# 2021-2022 Global Computing Index Assessment Report

# Contents

# Core Views

- The COVID-19 pandemic has accelerated global digitalization, traditional industries are adopting digital technology at an increasingly faster rate. Based on the overall trend and forecast from 2016 to 2025, the digital economy accounts for a rising proportion of for each country. It is expected that this proportion will reach 41.4% by 2025.

- The regression analysis of the country' s Computing Index and economic indicators in this report show that there is a significantly positive correlation between the Computing Index and the GDP/digital economy. On average, for every 1-point increase in the Computing Index of the 15 key countries, the national digital economy and GDP will increase by 3.5‰ and 1.8‰, respectively, and that trend is expected to continue through 2025.

- Countries with a Computing Index score above 60 are classified as leading countries, evaluation results show that the US and China rank first and second, taking leading positions globally. Between 40 and 60 are rising countries which include Japan, Germany, the UK, France, Canada, South Korea, and Australia. Below 40 are startup countries which include India, Italy, Brazil, Russia, South Africa, and Malaysia.

- The competition among countries in terms of computing power has become increasingly fierce. All the countries, except South Africa, have achieved improvement in their computing power scores. The division of ranks for each country remains unchanged compared to the previous year. This partly reflects that the competitive landscape around computing power has taken shape among countries. The leading position of the United States and China in the global computing field is only strengthening.

- The position of leading countries in the Computing Index has been extended due to the growth in computing power supply, market space for application, and infrastructure support. The advantage of rising countries  in computing power lies in efficient computing resources, extensive application of emerging technologies, and sound infrastructure support. Startup countries are dominated by developing countries and they enjoy a broad market space and remarkable late-mover advantages in computing power. Complemented by an ever-improving infrastructure, they are narrowing the gap with rising countries.

- AI computing reflects a country's cutting-edge computing capacity. An analysis of the 15 countries shows that spending on AI computing increased to 12% of total computing, up from 9% in 2016, and is estimated to reach 25% by 2025.

- This year's study found improvements in the development of edge computing among the 15 countries. In addition to the prominent performances of the US and China, countries like Germany and the UK have stepped up their efforts in edge computing at a much faster pace than developing countries. IDC estimates that investment in edge computing power will grow much faster than core computing power over the next five years, and worldwide spending on edge computing servers will account for 24.9% of total servers by 2025.

- The Internet industry is still ahead of traditional industries. The top 5 industries also include finance, manufacturing, telecom, and public affair. Finance has overtaken manufacturing for second place. The financial industry has outperformed the manufacturing industry in terms of total investment and growth rate in computing capacity and applications represented by AI and big data, resulting in its rise to second place. In the post-COVID-19 era, most financial institutions are faced with the challenges of lower yields and increased bad debt rates. Therefore, such institutions are moving faster to build intelligent platforms, improve risk control capabilities, and further innovate service models.

- The social value of computing power is increasingly prominent. Computing power can facilitate vaccine and drug development, dramatically improving drug discovery, lowering average R&D costs, and reducing the risk of clinical failure, AI-assisted drug discovery has become the focus of the global market in recent years. Green computing power ensures sustainable development of society, driven by the demand to address climate change with net-zero emissions, a green and centralized transformation of computing power is continuing to accelerate. Computing power can also help companies cope with the pressure to reduce emissions and gain a commercial head start in digital transformation.

# Introduction

## The COVID-19 pandemic has accelerated global digitalization; traditional industries are adopting digital technology at an increasingly faster rate.

COVID-19 has forced the global economy to deal with added uncertainty and dramatic upheaval. This caused many countries to experience a decline in economic growth. In response to the economic impact of the pandemic, and in order to boost economic recovery, governments around the world adjusted their policies to promote the convergence of traditional industries with digital technology, advance the digital transformation of industries, and develop the "digital economy".

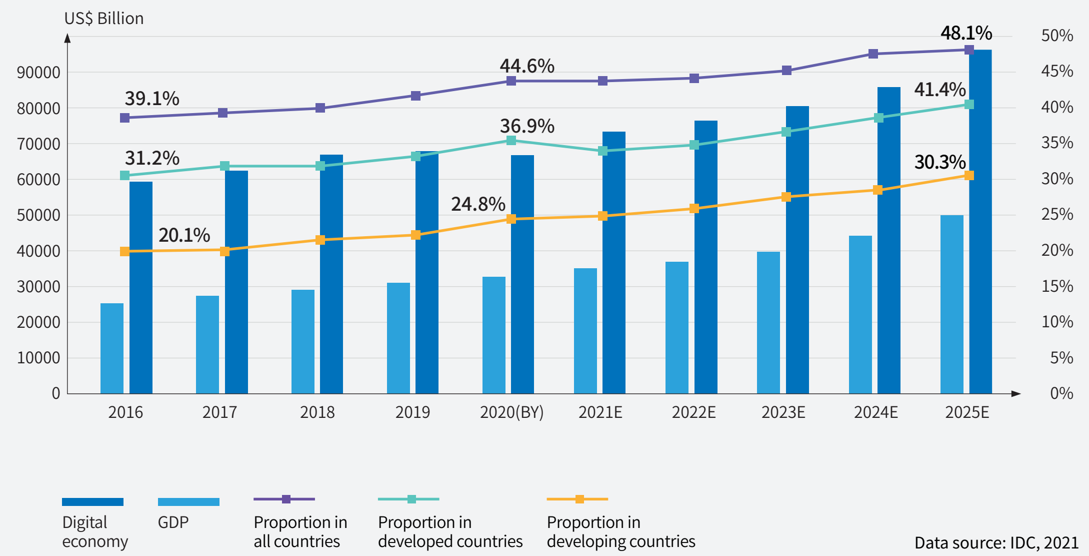
During the pandemic, digital technology provided an important safeguard for much of the offline economy, preserving people's livelihoods. Additionally, emerging technologies such as artificial intelligence (AI), 5G, the Internet of Things (IoT), and cloud computing quickly converged with traditional industries to boost productivity, cushioning the impact of any economic downturns. Under the impetus of the digital economy supported by immense computing power, new industries have been developing rapidly. New convergent industries and entirely new business concepts and models such as the Industrial Internet, intelligent manufacturing, and the Internet of Vehicles are emerging and making a quantifiable impact. This has resulted in computing power emerging as a key factor for reviving the economy.

# The digital economy continues to grow steadily, with developing countries growing faster.

As digitalization accelerates, the digital economy is set to become a major driver for global economic recovery and will be a source of continued economic growth in the future. Based on the overall trend and forecast from 2016 to 2025, the digital economy accounts for a rising proportion of GDP (hereafter refers to proportion) for each country. It is expected that this proportion will reach 41.4% by 2025. Buffeted by COVID-19, the overall global economy declined, but the digital economy actually grew. According to the latest data, the digital economy now accounts for 44.6% of GDP in developed countries, significantly higher than the 24.8% in developing countries, but the proportion in developing countries grows at a rate of 4.7%, slightly higher than the 2.4% in developed countries. Some newly added countries in this assessment report (Canada, Italy, Malaysia and India) have a lower digital economy to GDP ratio, making the overall a lower proportion compared to the previous year. However, that proportion continunes to grow.

In the future, the digital economy will be the mainstay of economic development and recovery. Digital transformation has become the focus of global attention during the pandemic, with both developed and developing countries continuing to stress the importance of the digital economy.

**Trends of the proportion of digital economy in sample countries from 2016 to 2025**




Data source: IDC, 2021

## The explosion of industry applications provides a driving force for the digital economy.

With the technological advancement and quickly evolving product innovation typified by AI, digital technology has accelerated its deep convergence with vertical industries, and its applications have been undergoing constant improvement and innovation.

AI has accelerated its convergence with other digital technologies, which helps optimize operating procedures and improve productivity. Edge computing enhances the effectiveness of solutions, providing programs with faster response times and stronger autonomous operational capabilities. Robotics also plays an extensive supporting role in production, including working in dangerous environments and COVID-19 control. In the digital economy, data is a key factor for production, the Internet is a basic carrier, and computing power is an important tool to improve productivity.

The world is accelerating the deployment of the digital economy in key areas. The United States (US) is focusing on cutting-edge technologies and high-end manufacturing with the theme of "AI". China is striving to accelerate the pace of digital technology industrialization in an effort to spur the development of digital technology along with the digital transformation of traditional industries. Additionally, China is working to promote the deep convergence of digital technology and the real economy to form an internationally competitive digital industrial cluster. The United Kingdom (UK) aims to build itself into a global AI and data-driven innovation powerhouse. South Korea is focusing on smart factories. Japan is targeting the industrial Internet. This technology-driven focus across so many countries indicates an increasing emphasis on digital technology as a econonomic cornerstone, making the digital economy a priority for policymakers.

When it comes to the practical application of digital technology, the decisive factor is computing power. Huge computing resources are behind the practical application of every new technology. As the digital economy continues to grow, so too will the computing power required to run it.

# Global Computing Index Assessment Results

# Updates on the Global Computing Index Assessment Methodology

The Global Computing Index is an index that evaluates how computing power, GDP, and the digital economy promote each other and grow together.

> This report explores the connections between computing power and economic indicators by setting up a Global Computing Index framework and evaluating the correlation between computing power, GDP, and the digital economy. It aims to emphasize the importance of computing power in economic development where "computing power is productivity."

The Global Computing Index research covers 15 countries on six continents. Developed countries include: the United States, Canada, Japan, South Korea, Australia, the United Kingdom, France, Germany, and Italy. Developing countries include: China, India, Malaysia, Brazil, Russia, and South Africa. Canada, Italy, Malaysia, South Korea, and India are new additions to this year's evaluation. In the indicator system, the level-2 indicator of edge computing is added to the computing power category, which reveals the computing power form and development level in various countries more comprehensively. The new technology (such as SSD/SCM) utilization level-2 indicator is added to the computing efficiency category. Combining this with the utilization of computing, memory, storage and other resources can enable higher efficiency in evaluating the utilization of computing power. Furthermore, the data center software and service level-2 indicators are added to the infrastructure support category, increasing the diversity of the computing power support elements.

### Computing Capacity

**General computing capacity:** Proportion of server expenditure to GDP and server shipments
**Scientific computing capacity:** Number of global top 500 supercomputers and their rankings
**AI computing capacity:** Proportion of AI computing hardware (server) expenditure to GDP and shipments
**Terminal computing capacity:** Proportion of smartphone and PC expenditure to GDP and shipments
**Edge computing capacity:** Proportion of edge computing expenditure to GDP

### Application Level

**Big data:** Proportion of overall expenditure to GDP on software, hardware and services
**AI:** Proportion of overall expenditure to GDP on software, hardware, and services
**IoT:** Proportion of overall expenditure to GDP on software, hardware and services
**Blockchain:** Proportion of overall expenditure to GDP on software, hardware and services
**Robot:** Proportion of overall expenditure to GDP on software, hardware and services

### Computing Efficiency

**Cloud computing penetration:** Proportion of servers with cloud management software installed (survey data) and cloud computing-related expenditure of total server expenditure
**CPU utilization:** Average utilization of server CPU (survey data)
**Memory utilization:** Average utilization of server Memory (survey data)
**Storage utilization:** Average utilization of server storage devices (survey data)
**New technology utilization:** Average utilization of technologies such as SSD/SCM (survey data)

### Infrastructure Support

**Data center software and services:** Proportion of data center software and service support
**Data center scale:** Number of data centers (statistical data)
**Data center efficiency:** Average data center PUE (research data)
**Network infrastructure:** Annual shipments of enterprise network devices and annual proportion of operator network expenditure
**Storage infrastructure:** Annual storage shipment capacity (TB) and annual proportion of storage expenditure

# Analysis of Global Computing Index Assessment Results

Based on the scores of the Computing Index for each country, cluster analysis of each indicator, and the impact of the Computing Index on the digital economy and GDP when the Index's value is increased, this report divides these countries into three ranks: leading countries, rising countries and startup countries.

By observing the distribution of the Computing Index in various countries and the economic growth resulting from an increase in the Computing Index, this report finds that the boundaries of the Computing Index for the countries of the three rank types are at 60 and 40 points respectively. Countries with a Computing Index score above 60 are classified as leading countries; between 40 and 60 are rising countries; below 40 are startup countries.

Evaluation results show that the US and China rank first and second, taking leading positions globally. Rising countries include: Japan, Germany, the UK, France, Canada, South Korea, and Australia. Startup countries include: India, Italy, Brazil, Russia, South Africa, and Malaysia.

The competition among countries in terms of computing power has become increasingly fierce. All the countries, except South Africa, have achieved improvement in their computing power scores. The division of ranks for each country remains unchanged compared to the previous year. This partly reflects that the competitive landscape around computing power has taken shape among countries. However, compared to the previous year's data, the gap between rising and startup countries is narrowing. In contrast, the gap between leading and both rising and startup countries is widening. This reflects that the leading position of the United States and China in the global computing field is only strengthening.

**Leading countries: Their leading position in the Computing Index has been extended due to the growth in computing power supply, market space for application, and infrastructure support.**

The level of computing power in the US increased by 5% year-on-year to 77 points. With the negative impact of COVID-19 on the overall macro economy and the prominent market size as well as development level, the US still achieved significantly better scores on some level-2 indicators. More specifically, the country's edge computing servers increased by 13.6%, and cloud computing development increased by 4.3%. In addition, the country's application of emerging technologies such as AI, big data, Internet of Things and blockchain has matured, and its growth in these indicators is ahead of the global average. What's more, the hyperscale data centers in the US have gained further advantage due to their immense size and maintained their top position worldwide. Driven by world-leading hyperscale cloud service providers, the overall energy efficiency of the country's data centers has improved, but there is still room for improvement in the energy efficiency of enterprise-level data centers compared to hyperscalers.

**Rising countries: Their advantage in computing power lies not in computing capacity, but in efficient computing resources, extensive application of emerging technologies, and sound infrastructure support.** There are 7 rising countries, all of which are developed countries. Japan, Germany and the UK are ranked 3-5 in the Computing Index, with South Korea, Canada and Japan showing the fastest growth. The total number of data centers in rising countries accounts for about 33% of the total among the complete set of 15 countries, and the PUE indicators of these countries are generally leading the world. In particular, European countries prioritize the transition toward a circular economy. It is estimated that by 2023, Europe will invest more than 60 billion USD in enabling digital technology to support sustainable development. At the same time, European countries are experiencing steady growth in computing power as European companies focus increasingly on digital-first development strategies. A summary of the evaluated performance of several rising countries is available:

Germany enjoys a strong industrial foundation. The country put forward the concept of "Industry 4.0" in 2013, allowing it to seize the opportunity opened up by the new wave of industrial revolution and play a leading role in the digital transformation of global industry. The country's long-term digital investment has made it more resilient during the pandemic, and is key to the rapid recovery of its economy. The evaluation results indicate that, driven by the demand of digital transformation of the industry, Germany's edge computing expenditure increased by 29.3%. Its expenditure in the Internet of Things and blockchain also increased rapidly, driving a 16.1% increase in Germany's application level of computing power.

Japan is also a global manufacturing powerhouse despite the lack of large domestic IT, internet, and other tech companies. The country is highly ranked in high-end manufacturing fields such as basic electronics, integrated circuits, materials, automobiles, and equipment. In recent years, the Japanese manufacturing industry has leveraged digital technology to consolidate its global edge in high-end manufacturing, making it more difficult for other corporate competition to keep up. After the outbreak of COVID-19, the Japanese government introduced and implemented a large-scale economic stimulus plan. Digital transformation based on computing power has become an important basis for Japan to promote industrial upgrades and stimulate economic recovery in the post-pandemic era. As shown in the assessment results, the overall level of Japan's computing power has increased by 12.7%. Japanese manufacturers in medical devices, semiconductors and other industry sectors have used AI and other digital technologies to fully empower business innovation. Significant progress has been made in AI computing power.

The overall development level of computing power in France has improved by 4.6%, mainly contributed by the application level, with AI application expenditure achieving a significant increase of 32.7%.

**Startup countries: These countries are dominated by developing countries and they enjoy a broad market space and remarkable late-mover advantages in computing power. Complemented by an ever-improving infrastructure, they are narrowing the gap with rising countries.** The results of the computing power evaluation demonstrate that startup countries have achieved outstanding performance in different indicators relying on their respective resource endowments:

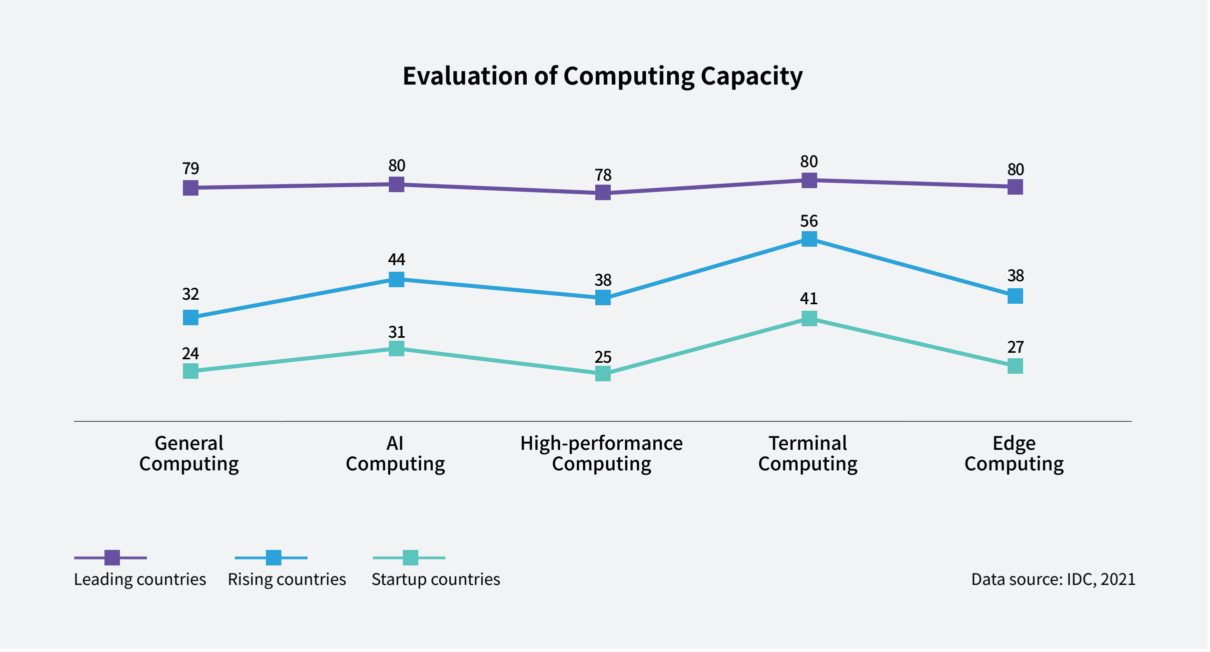
Italy is the only developed country ranked as a startup. Although its GDP ranks high, the digital economy accounts for a lower proportion of Italy's economy compared to other Western European countries. Hence, there is still much room for improvement in terms of investment in computing technology and new technologies such as AI, and infrastructure support such as storage and networks.

India's Computing Index has a score of 38. In terms of computing power, India has achieved a large increase in AI computing and edge computing. For mobile and desktop computing markets that constitute a global structural growth point, the country leads the world in its end user base, expenditure, and growth rate. In addition, India's expenditure on storage and network infrastructure has been growing rapidly, with spending growing faster than any other country in the world. Although the outbreak of COVID-19 has affected the growth momentum of India's computing power, the gap between India's computing power level and that of the rising countries is only 2 points. It' s overall computing power level still has great growth potential over the next few years, and is expected to transition to a rising country very soon.

# Analysis of Each Component of the Global Computing Index Level-2 Indicators

## Computing capacity

As a core component of the Global Computing Index, computing capacity indicates overall levels of computing power investment in various countries along with each country's focus by looking at the number and investment proportion of servers, mobile devices and PCs.

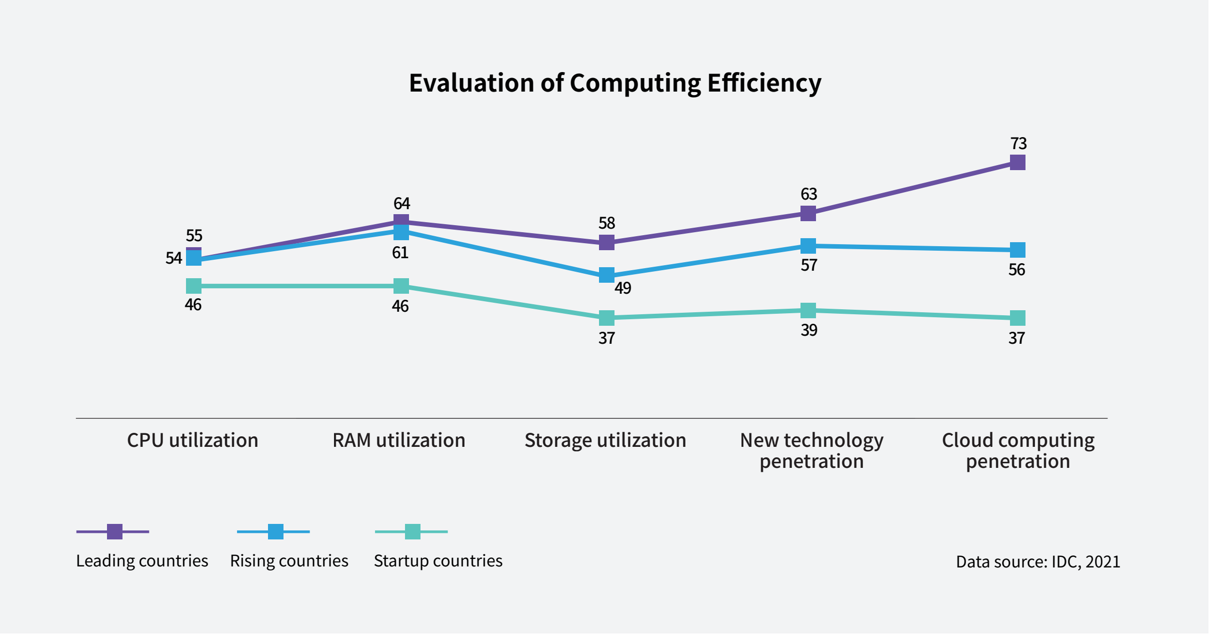



Due to factors such as the COVID-19 outbreak and structural imbalances in economic development, countries registered a decline in overall spending on servers, but most maintained rapid growth in edge computing. **By innovating and expanding the functions and scope of core data centers, edge computing has been an important driving force behind global growth in enterprise infrastructure.** This year's study found improvements in the development of edge computing among the 15 countries. In addition to the prominent performances of the US and China, countries like Germany and the UK have stepped up their efforts in edge computing at a much faster pace than developing countries. Edge computing provides an important platform for emerging technologies such as 5G, the Internet of Things, robotics, and AI. The International Data Corporation (IDC) estimates that investment in edge computing power will grow much faster than core computing power over the next five years, and worldwide spending on edge computing servers will account for 24.9% of total servers by 2025.

**European countries boost their regional competitiveness in edge computing mainly by rebuilding the industrial value chain, exploring use cases with strong demand, and providing strategic guidance at the macro level.** Regarding edge computing as a key driver for digital transformation in Europe, European countries and organizations have picked up the pace in deploying edge computing infrastructure in recent years. Nearly 30% of European organizations plan to start using edge computing technologies in the next two years. In industries that are at the forefront of edge computing, such as transportation/logistics, manufacturing, and energy, some organizations have moved beyond the pilot phase to deploy edge computing solutions on a broader scale. Edge computing is essentially a distributed computing paradigm oriented to specific use-case scenarios. Therefore, the synergy between industries and systems is an important factor affecting the deployment of edge computing. European telecom operators, solution providers, and organizations in verticals are strengthening industrial collaboration and business capability integration to empower various industries through ever-improving ecosystems. In Germany, seamless switching across operator networks has been realized for autonomous driving, ensuring the continuity of key mobile services such as collision warning systems. In many verticals, European organizations actively explore application scenarios with strong demand for edge computing, such as real-time analysis of user shopping behavior in retail, management of complex tasks, automation of back-end processes and operations, and AR-assisted surgeries and remote imaging diagnostics in the medical industry. In addition, aiming to satisfy the rigid demand of European enterprises and public administrations for processing sensitive data, the European Union has established the European Alliance on Industrial Data, Edge and Cloud as an important part of the European data strategy to consolidate Europe's leading position in industrial data. **AI computing reflects a country's cutting-edge computing capacity. In China, AI computing is developing rapidly.** An analysis of the 15 countries shows that spending on AI computing increased to 12% of total computing, up from 9% in 2016, and is estimated to reach 25% by 2025.

## Computing efficiency

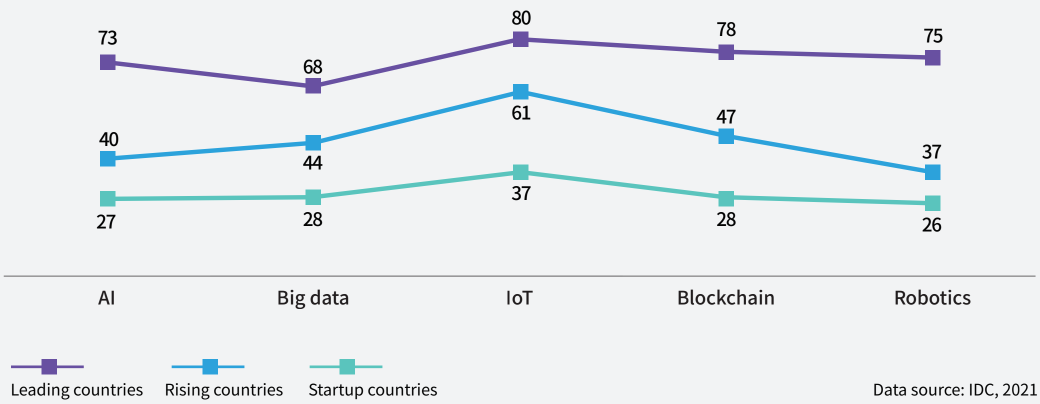
This metric reflects the current utilization of computing power in a country. Due to their higher adoption rates of cloud computing, some countries also have higher computing capacity utilization rates than others.




**Spending on cloud infrastructure continues to grow, and cloud computing accounts for a smaller share of investment in startup countries,** this report found that investment in cloud infrastructure accounted for an average of only 20.4% of overall IT infrastructure in startup countries, but up to 60.7% and 31.7% in leading and rising countries, respectively. After more than a decade of development, cloud computing has entered a new era characterized by multi-cloud and hybrid cloud architectures. Looking at the segments of infrastructure spending, traditional data centers remain the largest component. Nonetheless, public and private cloud segments are growing much faster, and that trend will continue in the coming years.This report found that investment in cloud infrastructure accounted for an average of only 20.4% of overall IT infrastructure in the startup countries, but up to 60.7% and 31.7% in the leading and catch-up countries, respectively.This report found that investment in cloud infrastructure accounted for an average of only 20.4% of overall IT infrastructure in the startup countries, but up to 60.7% and 31.7% in the leading and catch-up countries, respectively.

## Application level

The application of emerging technologies such as big data, AI, the Internet of Things (IoT), blockchain, and robotics is the core driving force of future IT expenditures, and will also reflect a country's economic development potential and comprehensive national strength. AI and IoT applications in particular have made significant contributions to countries and industries.




The evaluation shows that the US and China are at the forefront in terms of total spending on AI applications, with a high growth rate of 27.9% and 34.7% respectively, and that momentum is expected to continue over the next five years.

**Countries around the world are stepping up efforts in AI, a frontier technology for national strategies.** For their "Society 5.0" vision, Japan has introduced a series of policies to promote the development of AI technologies and AI applications in society, such as the "Cross-Ministerial Strategic Innovation Promotion Program (SIP) Phase II" and "Artificial Intelligence Technology Strategy". France has launched a national strategy for AI, which aims to improve the country's AI competitiveness, consolidate its leadership in embedded AI and trusted AI, and accelerate AI applications in the economic sector, with an additional investment of 2.2 billion EUR. This strategy also clarifies AI applications in the four areas of healthcare, environment, transportation, and national defense.

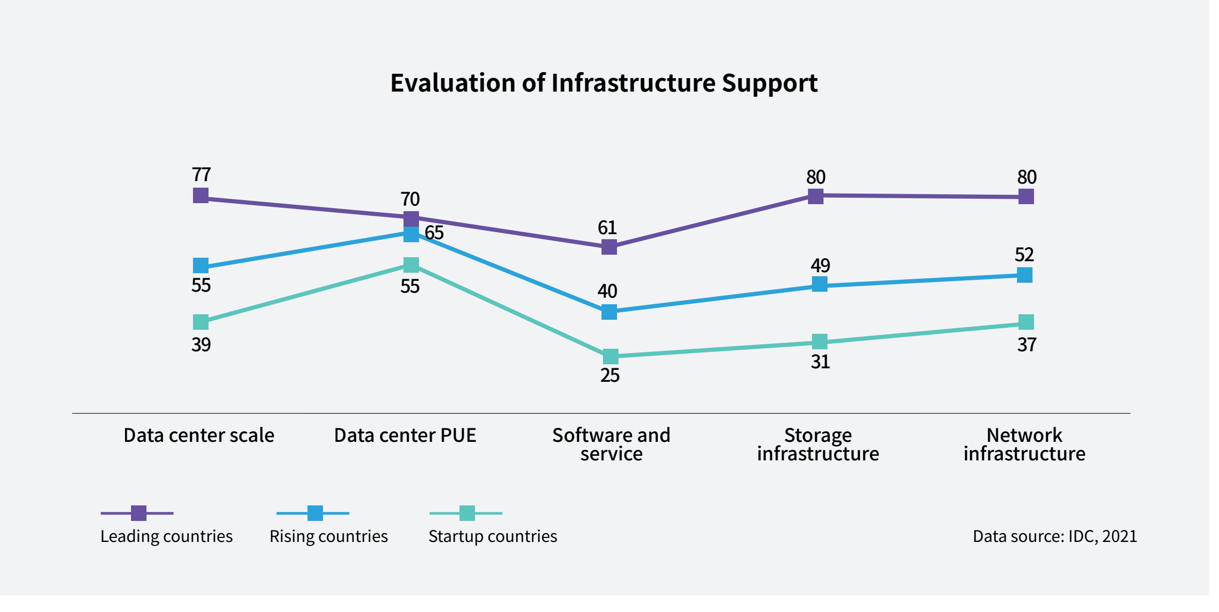
Based on distributed computing systems, large-scale pre-trained models have demonstrated unprecedented performance in many AI tasks, continuously increasing the industry's expectations of the capability boundaries of deep learning models. Currently, it has gradually become an industry consensus to serve specific downstream AI tasks by fine-tuning large-scale pre-trained models instead of training models from scratch. With an ever-growing wealth of application scenarios and the rapid growth of data volume, large models may become the basis for scaling innovation. AI companies around the world are actively developing and commercializing technologies for large-scale pre-trained models. In the US, OpenAI, Google, Microsoft, Meta, and other organizations have established large models with hundreds of billions or trillions of parameters, such as GPT-3, the Switch Transformer, and MT-NLG.

In China, organizations like Inspur Information, and Alibaba launched the large-scale pre-trained models Yuan 1.0 and M6. Inspur Information's Yuan 1.0 is a massive model with 245.7 billion parameters that has been trained on a dataset of more than 5TB. These models will empower all industries and accelerate the intelligent transformation of traditional industries, and will have an especially noticeable and positive impact in critical fields such as law, healthcare, and education.

**The business value of AI is widely recognized, and global spending on AI applications is growing rapidly.** Most businesses in South Africa are actively experimenting with AI technologies. Agriculture is a pillar industry in South Africa, and innovative technologies are increasingly important to modernize the sector and improve the livelihoods of large farming communities. AI technologies help local farms analyze and process maps, and identify problem areas for crops, thus optimizing yields. In the US, a large number of AI technologies are applied to the treatment and diagnosis of a variety of diseases such as genetic syndromes, lung cancer, breast tumors, and post-traumatic stress disorder, as well as research on protein folding, the detection & identification of antimicrobial resistance genes, and the development of new drugs. Major hospitals in South Korea are also strategically setting up their big data imaging databases to accurately interpret medical images with AI technologies to assist physicians in diagnosing breast cancer and tuberculosis from over 100,000 X-ray images, and recognize and decipher signs of diseases using images of tissue sections.

## Infrastructure support

Infrastructure support in the form of data center scale, data center PUE, software & service, and storage & network infrastructure provide a guarantee for computing capacity, computing efficiency, and application levels at a macro level.



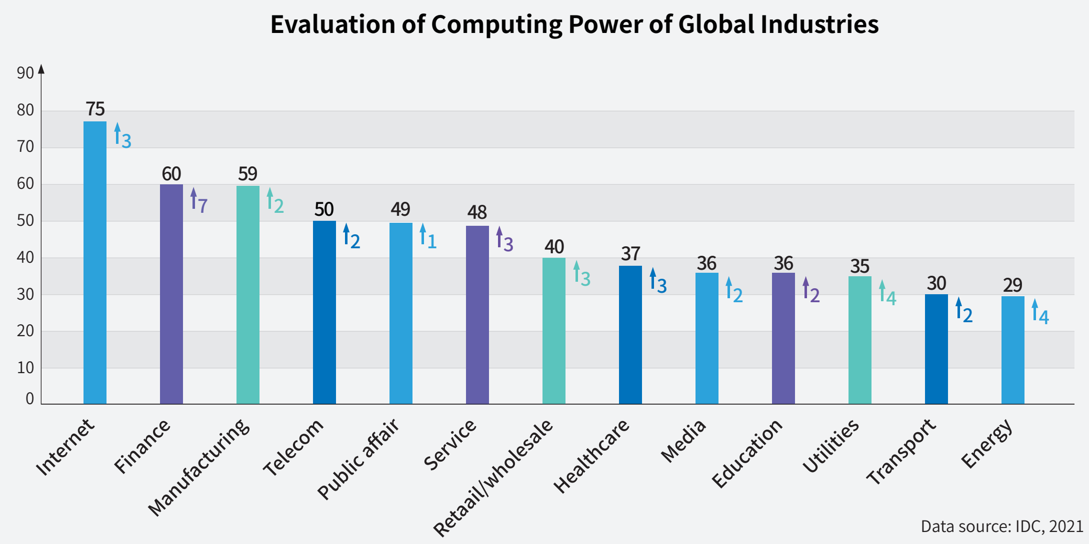
**Data centers are the foundation for the digital transformation of a country' s industries. The scale and energy efficiency of data centers will affect the future development of computing power in the country.** Leading countries have prominent advantages in hyperscale data centers, altogether accounting for more than 50% of the scale of the 15 countries. The US has the most hyperscale data centers of any country—four times as many as China, which has the second highest—mainly due to the continued infrastructure construction by world-leading cloud service providers such as Amazon, Google, and Microsoft. Driven by the sustained and rapid development of cloud computing and new infrastructure policies, China has experienced strong growth momentum in the number of hyperscale data centers, providing a strong backbone for the overall development of the digital economy and the deep integration of digital technologies and the real economy.

In terms of data center PUE, an increasing number of enterprises are turning to modular data centers and liquid cooling technology to reduce their PUE, while managing energy efficiency using big data mining & analytics, AI, or virtual simulation technologies. According to the latest research results, computing infrastructure in developed countries including the US, Germany, the UK, France, Australia, and Canada are more energy-efficient among the 15 countries, with an average PUE value of 1.4. Consuming 0.01% of the world's electricity, Google has worked for years to integrate sustainability into its operations by improving the energy efficiency of its infrastructure and reducing carbon emissions from its data centers. As the world's largest buyer of renewable energy in the non-utility sector, Google operates 13 renewable energy projects in Europe alone, and the average PUE of its data centers has now reached 1.1.

# Assessment of Computing Power Development

# Levels in Different Industries

This is the second consecutive year that the computing power of global industries has been evaluated by taking into account the investment of each industry in general computing, AI computing, and edge computing, along with the application maturity of emerging technologies. As per the latest data and user surveys, the distribution of the investment in computing power of global industries is shown below. Overall, the Internet industry is still ahead of traditional industries. The top 5 industries also include finance, manufacturing, telecom, and public affair. Finance has overtaken manufacturing for second place.




Over the past few years, the finance sector has been increasing its investment in computing power, especially in heterogeneous computing servers for AI application scenarios. In the post-COVID-19 era, most financial institutions are faced with the challenges of lower yields and increased bad debt rates. Therefore, such institutions are moving faster to build intelligent platforms, improve risk control capabilities, and further innovate service models. Judging from the evaluation results, the financial industry has outperformed the manufacturing industry in terms of total investment and growth rate in computing capacity and applications represented by AI and big data, resulting in its rise to second place.

## Internet: Leadership in global computing power by actively embracing emerging technologies

As digital-native enterprises, the Internet industry is most open to emerging technologies like cloud computing, big data, and AI. Statistics from IDC show that more than 90% of the IT infrastructure purchased by Internet enterprises in 2021 was applied to cloud computing deployments,that share was less than 50% for traditional industries. In addition, the integration of the Internet with AI, big data, and other emerging technologies has also generated demand for massive computing capacity. According to the data used in this report, the Internet industry is at the forefront in spending on AI, big data, the Internet of Things, and blockchain. In 2021, the Internet industry accounted for nearly 30% of global spending on servers, and this trend is expected to continue, according to IDC.

## Finance: Intelligent acceleration to effectively support the innovative development of financial services

The financial industry embraced AI very early on. Over time, validated applications have been rapidly promoted from large financial institutions to small and medium-sized institutions. AI as been adopted mainly for intelligent customer services and risk control. AI was used earlier in customer service and is therefore more mature. In this sector, intelligent customer service is mainly used for optimizing artificial collaboration, Q&A bots, HR services, and data/service supervision. Chatbots, intelligent customer service, and virtual assistants in the finance sector can provide users with accurate, personalized consultation and services through text or voice dialogue, thus greatly saving the costs of operating traditional call centers. By autonomously learning user preferences and habits, they can accurately identify potential needs and significantly improve user stickiness and conversion. Major global banks, including the Bank of America (BOA), JPMorgan Chase, Capital One, Mastercard, and American Express, have adopted chatbots to optimize their digital banking services. Over time, the voice recognition rate of AI-powered customer service has increased from 55% on average to over 85%. Banks have created AI virtual assistants for corporate clients to get their account balance information through a simple consultation.

***JPMorgan Chase - Innovative applications for AI virtual assistants***

*JPMorgan Chase has launched an AI virtual assistant for corporate clients to better meet their needs for business settlements. Since corporate clients have multiple accounts in different currencies, they often have to look up or export account information from as many as 1,200+ webpages in the portal to access account information, settle funds, and send remittance. The AI assistant not only learns from customer interactions, but also categorizes and summarizes the questions it gets in order to quickly find the appropriate answers. Eventually, the assistant will be able to take proactive actions, such as making advance phone calls to clients who may delay payments. The AI virtual assistant will be available via computer, mobile apps, and a voice virtual assistant device to provide an efficient and convenient experience.*

## Manufacturing: Building digital factories for intelligent manufacturing

Manufacturing is a key pillar that underpins the development of the real economy. It is one of the traditional industries utilizing the highest level of computing power. In 2021, investment in manufacturing-related computing power accounted for 12% of the world's total. Among the major traditional industries, only finance accounted for a higher share. While promoting digital transformation, the manufacturing sector not only needs to support the operation of large ERP systems, but also needs to take into account the application of new technologies such as the Internet of Things and sensors. From a global perspective, manufacturing makes the largest investment in two emerging technologies: the Internet of Things (IoT) and robotics. In 2021, spending on IoT and robotics in this sector accounted for 37% and more than 60% of the world's total, respectively. In addition, manufacturing is also ahead of most traditional industries in the application of AI, big data, blockchain, and other emerging technologies.

As the industry moves toward smart manufacturing and high-end manufacturing, an increasing number of excellent business practices have been adopted. For example, in a large manufacturing plant in Europe, a new laboratory facility utilizing these technologies responds twice as fast as its predecessor, which helps reduce factory operational costs 11% via the automation of low-value tasks since it was put into production. The benefits of the five use cases are as follows: the smart factory reduced design refinements from concept to implementation by 45%; the fully automated inbound logistics reduced indirect labor for individual products by 29%; digital online visual quality control reduced indirect labor for individual products by 17%; process linkage and traceability cut material usage errors by nearly 100%; and smart personnel matching increased overall equipment efficiency (OEE) (OEE = Availability * Performance Index * Quality Index) by 3%. These would not have been possible without substantial computing power.

## Telecom: Optimizing internal management and enabling business innovation with computing power investment

With the application of technologies such as 5G and cloud computing, telecom operators, faced with internal pressure for business growth, need to better support business support systems (BSS) to increase customer stickiness and optimize operations support systems (OSS) to improve operation efficiency. Externally, they need to provide support for value-added businesses such as smart transportation, smart retail, Internet of vehicles, games & entertainment, and AR/VR applications.

It was found that most telecom operator equipment is aging with high failure rates and subpar performance. Moreover, traditional data centers occupy large tracts of land and have high energy and maintenance costs, which result in a high OPEX. With concurrent growth in key businesses, such as a sharp increase in computing demand from billing and CRM, telecom operators are more willing to purchase new IT infrastructure. In order to provide efficient computing power, they accelerate the integration with and replacement of old equipment to modernize IT systems. Meanwhile they significantly optimize infrastructure investment, allowing the industry to better handle business growth and ensure business efficiency.

## Healthcare: Increasing investment in computing power to promote the construction of information platforms

Amidst an aging global population, the bar is being raised for healthcare standards. The global healthcare industry will maintain high investment in biotechnology, pharmaceuticals, and medical informatization. It shows a positive growth trend in the procurement of ICT infrastructure. The industry has seen preliminary results in digital development, with comprehensive information systems centered on computing platforms, and hospital-wide systems for data interoperability, regional collaboration, tiered diagnosis & treatment, and health services.

Medical institutions are dedicated to establish unified health information platforms to provide better diagnosis and treatment services for patients within and across regions. With the development and application of new technologies such as 5G, AI, IoT and cloud computing, big data will enable an intelligent upgrade of the medical industry. As hospitals continue their digital transformation, the number of business systems, such as public application services, clinical information, collaborative interaction, and electronic medical records are increasing and resulting in massive amounts of data. Consequently, there is a growing demand for centralized management, sharing and analysis of data resources. Increased investment in computing power can effectively guarantee business systems operation, improve operation capacity & continuity of key businesses, ensure system response during peak hours, and maintain high system availability and security. In addition, by streamlining system structures and establishing more linked data relationships, hospitals can realize data connectivity and collaboration efficiently, promoting the medical informatization to support data structures. These efforts lay a solid foundation for a smoother medical care experience and provide effective support for the construction of big data platforms and core systems operation in hospitals as well as application scenarios such as public health and community governance.

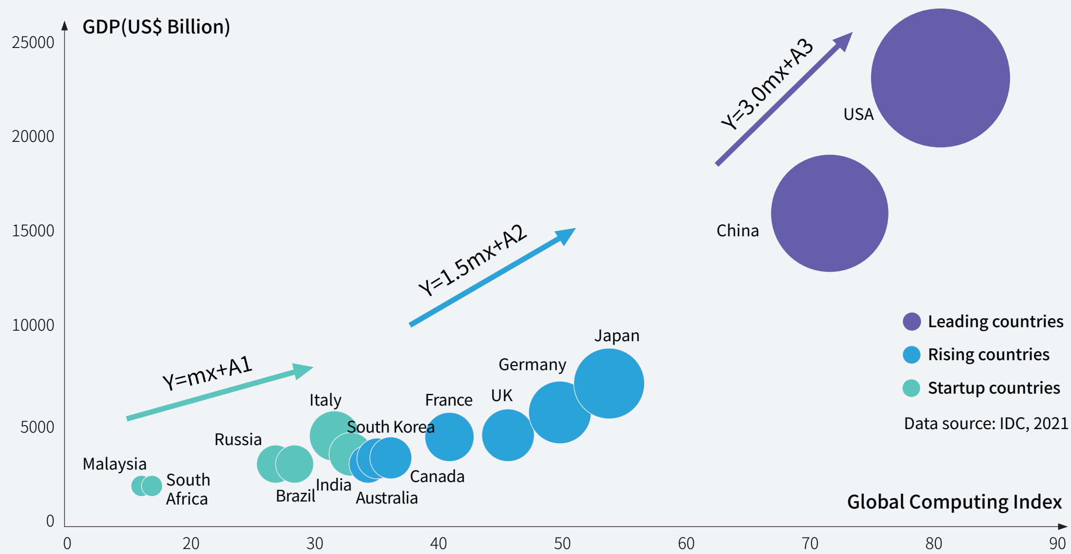
# Economic Impact of Computing Power

From a quantitative perspective, computing power plays a significant role in a country's macroeconomic development. The regression analysis of the country's Computing Index and economic indicators in this report show that there is a significantly positive correlation between the Computing Index and the GDP/digital economy. In the linear regression goodness-of-fit test, the model has a better fit when the Computing Index is the independent variable and the digital economy and GDP are the dependent variables, as opposed to having the Computing Index as the dependent variable and the latter two as the independent variables. Therefore, using the Computing Index to predict the digital economy and GDP better fits the reality than using the latter two to predict the Computing Index.

On average, for every 1-point increase in the Computing Index of the 15 key countries, the national digital economy and GDP will increase by 3.5‰ and 1.8‰, respectively, and that trend is expected to continue through 2025. After further regression analysis on the Computing Index and GDP of countries at different tiers, it was found that the influence of a country's Computing Index on GDP is different based on the point range. If m refers to the impact of every 1-point increase when the Computing Index is below 40 points, then the impact will increase to 1.5m or 3m when the index is more than 40 points or 60 points, respectively, which means more significant economic growth.

As mentioned above, the increase in the Global Computing Index mainly depends on the computing capacity and application level of emerging technologies. That is, while computing power investment provides a basic guarantee for the development of emerging technology applications, it is also further promoted by the demand from emerging technology applications, thus having a multiplying effect on overall economic growth.

**Regression analysis of Computing Index and GDP**



# Social Value of Computing Power

# Computing power facilitates new drug development and epidemic prevention and control

## Vaccine development

In recent years, emerging infectious diseases such as the novel coronavirus (COVID-19), severe acute respiratory syndrome (SARS), avian influenza (H5N1, H7N9), influenza A (H1N1), Middle East Respiratory Syndrome (MERS), and Ebola (EBOV) have had a global impact. They are all highly infectious and wide spreading. Most lack an effective drug or vaccine treatment and are incredibly unpredictable. They seriously endanger human life and health, undermine social stability and economic development, and present a major challenge to public health systems around the world. The development of vaccines and drug therapies to fight against such diseases is of the utmost importance.

**Computing power can facilitate vaccine and drug development, dramatically improving drug discovery, lowering average R&D costs, and reducing the risk of clinical failure.** After four decades of global development, computational drug discovery and design (CDDD) has been widely used in drug discovery research. For example, with the help of parallel computing clusters, technologies like high-throughput virtual screening (HTVS) can obtain candidate compounds in a short period of time. These technologies have significantly improved the efficiency and success rate of drug molecule design, and provided a solution for the long development cycles previously associated with developing drug therapies. **AI-assisted drug discovery has become the focus of the global market in recent years.** New drug development includes such steps as target selection and validation, compound screening & optimization, pre-clinical research and clinical trials. The development of AI technologies has provided new techniques for drug development and assisted the biopharmaceutical industry in accelerating digital and intelligent transformation. According to Deep Pharma Intelligence, there were 240 AI-assisted drug development companies worldwide as of 2020. Major pharmaceutical companies, such as Pfizer, GlaxoSmithKline, and Novartis have launched schemes in AI new drug R&D, with popular research directions being target selection and validation, and lead compound screening and optimization.

## Epidemic prevention and control

**AI computing has been critical in epidemic prevention and control since the COVID-19 outbreak.** AI computing has played an integral role in the prevention and control process.

**AI computing accelerates genetic sequencing analysis of suspected cases and significantly reduces contract tracing time.** Genetic sequencing has become a key tool for the prevention and control of epidemic infectious diseases caused by viruses. By sequencing the genes of pathogenic microorganisms, the genome sequence information of new unknown viruses can be obtained very quickly. This allows researchers to reveal pathogen-related characteristics, analyze the evolutionary origin of viruses, and study the pathogenic and pathological mechanism of viruses, thereby supporting the prevention, control, and research of outbreaks. Each genetic sequencing generates data over 10TB in size. AI is required to analyze such massive amounts of data. Analysis is further enhanced by edge computing, which allows analysis to take place in a wide range of environments and locations, significantly boosting the sequencing capabilities and efficiency for microorganisms, viruses, and human genes.

# Green computing power ensures sustainable development of society

**Computing power can help companies cope with the pressure to reduce emissions and gain a commercial head start in digital transformation.** Oil and gas companies are exploring how to use depleted underground oil and gas fields and reservoirs for carbon storage. Graphics computing technologies can enable geographic information systems (GIS), 3D modeling, and imaging, which allows these companies to assess the target sites efficiently. Non-ferrous metal manufacturers use edge computing and AI to upgrade metallurgical processes, optimize drilling rig operations, and shave peak loads, thereby ensuring safe production and improving resource usage efficiency. Equipment manufacturers integrate equipment systems for a higher level of automation and intelligence to monitor, analyze, and optimize plant energy usage, which generates data to support asset management and production processes. With the help of AI computing power, car makers optimize the distribution of charging stations and vehicle operators' fleet mix, routing, and resource allocation to reduce their carbon footprint. Power grids control power transmission and distribution through edge computing and the Internet of Things. Transmission efficiency is enhanced without increasing the carbon footprint. Data from all segments is collected through sensors and smart meters, and recommendations on power consumption optimization are offered via AI and big data analytics.

**Driven by the demand to address climate change with net-zero emissions, a green and centralized transformation of computing power is continuing to accelerate.** As cloud computing develops, modern data centers take on massive computing and storage tasks. The boom in AI technologies and the popularity of accelerated computing applications continue to drive the exponential growth in processing power consumption (270/280W+ for CPUs and 500W+ for GPUs), which has become a serious bottleneck for efficient data center system design. Challenges such as reducing the carbon footprint and greenhouse gas emissions of data centers, integrating energy conservation into daily operations, reducing operational expenses, and lowering PUE are becoming key considerations for solution providers and data center owners.

**From a green perspective,** to build green data centers, a variety of initiatives are being taken to reduce carbon emissions from data centers, including adopting liquid cooling for higher cooling efficiency, introducing new energy sources such as wind and solar energy, using AI/ML technologies to upgrade operation & maintenance management processes, and adopting new chip architectures to achieve higher computing power output per unit of power consumption. The world's leading cloud computing players are embracing more new energy. AWS has built solar powered and wind powered plants to power its data centers in Spain, Scotland, Sweden, Ireland, and many other countries. Since 2010, Google has been buying renewable energy on a large scale, and it operates 13 renewable energy projects in Europe alone. In 2019, the average PUE of Google's data centers reached 1.1. Equinix, a leading third-party data center provider, is driving intelligent upgrades to data center infrastructure management and adaptive control systems by deploying liquid cooling, AI/ML, and other operational technologies, with its global annual average PUE lowering to 1.5.

There are two types of liquid cooling: direct liquid cooling (DLC) and immersion cooling (IC). Cold plate liquid cooling is the primary form of DLC solution, which is a direct upgrade to existing rack systems for more efficient cooling, especially for high computing power/high power processors. IC has a higher cooling efficiency than the cold plate solution, but it costs more.

Of all liquid cooling solution options, IDC believes that DLC solutions will be more widely used in the data centers, especially for enterprise users, thanks to cost-effectiveness and scalability based on existing cooling systems and data center infrastructure. For IC, given factors such as the redesign/reconfiguration of data center systems, racks, floors, and other facilities, as well as costs associated with data center construction and operation (CAPEX/OPEX), such solutions will be more suitable for enterprises such as cloud service providers that are already running large-scale systems and data centers.

Liquid cooling solutions still in their infancy are mainly used in accelerated computing systems and hyperscale data centers. As the demand for green and energy-saving operations in data center systems continues to increase, IDC believes that liquid cooling solutions will be more widely adopted in the data center market, with at least 40% of systems with high computing power in data centers to be equipped with liquid cooling by 2023.

**From a centralized perspective,** one of the key factors in reducing carbon emissions is to increase the density of computing resources for higher efficiency. IDC has found that the average PUE of enterprise data centers is 2.8, while cloud service providers are between 1.1 and 1.3. Large cloud service providers and data center operators are also leaders in clean energy applications such as solar power, wind power, and hydropower. They have been ranking highly on the Green Power Partnership National Top 100 list of the US Environmental Protection Agency (EPA) for several years. When computing resources from discrete enterprise data centers are aggregated into larger data centers, power capacity can then be managed more efficiently, cooling facilities can be optimized, and server utilization can be improved to maximize the energy efficiency of IT resources and achieve reductions in emissions. According to IDC's *Global cloud computing carbon dioxide emission reduction forecast, 2021-2024,* continued adoption of cloud computing through 2024 could reduce carbon dioxide emissions by more than 1 billion tons.

# Recommendations for Actions



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As one of the important indicators to measure the development of a country's digital economy, computing power plays a fundamental supporting role for countries to enhance their competitiveness under the new technological revolution and industrial changes. Its strategic significance has been recognized worldwide. The acquisition and enhancement of computing power requires large and continuous investment. At the same time, there are high risks in technology development and application. These features mean that the global competition for computing power is inevitably a competition among major countries.

Against a complex and changing international political and economic landscape, countries around the world are moving faster to localize their computing power industry. All countries, whether they be leading, rising, or a startup, need to outline a feasible path for building their own computing power ecosystem by taking into account their own conditions, development stages, and resource endowments. They should also draw on the successes of other countries in terms of top-level facilities and infrastructure for computing power development and relevant talent cultivation, and should actively seek cooperation with other countries in digital infrastructure and other fields.

## Encourage countries to invest more in computing power infrastructure

Developed countries generally attach more importance to investment in computing power, and large economies' spending on computing power takes up a bigger share of their GDP. Among the 15 countries in this report, the US spends 1.9% of its GDP on servers, while developing countries, excluding China, spend only 0.5% on average. Through empirical analysis and theoretical model construction, the report proves that computing power construction has a non-negligible impact on the country's macroeconomic development. Computing power construction has become a core economic powerhouse. First, all countries should give full play to the positive network externality effect and spillover effect of computing power investment, and invest even more in computing power-related industries, especially data center infrastructure. For rising and startup countries, increasing computing power comes as an important means to fuel the digital transformation of traditional industries.

Second, efficient computing capacity, extensive application of emerging technologies, and sound infrastructure support are why developed countries can lead in computing power. The startup countries should, on one hand, invest more in computing power, and on the other, actively leverage various new technologies to enhance the usage efficiency of computing power and promote the synergistic development of computing, storage, and network infrastructure. In addition, rising and startup countries should be careful to avoid overcapacity and over-competitiveness in data center construction. They should strike a balance between participation in international competition and fulfilling their own demand, and avoid duplicate investment and uneven development.

## Strengthen international cooperation and shared development in computing power

Open cooperation in the digital economy is an important part of each country's global integration. International political risks are impacting the synergy and cooperation of countries in the computing power industrial chain. The leading, rising, and startup countries should invariably seek cooperation with other countries in the digital economy, especially in promoting international cooperation and shared development of computing power.

International cooperation faces many practical challenges in cross-border information sharing, localization of computing power infrastructure, international regulation and governance of the Internet, etc. That said, when the leading countries are shaping their own computing power ecosystems, they must undertake the responsibility of building a new mechanism to drive globalization through the digital economy, promoting the formation of a diversified and multi-level international cooperation and exchange mechanism in computing power, creating an international open-source platform, participating in the formulation of international standards & data governance mechanisms, strengthening international training & research cooperation of computing talent, guiding the green development of the computing industry, working together to provide digital infrastructure public goods for the world, and improving the global digital economy governance system.

# Appendix

## Methodology

The Global Computing Index is calculated by weighting four sub-items: computing capacity, computing efficiency, application level, and infrastructure support. The score of each sub-item is calculated by weighting the scores of the indicators for the sub-item. The specific score of each indicator is calculated as follows:

• The total score for each indicator is 100 points.

• For each country, the score of an indicator is calculated based on the comparison between the value for the current year and the target value for 2025. If the actual value for the current year is the same as the target value for 2025, the score for this indicator is 100 points. If the actual value is different from the target value for 2025, the indicator data is standardized and converted to the score based on the target value for each country. The target value for 2025 is calculated based on the data from authoritative organizations, institutions, and enterprises in various industries.

Score of Sub-item A = Score of a1 * Weight of a1 + Score of a2 * Weight of a2 + Score of a3 * Weight of a3 + ... + Score of aN * Weight of aN

The data sources of this research include IDC, EIU, IMF, the World Bank, International Telecommunication Union (ITU), China Academy of Information and Communications Technology (CAICT), Ookla, etc. In this research, telephone surveys are carried out for a total of 900 samples across 15 countries and regions. This research is based on the data from various industries, such as telecom, Internet, finance, manufacturing, energy, transportation, public utilities, public affair, medical care, retail, and professional services, ensuring that the first-hand research information is obtained.

The global Computing Index is a comprehensive, extensive, and complete indicator system that adopts a sound model system and credible data sources. The index provides organizations and individuals with a comprehensive blueprint for analyzing the relationship among computing power, the economy and the digital economy. The overall ranking of the global Computing Index scores reflects the current status of the global economy and computing power, and provides suggestions for the development and evolution of ICT in the next decade.

In this research, regression analysis is performed on the Computing Index and the economic development to obtain the degree of impact between them. In addition, the Computing Index of different countries and regions are categorized for presentation, and suggestions for future development are provided.

From the quantitative perspective, IDC performs linear regression to analyze the relationship between the Computing Indexes and economic indicators. In the linear regression, it is assumed that the relationship between two variables can be represented by one straight line and reflected in the formula $y = a + b(x)$:

- y represents a dependent variable and can be understood as the predicted variable.

- x represents an independent variable and can be understood as a predictor variable.

- b represents the inclination of the straight line. The magnitude of b represents the change in y caused by each unit change in x. In other words, when x increases by 1 unit, y changes by b units.

- a represents the y-intercept. In other words, a is the point where the straight line intersects the y-axis when x is 0.

The value of y is the year-on-year growth rate of the GDP or digital economy for the country. The value of x is the year-on-year growth rate of the Computing Index for the country. The value of b represents the change in the total GDP/digital economy of the country caused by each unit of change in the Computing Index. In this analysis, the reliability of the results is tested. according to the normal distribution and the 2σ rule. If the 95% confidence interval is between (-2σ, 2σ), the analysis results are 95% reliable. In other words, the analysis results fully explain at least 95% of the samples and are consistent with the actual situation reflected by the samples.

## Data Specifications

The model for evaluating the Global Computing Index consists of four Level-1 indicators and 20 Level-2 indicators. The model is used to evaluate the development level of the computing power and the potential for future development of the 15 key countries around the world. The four Level-1 indicators include computing capacity, computing efficiency, application level, and infrastructure support. The indicators are independent of each other, but are also closely correlated. The computing capacity reflects the theoretical maximum computing power of a country. It is the core of the entire evaluation system and occupies the highest weight among the four indicators. The computing efficiency reflects the current level of computing power utilization of the country. Some countries have higher utilization in cloud computing and virtualization, and therefore are more efficient in using their computing power. The application level is complementary to the computing capacity and the computing efficiency. The computing capacity and efficiency of a country are fundamental to the implementation of emerging technologies. In addition, the application of emerging technologies greatly promotes the development of the computing power of a country in the future. Therefore, the application level can reflect the development potential of the computing power of a country. Infrastructure support provides guarantees for the computing capacity, computing efficiency, and application level at a more macro level. Only when a country achieves balanced and synergistic development in these four dimensions can the country increases the overall Computing Index and gain greater economic benefits.

The computing capacity covers general computing, AI computing, edge computing, scientific computing, and terminal computing. It indicates the overall level and focus of computing power investment in different countries by evaluating the number and proportion of servers and terminal equipment. For general computing, AI computing, and edge computing, statistical specifications include the number and spending ratio of servers, AI-based servers, and edge computing servers. For scientific computing, the number and ranking of supercomputers of a country in the list of global top 500 supercomputers are evaluated and the comprehensive scientific computing power of the country is calculated using weighted algorithms. For terminal computing, statistical specifications include the number and spending of smartphones and PCs.

The computing efficiency reflects the current utilization of computing power in terms of the utilization of the CPU, memory, storage, new technologies, and the penetration of cloud computing. Virtualization, the basis of cloud computing, pools resources to implement on-demand computing, improving the utilization efficiency of software and hardware resources. Therefore, the penetration of cloud computing plays a crucial role in improving the utilization of existing computing capabilities. This indicator has a higher weight in the computing efficiency evaluation.

The application level focuses on the application of several emerging technologies such as AI, big data, IoT, robotics, and blockchain in different countries. Among these five emerging technologies, AI, IoT, and big data are most widely applied in industries, and therefore have higher weights in this evaluation.

Infrastructure support measures the sustainability of the future development of the computing power of a country in various dimensions, including the data center scale, software and services of data centers, power usage effectiveness (PUE) of data centers, storage infrastructure, and network infrastructure. Server spending accounts for about 70% of the overall hardware spending and is the core of infrastructure spending. The balance between storage and network spending is also important for the future development of computing power. Therefore, storage and network infrastructure are fully evaluated in this indicator.

| Level-1 indicator | Level-2 indicator | Level-3 indicator | Statistical specification |
|---|---|---|---|
| Computing capacity | General computing capacity | Server spending[1] | Server spending / GDP of the country for the current year |
| | Scientific computing capacity | Number of global top 500 supercomputers and their rankings | Weighted score of the ranking of all supercomputers of the country in the global top 500 supercomputers |
| | AI computing capacity | AI server spending[1] | AI server spending / GDP of the country for the current year |
| | Terminal computing capacity | Smartphone and PC spending[1] | Smartphone and PC spending / GDP of the country for the current year |
| | | Smartphone and PC user base[2] | Smartphone and PC user base |
| | Edge computing capacity | Edge computing hardware spending[1] | Edge computing hardware spending |
| Computing efficiency | New technology utilization | New technology utilization[1] | Average utilization of new technologies (SSD, SCM, and heterogeneous storage) |
| | Cloud computing penetration | Cloud computing penetration | Cloud computing spending / GDP of the country for the current year |
| | CPU utilization | Average utilization of server CPU | Average utilization of server CPU |
| | Memory utilization | Average utilization of server memory | Average utilization of server memory |
| | Storage utilization | Average utilization of server storage devices | Average utilization of server storage devices |
| Computing application level | Big data | Overall spending of software, hardware and services | Spending / GDP |
| | AI | | |
| | IoT | | |
| | Blockchain | | |
| | Robotics | | |
| Infrastructure support | Data center software and services | Data center software and service spending | Data center software and service spending |
| | Data center scale | Number of hyperscale data centers | Number of hyperscale data centers (with over 10,000 server racks) |
| | Data center efficiency | Average data center PUE | Average data center PUE |
| | Network infrastructure | Network spending[1] | Network infrastructure spending / GDP of the country for the current year |
| | | Telecommunication spending[2] | Telecommunication spending / GDP of the country for the current year |
| | Storage infrastructure | Storage device spending[1] | Storage device spending / GDP |
| | | Shipments of storage devices (TB)[2] | Shipments of storage devices (TB) |

• GDP: the GDP calculated by International Monetary Fund (IMF).
• If level-2 indicators include multiple level-3 indicators, [1] means the primary scoring items, and [2] means reference item.