scope 2 emissions. This capability markedly supports 24/7 carbon-free energy (CFE) matching, fostering nearly continuous use of renewable energy and reducing dependence on fossil fuels.

Using DARE, Deloitte's energy system model, this analysis examined the impact of adopting spatiotemporal flexibility in Western Europe. In the "High Adoption" scenario, which anticipates an 80 TWh demand from data centers in 2030 and 200 TWh in 2050, a 20% space-shifting capability could facilitate an additional 4 TWh in renewable energy production across Europe in 2030 and up to 13 TWh in 2050. Considering that data centers' flexible power demand would constitute only 0.5% of the Western European electricity demand in 2030 and around 1.5% in 2050, the results appear to be significant. This flexibility offers a notable reduction in fossil-based power production and could decrease the average carbon intensity of the European grid by 1.5% over the entire period.

For operators, spatiotemporal flexibility presents a considerable opportunity, with projections indicating an average captured market price reduction of 7% by 2030 and 8% by 2050. Specific contracts, such as 24/7 CFE pricing, could see an even higher reduction.[123] This underlines the benefits of implementing dynamic electricity retail pricing, which should provide the necessary price signals and fortify the business case for power operators to adopt this innovative approach.

4.4. Adopting an ecosystem approach

Achieving "Green AI" involves strategically planning the location of data centers by considering key factors such as the local power grid or water stress level, as well as achievable cooling efficiency improvements beyond current regulation, tax incentives and renewable energy availability. Enabling actors to anticipate and refine their assessment before coming to a moratorium would help improve visibility and limit specific area mandates for large data center development, like in Singapore and Amsterdam. Public policies should therefore focus on improving the quality of information available for actors to enhance their assessment. Publishing grid hosting capacity maps[124] to show potential tension areas on the grid notably allows for better feasibility assessments. Likewise, moving toward nodal pricing or regional cost components for electricity could provide price signals for operators to locate in preferred areas.

Strategic site location also includes evaluating local actors' capacity to support data center operations in an ecosystem approach. Collaboration within regional hubs is essential to further enhance data center sustainability. This implies working closely with local utilities and renewable energy providers to help maximize the use of clean energy or waste heat within a locality.

Finally, encouraging the use of green and sustainability-related bonds as financial instruments for data centers could effectively help advance sustainability objectives. These bonds provide the necessary capital to invest in innovative and sustainable technologies and infrastructure. They also ensure that private actors support the adoption of leading approaches by tying interest rates to the achievement of specific sustainability metrics.[125]

4.5 Promoting research and operational improvements

Looking ahead, policymakers and industries should continue to invest in research and innovation as major levers for further efficiency and sustainability improvements. This could involve collaborating with academic institutions and industry consortia to explore ways to optimize energy consumption, enhance cooling techniques, and decrease carbon emissions. One promising development is immersed liquid cooling, where data center racks are immersed in a dielectric fluid. This method is anticipated to significantly reduce overall energy consumption by eliminating the need for computer fans, while reducing water consumption compared to current cooling methods[126]. Similarly, Google has demonstrated its commitment to innovative approaches, with pilot projects using wastewater or seawater for cooling.[127]

Data center operators can also achieve significant operational improvements by leveraging "AI for Green" strategies, such as implementing AI to optimize cooling systems,[128] and using techniques like virtualization to optimize server utilization. This keeps server vacancy rates low, reducing the need to build new data centers. Promoting efficient software implementation can also further reduce energy consumption during the training and inference phase of AI models, with specifications such as the emerging Software Carbon Intensity.[129] This involves advocating for leading practices in AI software, monitoring energy consumption, and finding a balanced trade-off between AI performance and energy use. Various initiatives exist aimed at raising awareness and transparency regarding software carbon intensity.[130]

In this realm, adopting smart Energy Management Systems allows real-time energy use monitoring and optimization, leading to more informed decisions and reduced energy consumption. Additionally, engaging in industrial load-shifting programs can provide data centers with financial incentives to reduce energy consumption, notably during peak periods, contributing to overall grid stability and reducing the need for additional power generation. Policymakers can also support the alignment of data center operations with electricity markets by enforcing dynamic electricity prices, increasing the value of renewable energy sources, and helping reduce the operator's scope 2 emissions.

Figure 8. Industrial framework for "Green AI"

	Tools and instruments	Description	Current stage of implementation	Impact: Energy use	Impact: Water use	Impact: Local grid stability	Impact: Carbon intensity
Design efficient infrastructure	Monitor data centers	PUE, WUE, etc.	High	Medium	Medium	Low	
Design efficient infrastructure	Engage in certification	LEED, EU CoC, EnergyStar, etc.	Medium	High	Medium	Low	
Design efficient infrastructure	Tailor cooling solutions	Cold aisle confinement, liquid or free-air cooling, etc.	Medium	Medium	High	Low	
Engage in clean energy supply	Contract clean power	EACs, PPAs	High				Medium
Engage in clean energy supply	Engage in flexibility	Dynamic job shifting	Medium			Medium	Medium
Engage in clean energy supply	Ensure high spatial and temporal correlation	24/7 clean energy purchase	Low				High
Adopt an ecosystem approach	Develop regional energy hub	RES co-development, private wiring, waste heat recovery	Medium	High		Medium	High
Adopt an ecosystem approach	Issue green bonds	Sustainable projects funding	Medium	Medium	Low		Medium
Adopt an ecosystem approach	Strategically assess site location	Weather and climate risks, generation, grid, water tension	Low		High	High	High
Promote efficient operations	Optimize server utilization	Idle time reduction, virtualization	High	High		Medium	
Promote efficient operations	Adopt smart energy management system	Energy consumption reduction and monitoring	High	Medium		Low	Low
Promote efficient operations	Promote efficient software design	Software carbon intensity specification	Medium	Medium			Low
Promote efficient operations	Invest on research and development	Chips performance and energy-efficiency improvements		High	High	Medium	High

High Medium **Low**

Source: Deloitte Global analysis.

Figure 9. Policy blueprint to achieve sustainable digital infrastructure

	STAGE 1 Monitor	STAGE 2 Incentivize	STAGE 3 Regulate upfront	STAGE 4 Intervene
Set efficiency standards and foster transparency	Mandate transparent reporting of data center energy performance	Define efficiency standards Set efficiency requirements for public procurement	Set efficiency requirements for new data centers	Set efficiency requirements for existing data centers
Promote clean energy supply	Ensure clean energy options are available to project developers	Enforce high spatiotemporal granularity of clean energy certificates	Set clean energy requirements for new data centers Set geographical and temporal correlation requirements Allow private wire	Mandate on-site RES Consider stricter correlation or additionality requirements for data centers
Plan suitable location	Publish grid hosting capacity map	Incentivize brownfield data centers development Implement nodal electricity and water pricing	Mandate areas for data centers Moratoriums for congested areas	Impose general moratoriums, e.g., per types of data centers
Incentivize efficient operations	Mandate transparent reporting of data center IT performance	Implement dynamic electricity and water pricing Frame spatial load-shifting and green software design	Enforce dynamic pricing and industrial load curtailment programs Mandate energy management systems	Strengthen requirements for existing data centers

Foster research and development

Source: Deloitte Global analysis.

5. Conclusion

The rapid advancement and scaling of AI presents opportunities to help foster climate change mitigation, but also introduces challenges for the power sector. This study addresses critical questions surrounding the evolution of AI and data centers, aiming to provide a comprehensive overview and actionable insights for stakeholders.

Firstly, **monitoring and adapting to current dynamics is imperative to help ensure energy-efficient operations as AI and data centers become more prevalent**. The study outlines the need for robust policies, standardized metrics, and practices to help guide the sustainable growth of AI technologies.

Secondly, the trajectory of electricity consumption from data centers could become a concern depending on the extent to which AI applications make inroads to our social life and economic activity. However, **the focus should be on (1) our capability to ensure that additional electricity demand will be supplied with clean power; and (2) the fact that existing thermal assets are either phased out or retrofitted to align with the global climate neutrality objective**. As electricity demand from data centers is poised to experience significant growth and become one of the drivers of power consumption by 2050, strategic planning and implementation of energy-saving measures to mitigate the associated carbon footprint will become increasingly important.

Thirdly, AI has a substantial potential to contribute to integrating renewable energy sources and decarbonizing other economic sectors. **Through innovative approaches such as flexible load shifting, regional energy hubs and waste heat recovery, data centers can enhance the efficiency of power systems, thereby supporting broader sustainability goals.** Additionally, the significant second-order impacts of AI in fostering more efficient operations should be a key consideration in its development and application. Given this potential, it is essential to balance AI's direct environmental footprint against its benefits to help ensure a net positive impact on energy and GHG emissions, thus making "AI for Green" a tangible reality.

Lastly, **businesses and governments play a pivotal role in helping reduce the climate impact of AI's energy consumption**. By supporting leading practices, increasing the alignment between market price and operations, investing in next-generation technologies, and supporting regulatory frameworks that promote sustainability, stakeholders can drive the way AI is used toward a more climate-neutral future. This study serves as a roadmap for policymakers and industry players, offering strategic insights and recommendations to help ensure that the growth of AI aligns with global sustainability objectives. Through concerted efforts and ongoing collaboration, the transformative potential of AI can be harnessed while safeguarding the future of our environment.

Authors

Prof. Dr. Bernhard Lorentz
Deloitte Center for Sustainable Progress Founding Chair
Deloitte Germany
+49 1511 4881437
blorentz@deloitte.de

Dr. Johannes Trüby
Deloitte Economics Institute
Deloitte France
+33 1 55 61 62 11
jtruby@deloitte.fr

Geoff Tuff
Sustainability leader for Energy, Resources & Industrials
Deloitte Consulting LLP
+1 617-460-0647
gtuff@deloitte.com

The following specialists crafted and created the insights in this report:

Dr. Quentin Perrier
Deloitte Economics Institute
Senior Manager | Deloitte France

Clémence Lévêque
Deloitte Economics Institute
Consultant | Deloitte France

Bertille Le Dizes
Deloitte Economics Institute
Consultant | Deloitte France

Contacts

Jennifer Steinmann
Deloitte Global Sustainability Business leader
jsteinmann@deloitte.com

Prof. Dr. Bernhard Lorentz
Deloitte Center for Sustainable Progress Founding Chair
blorentz@deloitte.de

Geoff Tuff
Sustainability leader for Energy, Resources & Industrials
gtuff@deloitte.com

Dr. Johannes Trüby
Deloitte Economics Institute
jtruby@deloitte.fr

Jim Rowan
US Head of Artificial Intelligence (AI)
jimrowan@deloitte.com

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Ashley Pampena, Deloitte Global
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Phillipa Smith, Deloitte Global
Dr. Pradeep Philip, Deloitte Global
Rachael Ballard, Deloitte Global
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Richard J Bailey, Deloitte Global
Tracey McQueary, Deloitte Global
Vijay Sharma, Deloitte Global

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