HUAWEI

Intelligent World 2030

Building a Fully Connected,
Intelligent World

Foreword

George Gilder

Imagine an intelligent real-time world where waits and delays, queues and paperwork, hassles and drudgery dissolve in almost instantaneous provision of goods and services when and where you need them most.

Imagine a digital domain measurable in Yottabyte, ten to the 21th characters, where intelligence is as ubiquitous and broadband as air. Imagine nearly all homes and vehicles and people linked at a rate of at least 10 gigabits or billions of bits a second.

Imagine a world of “computable health services,” where no one has to wait in lines for care, where cancer and pandemic alike are cancelled...a world turning data into food to solve world hunger in farms that become skyscraping factories unaffected by climate or scarcity of land...a world where people commute in self-driving cars that are colleges, opening up a new “third space” of mobile learning and entertainment...a world where the self-driving revolution engulfs the skies, with electric taxis of the air available at a whim...

Imagine a world where cities are all-smart, all-optical, all-human, all connected, and all green...a world where 85 percent of all companies use unbreakable blockchain technology to protect personal identity and security and where more than half of all computing is “privacy enhanced”...a world where energy is clean, smart, and cloud- controlled...a world where companies are as flexible and resilient as human minds in new webs of digital trust.

In other words, an intelligent world.

As one of the world’s leading technology pioneers, spearheading the future of an ever more digital planet, Huawei has always subsisted on a luminous vision of coming innovations. Now, in Huawei Intelligent World 2030, the company cascades a new skein of oracular ideas and prophecies for the global economy.

Huawei’s “Intelligent World” research team met with some 1000 scholars without succumbing to their narrow disciplines. It tapped the ideas of scores of its customers without being captured by their short- term concerns. It consulted its partners without stinting on the contributions of its global rivals. It analyzed reams of data from international organizations, scientific journals and consultancies without losing its way in the mazes of jargon or special expertise. It held over 2000 workshops without falling into the cliches of conventional thought.
Soaring above its sources, this book integrates all narrow disciplines and specializations into a transcendent holistic unity guided by the theory of information.

In the information theory of economics, wealth is most essentially knowledge (the caveman after all had all the material resources we command today). Economic growth is learning, manifested in “learning curves” of collapsing costs throughout all competitive companies.

Constraining the processes of learning is time—what remains scarce when all else becomes abundant.

This is the vision of Intelligent World. Here Huawei's wealth of practical knowledge feeds on continuous learning. Here the limiting cadence of time restricts waste and assures ever growing efficiency and ever diminishing costs for all of us.

In this world, the test of worth is time-prices that measure value by the number of hours and minutes a worker needs to labor to gain the means to buy any particular good or service. Combining the rise in incomes with the decline in costs, time-prices reduce the metric of progress to one universal signature of time.

By this measure, we live in an age of ever-expanding abundance. From an era when people had to spend every waking hour chasing and collecting food just to live, a typical human today earns his food in a matter of minutes. People now can devote their hours to creating new things and new services, like the bonanzas of innovation envisaged in this book.

Gauged by time prices, economic growth has been at least twice as fast as is usually estimated. While the world's population has risen 75 percent over the last 40 years, the time prices of the commodities of life have dropped 75 percent. Moreover, for the last 40 years, China at a rate of nearly 12 percent a year has massively led all other nations in the speed of its advance.

A key to this enriching cascade has been the prophetic visions of companies such as Huawei, as epitomized by this book.

George Gilder

Futurist, author and venture capitalist

Wu Hequan

Today, we can clearly see the huge role industrial development has played in driving economic and social progress. However, we are also facing increasingly severe challenges. Population ageing and urbanization have been accompanied by a surge in healthcare demand, labor shortages, increased CO_2 emissions, urban traffic congestion, and environmental pollution. The outbreak and resurgence of COVID-19 over the past two years, and frequent disasters caused by extreme weather events, all highlight the vulnerabilities of today's world.

To address these challenges, the UN has set 17 sustainable development goals (SDGs) for 2030. The achievement of these goals will require scientific and technological innovation as well as supportive policies and regulations. We will need to embrace an intelligent world through digital and intelligent transformation.
Network infrastructure is the foundation of this digital and intelligent transformation process, and also the foundation of the future world that everyone will live in. So what requirements does the future world have for networks?

Internet penetration has reached 52% worldwide, and continues to increase by around three percentage points on average every year. Over the next decade, the number of Internet users will continue growing in developing countries, and by 2030, 70% of people will have access to the Internet. The number of network connections will increase even faster. The number of connected things already exceeds the number of connected people. The number of connections to the Internet of Things (IoT) worldwide has grown at a rate of 10% every year for the past decade. By 2030, the number of IoT connections is expected to be growing more than 10 times faster than the number of Internet users.

According to IDC, the total volume of global data increased by 30% year-on-year from 2016 to 2020. Assuming this rate continues, the world's total data will increase 14-fold over the next decade. Data drives the rollout of broadband. In the past decade, the average bandwidth required by consumer applications has increased more than tenfold. Over the next decade, 10 gigabit access will be available to massive numbers of applications. At the same time, the focus of Internet applications will shift from consumer use to industrial applications. Applications for industrial settings demand low latency, deterministic communications, and high-precision spatial positioning; they must also require high levels of security, reliability, and data protection.

To ensure networks can meet the requirements of the future world, efforts have been made to plan future network technologies, targeting 2030. We are seeing the first fruits of these efforts today. The move to IPv6 will enable sensing applications and in-band signaling, based on which new routing protocols can be developed to support low-latency, high-reliability services. Flexible Internet protocols (IP) can be used to make networks adaptive to the services they carry.

Some new network architecture solutions have been proposed to provide highly secure, green, intelligent, and ubiquitous networks that combine deterministic services, endogenous security, and border security, and can meet the requirements of different applications. Moving forward, next-generation information technologies, such as 5G, cloud computing, IoT, big data, artificial intelligence (AI), and blockchain, will be added to the technology stack. They will enable intent-based services and applications and more efficient use of network resources, and ensure secure and trustworthy cloud-network synergy.

Huawei's Intelligent World 2030 report provides a glimpse of what the world will look like in 2030 in eight domains: healthcare, food, living spaces, transportation, cities, enterprises, energy, and digital trust. Powered by next-generation information technologies, health will be computable; people will enjoy higher quality of life; food production can be driven up by data; cities will become more livable; buildings will become greener; travel will become more convenient than ever; industries will become more intelligent; and trust will become more widespread in society.

The report lists the benefits delivered by some early showcase applications, and includes forecasts from global leaders in the eight domains, providing a clear picture of the world 10 years from now. The report also includes four separate industry reports on communications networks, computing, digital power, and intelligent automotive solutions.

As its title suggests, the report is a just a forecast; many unknowns loom ahead. The projections provided in this report are intended only as a reference for scientists and technology professionals, to help them envision the upcoming intelligent world. This report aims to stimulate innovative thinking and explorations into disruptive technologies to meet the challenges that lie ahead.

邬贺铨

Member of Chinese Academy of Engineering (CAE)
Director of the Advisory Committee of Internet Society of China (ISC)
Director of China Standardization Expert Committee (CSEC)

Gao Wen

The past decade has witnessed huge advances in artificial intelligence (AI). Various AI applications have been woven into the fabric of our lives, including clothing, food, living spaces, and transportation. In particular, the major role that AI has played in tackling COVID-19 helped us see its value to all.

China has major advantages that can drive the development of AI: huge data volume, many industrial use cases, and a young and well-educated workforce. But improvements still need to be made in original algorithms, core components, and open-source and open platforms. We need to carefully consider and plan how to make rapid advances in these areas so that we can sustain healthy AI development in China.

The thriving of AI depends on three elements: data, algorithms, and computing power. The progress in AI to date has created a demand for levels of super computing power that far outstrip what Moore's Law can provide. For example, since the emergence of deep learning in 2011, the demand for computing power has been growing exponentially, doubling every 3.4 months.

In 2020, training Generative Pre-trained Transformer 3 (GPT-3), the natural language processing model with 175 billion parameters, consumed 3,640 petaFLOPS-days of computing power. In 2021, Pengcheng Pangu, the industry's first fully open-source Chinese pre-training language model with 200 billion parameters, demanded even more computing power: 25,000 petaFLOPS-days. It took Pengcheng Cloud Brain II, a supercomputer that has computing power measured by exaFLOPS, 50 days to complete the training of Pengcheng Pangu. By 2023, the demand for computing power from hyper-large models will reach millions of petaFLOPS-days, which will pose a severe challenge to existing computers and their computing power.

The development of AI relies on sharing of data, computing power, and ecosystem resources. Areas for exploration in the coming years will be how computing centers can work together for joint model training, while still ensuring data security, and the balance between privacy protection and data mining. Technologies such as federated learning and Trustworthy platform-based AI model generator have offered a solution to these problems. We believe that as these technologies mature, we will be able to use data resources to the fullest extent without undermining data security. Trusted computing platforms will also support further advances in computing networks.

This report gives a comprehensive account of Huawei's research to date. Huawei's insights into the computing industry can offer invaluable experience to those who are interested in the development of this industry.

Looking ahead to the next 5 to 10 years, the use of AI will be spread to more areas, such as AI-led 6G intelligent sensing networks, and Neuromorphic systems that will go beyond existing machine vision imaging systems. Let's work together to embrace a brighter future for the computing industry.

Academician, Chinese Academy of Engineering
Director, Peng Cheng Laboratory
Boya Chair Professor, Peking University

Chen Qingquan

When cars first appeared, they changed the world, making travel more convenient and flexible. However, cars have also been the cause of many woes in urban environments, like air pollution, traffic jams, and unsustainable energy use. This must change. In the next 10 to 20 years, we will see a new automotive revolution.

The automotive industry has been around for more than 100 years. Its "body" remains strong, but its "brain" is weakening. In contrast, the information and communications (ICT) industry has a powerful "brain", but its "body" lacks strength. If we want to ride the tide of the automotive revolution, these two industries must work together to develop a new generation of vehicles. This new revolution will be focused on the user. In essence, it is about moving the automotive industry towards connected, autonomous, shared, and electric (CASE) mobility. Its ultimate purpose is to support safe, comfortable, green, efficient, and at-will transport by making vehicles, roads, and cities more intelligent.

China, for example, has seen its economy shift from high-speed growth to high-quality development, in line with trends associated with the fourth industrial revolution. To cope with this revolution, we need to replace traditional linear thinking with strategic thinking. China's "4N4F" integration model is a prime example of how disruptive circular thinking can replace a linear approach. 4N4F refers to "four networks" and "four flows", where "four networks" refer to the nation's energy network, information network, transportation network, and human network; and "four flows" refer to energy flows, information flows, material flows, and value flows.

The 4N4F integration model will help bring human creativity to the energy revolution, information revolution, and transportation (mobility) revolution. This model is essentially about integrating information technologies, cloud, 5G, AI, and other leading technologies so that data can become useful information, and digital information can be analyzed to output knowledge and intelligence. This model also takes a step further by integrating intelligence into energy to create the intelligent energy sector. This new sector will be able to recycle waste energy while helping us achieve carbon neutrality and delivering increased economic and environmental benefits.

This marks a novel approach to integrating humans, cyber systems, and physical systems (HCPS). These composite systems will produce new kinds of productive arrangements, allowing us to tap into the huge potential of data monetization in the fourth industrial revolution. This revolution will drive exponential growth in productivity, building upon the advancements made in the previous three industrial revolutions. We will soon see a shift from electric vehicles to intelligent vehicles, to intelligent transportation, to smart cities, and ultimately to an intelligent world. During this process, we will be able to create greater added value and more opportunities for value creation.
We are already in the middle of an energy revolution, and have embarked a new journey to a new era. China is coming under huge environmental stress, so it is more desperate than any other country to transition to vehicles that use new energy sources. This is why developing new energy vehicles is a path that China must take. Now is the best moment to integrate the energy and Internet sectors.

Intelligent vehicles powered by new energy represent mobile units of energy production, energy storage, and information. We need to link the automotive revolution, energy revolution, and information revolution, use the 4N4F integration model, and turn energy flows into material flows. This will help us reduce our energy and carbon intensity and hit carbon neutrality targets. The 4N4F model also combines energy technologies with ICT, cloud, edge computing, AI, and big data through a smart energy operating system to deliver greater value. It will drive the energy transition from the fourth to the fifth industrial revolution.

A smart energy sector will need to provide more than just higher security and intelligence. It will need to turn previously useless energy into useful energy. Thermodynamically, this means changing entropy increase into entropy decrease, or turning entropy into exergy. At its core, this process is about turning disorder into order. The automotive industry should also be committed to carbon neutrality if it wants to grow steadily and sustainably.

We will soon enter an era of intelligent vehicles, where green, interconnected, and intelligent will be the way forward for technology in the automotive industry. Innovation will drive further development and transformation in vehicles. The automotive industry will see a transition to electric vehicles and facilitate a mobility revolution for all. This revolution will require more than just stronger research & development and manufacturing. It will also need intelligent networks, where connectivity technologies are key to enabling smart and agile transportation and building the smart cities of the future.

Vehicles are the ultimate products of deep integration between the Internet, big data, AI, and the real economy. Vehicles will be redefined by ICT, and become more connected and intelligent. Intelligent connected vehicles will be a key pillar of intelligent transportation. They will also present challenges in terms of technology, policy, laws, and regulations. The standardization of intelligent vehicles is still underway, and we will continue innovating as we build intelligent connected vehicles. We hope that our future transportation system will be safer and greener and more comfortable and convenient. Let's work together to make it happen.

陳清泉

Founding President of the World Electric Vehicle Association
Academician of Chinese Academy of Engineering
Fellow of Royal Academy of Engineering

David Wang

Exploring the Intelligent World

Technology is developing faster than we could have ever imagined. Digital technologies such as 5G, cloud, and AI are constantly being pushed to their limits, advancing in leaps and bounds. Innovation is no longer confined to a single discipline, but is intertwined with multiple disciplines. Innovation is no longer about a single technology, but about different technology classes. Innovation no longer happens in one industry, but in many industries. The digital, intelligent world is fast approaching.

The Internet currently connects 4.6 billion people and 20 billion devices, and has transformed how people live and work. But that same Internet is also evolving from a consumer-oriented to an industrial Internet. Huawei predicts that by 2030, there will be more than 200 billion global connections, and 10 gigabit connectivity will be available to every enterprise, household, and individual.

The smartphone in your pocket already carries more computing power than the Apollo shuttle that took us to the moon in 1969. By 2030, general computing power (FP32) will reach 3.3 ZFLOPS and AI computing power (FP16) will reach 105 ZFLOPS, a 500-fold increase over 2020. This will mean over 1 yottabyte of data will be generated around the world annually.

As we kick off this new decade, we can already see the outlines of the intelligent world of 2030. By 2030, the combination of ICT technologies and biological data will make health computable, improving healthcare and our quality of life. With big data, AI, and agronomic expertise, we can create scientific food systems that are resilient, sustainable, and "green".

Holographic communications and whole-house intelligent controls will be the key to adaptive, cozy, and friendly homes that understand our needs. The rapid development of new energy and autonomous driving technologies will make vehicles a mobile "third space" outside our home and workplace.

Digital technologies ranging from digital infrastructure, cloud computing, and blockchain will make cities more livable and city governance more efficient. Enterprises from countless industries will use more productive machines, such as collaborative robots, autonomous mobile robots, and digital employees. They will reshape our industrial and commercial models, and make companies more resilient.

An "energy Internet" will emerge, with digital technologies connecting power generation, grids, load management, and storage, systematically reducing carbon emissions, and digitalizing the entire clean energy process. Blockchain, digital watermarking, and privacy-enhancing technologies will lay a solid foundation for a sustainable digital culture.

Huawei has been tireless in our exploration of the future. Over the past three years, Huawei has hosted more than

2,000 seminars, bringing together over 1,000 academics, customers, and partners. Based on these discussions, our experts from around the world have compiled our thoughts on the next decade into this report: Intelligent World 2030.

We lay out eight directions for exploration, spanning multiple disciplines and domains, to answer questions like: How can ICT help people overcome the problems and challenges that we face? Over the next 10 years, what opportunities do organizations and individuals need to be ready for? In terms of our own industry, this report also systematically addresses future technologies and lines of progress in four domains: communications networks, computing, digital power, and intelligent automotive solutions.

More than 30 years ago, we set out to connect every family using phones and enrich life through communications. 10 years ago, we decided to connect our networks to every corner of the globe and build a fully connected world. Now, we are committed to bringing digital to every person, home and organization for a fully connected, intelligent world. We believe that a wonderful intelligent world is fast approaching.

Our imagination is the only limit on how far we can go, but it is the actions we take now that will determine how quickly we can get there. The best way to embrace the future is to build it ourselves. There may be ups and downs on our journey towards the intelligent world of 2030, but we will overcome them by working together and innovating continuously. Together, let's create a better, intelligent world.

DAVID WANG

Executive Director
President of ICT Products & Solutions, Huawei

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Executive Summary

We are making strides towards an intelligent world. When looking ahead to 2030, we hope that the future will bring improved quality of life, sustainable and green diets, and more comfortable living spaces. We also look forward to the end of traffic congestion and pollution in cities, fully green energy, and a wide range of new digital services. We dream of robots that can do repetitive and dangerous work for us so that we can devote more time and energy to more valuable, creative work, and to our personal interests. These are the goals that drive exploration in every industry.

Huawei is committed to bringing digital to every person, home and organization for a fully connected, intelligent world. In this report, we examine the prospects for the intelligent world over the next decade by analyzing macro trends in healthcare, food, living spaces, transportation, cities, enterprises, energy, and digital trust. We believe in the infinite possibilities of the intelligent world, but constant collaboration and exploration among many different industries will be required to build a better future.

Outlook for Healthcare: Making Health Computable, Bettering Quality of Life

By 2030, sensitive biosensors will be in widespread use, and massive amounts of health data will be stored on the cloud, making health computable. People will be able to proactively manage their health, shifting focus from treatment to prevention. Driven by technologies such as IoT and AI, personalized treatments will become a reality. Portable medical devices will enable people to access coordinated telemedicine services from the comfort of their homes.

Huawei predicts that by 2030

- Global general computing power (FP32) will reach 3.3 ZFLOPS, a 10-fold increase over 2020.
- AI computing power (FP16) will reach 105 ZFLOPS, a 500-fold increase over 2020.

Outlook for Food: Data-driven Food Production for More Bountiful, Inclusive, and "Green" Diets

By 2030, we will be producing visualized data graphs, which will make precision farming possible. Collecting data will enable us to control factors affecting crop growth, such as temperature and humidity, so that we can build vertical farms unaffected by the uncertainties of climate and weather. 3D printing technologies are also introducing the possibility of artificial meat designed according to taste and dietary requirements. By 2030, we will be building more resilient and sustainable food systems and relying on firm data rather than the vagaries of the heavens.

Huawei predicts that by 2030

- There will be 200 billion connections worldwide.
- 1YB of data will be generated annually worldwide, a 23-fold increase over 2020.

Outlook for Living Spaces: Personalized Spaces with Novel Interactive Experiences

By 2030, we will no longer have to live with clutter. We will manage our possessions with a digital catalog powered by a 10 gigabit network, holograms, and other technologies. Automatic delivery systems will bring household items from shared warehouses to our doors whenever we need them. Intelligent management systems that control our physical surroundings for automatic interactions will mean that the buildings where we live and work may produce net zero carbon. Next-generation IoT operating systems will enable people to live and work in adaptive environments that understand their needs.

Huawei predicts that by 2030

- There will be 1.6 billion fiber broadband subscribers.
- 23% of homes will have access to 10 gigabit fiber broadband.

Outlook for Transportation: Smart, Low-carbon Transport Opens up the Mobile Third Space

In 2030, the transport system will see innovations across many different dimensions. Vehicles using green energy and controlled by autonomous driving technology will provide us with a mobile third space. Electric vertical take-off and landing (eVTOL) aircraft will make emergency rescue faster, reduce the costs of delivering emergency medical supplies, and may even change how people commute. Mobility solutions will be efficient, customized, and shared, meaning that vehicles will be used much more consistently and travel will become greener.

All of these will require secure and stable autonomous driving algorithms; cost-effective, reliable sensors; high-speed, stable space-air-ground integrated networks; and a central brain with massive computing power for traffic management. These technologies will be indispensable for developing connected, autonomous, shared, and electric vehicles that deliver a low-carbon transport experience.

Huawei predicts that by 2030

- 50% of new vehicles sold will be electric vehicles.
- In addition, by 2030, the whole-vehicle computing power will exceed 5,000 TOPS.

Outlook for Cities: New Digital Infrastructure Makes Cities More Human and Livable

The spread of new digital infrastructure will make for better management of the urban environment, with more efficient use of resources and more effective city governance. Centralized digital platforms for government processes and services will make government services user-friendly and easier to access. This will help create more comfortable and livable cities.

Huawei predicts that by 2030

40% of companies will have access to 10 gigabit Wi-Fi networks.

Outlook for Enterprises: New Productivity, New Production Models, New Resilience

By 2030, digital transformation will have brought a new wave of modernization to enterprises. They will use more productive machines, such as collaborative robots and autonomous mobile robots. New business models will be more people-centric, with increased flexibility in manufacturing, logistics, and other activities. Digitalization will help companies interweave and graphically monitor their supply chains for better resilience in the face of dynamic market environments.

Huawei predicts that by 2030

Every 10,000 workers will work with 390 robots.

One million companies are expected to build their own 5G private networks (including virtual private networks).

Cloud services are forecast to account for 87% of enterprises' application expenditures.

AI computing will account for 7% of a company's total IT investment.

Outlook for Energy: Intelligent, Green Energy for a Better Planet

Energy will be greener and more intelligent in 2030. Power plants will be generating electricity from renewable energy sources in lakes and near-shore marine areas. An "energy Internet" will emerge, with digital technologies connecting generation-grid-load-storage, including virtual power plants and an energy cloud. Zero-carbon data centers and zero-carbon telecom towers could possibly become a reality.

Huawei predicts that by 2030

- Renewables will account for 50% of all electricity generation globally.

Outlook for Digital Trust: Technologies and Regulations Shape a Trusted Digital Future

In 2030, digital trust will be a basic requirement for our social infrastructure. We will need a combination of technical and organizational measures: blockchain, AI fraud detection, and privacy-enhancing computation. This will need to be combined with privacy and security regulations such as the General Data Protection Regulation (GDPR). Used together, these measures will deliver an intelligent world with digital trust.

Huawei predicts that by 2030

- Privacy-enhanced computing technologies will be used in more than 50% of computing scenarios.
- 85% of enterprises will adopt blockchain technology.

Healthcare

Making Health Computable,
Bettering Quality of Life

Over the past decade, the health of humanity as a whole has improved markedly. According to the World Health Organization's (WHO) World Health Statistics 2021, global life expectancy at birth has increased from 66.8 years in 2000 to 73.3 years in 2019[1]. This means that most people can now enjoy long lives, making a better quality of life the new priority.

The pace of population aging is accelerating worldwide. Projections indicate that 16.5% of the global population will be 60 years old or over by 2030[2]. This is expected to drive a surge in demand for healthcare services. According to the WHO's 2019 findings, spending on health is growing faster than the rest of the global economy, accounting for 10% of global gross domestic product (GDP). The WHO also predicts that by 2030, there will be a global shortfall of 5.7 million nurses[3] and 18 million[4] health workers in total.

In addition, chronic diseases and suboptimal health status are increasingly affecting people's quality of life. According to World Health Statistics 2021, seven of the 10 leading causes of deaths in 2019 were non-communicable diseases (NCDs) and global premature NCD mortality reached 17.8%[5].

At the same time, we are seeing wide disparities in the global distribution of medical resources – disparities that become especially clear when viewed in terms of population growth. According to the UN's World Population Prospects 2019, Africa's population is expected to reach 2.49 billion in 2050 while Europe's will be 710 million[6]. However, when we look at the distribution of medical resources, Germany alone has 10.5 times more physicians per 1,000 people than Nigeria, which is one of the more economically vibrant countries in Africa[7].

Looking to the future, new methods of reducing healthcare costs, diversifying healthcare resources and services, and creating new prevention and treatment methods are desperately needed to increase the quality of life and make medical treatment more accessible and affordable for all.

Many innovative solutions are emerging that may find application within the next ten years.

Direction for exploration: Using computing technologies to identify potential health problems, shifting the focus from treatment to prevention

According to the WHO, 60% of illnesses are caused by lifestyle factors[8], so maintaining good habits is a crucial part of staying healthy. Real-time health monitoring and health data modeling can help us cultivate healthy lifestyles and weave disease prevention into the fabric of our daily lives. This shifts the paradigm governing our healthcare system from treatment to prevention.

Snapshot from the future: Building a knowledge graph to achieve real-time and efficient health management

The growing popularity of wearables and portable monitoring devices combined with advances in technologies such as the Internet, IoT, and AI will make personal health data modeling a realistic prospect in the near future.

Technologies such as big data and IoT will enable doctors to build knowledge graphs based on users' data, including health indicators, medical diagnoses, and treatment results. Doctors can compare and analyze the knowledge graphs to formulate personalized health solutions for users.

In addition, we can take intervention measures which include guidance on nutrition, exercise, and sleep, as well as mental health support to incrementally improve our lifestyles. One digital health company built a knowledge graph to examine relationships between diet and disease. The company used the knowledge graph to help individuals improve their sleep quality and manage their weight. The health management survey conducted by the company showed that the participants recorded an average 35 minutes more sleep daily, and a total body weight roughly 1.5 kg lighter across the year[9], which translated into lower probability of disease.

We can also combine health knowledge graphs with medical knowledge graphs to predict users' disease risks and future health status, and help them obtain more accurate information about their medical conditions, including information about symptoms, medicine, risk factors, and doctors' diagnoses. Doctors can use this information to achieve more rapid and accurate diagnosis.

Snapshot from the future: Making infectious disease prediction more accurate

New digital technologies, such as natural language processing, can also broaden the amount of data that can be used for epidemiological management. These technologies allow public health institutions to collect and analyze news articles, reports, and search engine indexes to track major public health events around the world. These institutions can extract valid information from the collected data, build new scientific models, and conduct intelligent analyses of the data so that they can respond to incidents faster and more effectively.

ICT technology can also be used to monitor and predict the spread of infectious diseases. For example, a technology company has used natural language processing and machine learning to gather data from hundreds of thousands of public sources, including statements from official public health organizations, digital media outlets, global airline ticketing agencies, as well as livestock health reports and population demographics, to analyze the spread of disease 24 hours a day[10].

Direction for exploration: Precision medicine and treatment plans

A well-designed medical treatment plan is an indispensable part of administering effective, safe, and convenient treatment to patients. When designing a medical treatment plan, doctors have to track and evaluate the patient's symptoms and assess the efficacy of different treatments based on the patient's specific condition. If a patient's clinical symptoms are complex, finding the optimal solution among multiple potential treatment plans can be extremely challenging, but new computing technologies may be the best tool for this challenge.

Snapshot from the future: More accurate drug trials shifting treatment from "one-size-fits-all" to "bespoke"

Some of the factors that must be taken into consideration when designing a medical treatment plan include the physical condition of the patient, appropriate drug categories, timing, dosage, and treatment durations, and possible drug interactions and side effects. These plans, once formulated, also need to be regularly updated based on the treatment progress. All of this puts significant strain on physicians, whose resources are already stretched extremely thin, forcing them to rely on general expertise and experience rather than the patient's specific condition to quickly formulate a general treatment plan. However, AI can help doctors develop personalized treatment plans by analyzing thousands of pathology reports and treatment plans, and determining which would be most appropriate for each patient.

One research institute in Singapore has even created an AI-powered pharmaceutical platform that optimizes medication dosages. The platform can quickly analyze a patient's clinical data, provide the patient with a recommended drug dose or combination regimen based on their specific condition, and revise tumor sizes or biomarkers levels based on available data. In addition, doctors can use the data to determine new courses of treatment for patients[11].

Snapshot from the future: Achieving safe & precise identification of cancer cells with AI

Precision medicine can help the fight against cancer. Estimates showed that there were 19.29 million new cancer cases and 9.96 million cancer deaths[12] worldwide in 2020. Global cancer cases are projected to rise 75%[13] by 2030. Technology can improve cancer diagnosis and treatment, deliver better medical services, and help patients recover more quickly.

During traditional radiation therapy, radiation is directed at the general location of the cancerous tissue to kill cancer cells. Since the targeted area is quite broad, the radiation typically also kills a large number of healthy cells, putting significant strain on the patient's body and resulting in serious side effects.

With the help of AI technology, adaptive radiation therapy (ART) systems can automatically identify changes in lesion positioning and more accurately outline the target areas for radiation treatment. This helps focus the radiation on just the cancer cells and reduces damage to healthy tissue.

AI is already enabling accurate identification and automatic contouring of target areas for various types of medical imaging, including CT, ultrasound, and MRI. AI-based image registration can automatically identify organs and target areas based on clinical needs, making image registration faster and more accurate. With the help of AI, a contouring workload that would once have taken hours can now be completed in less than a minute, and the damage caused by radiation therapy to healthy tissue can be reduced by 30%[14].

▸ Direction for exploration: Home-spital: Using cloud-edge-device synergies to bring healthcare services into patients' homes

The changing role of technology in disease prevention and treatment has increased demand for medical products and personalized medical services that can manage health in real time. The healthcare industry is actively exploring ways to build coordinated telemedicine systems through synergy between cloud computing, edge computing, and on-device computing. Such systems would allow people around the world to access high-quality medical resources anywhere, whether in hospitals, community healthcare centers, or homes.

Snapshot from the future: Cloud-based diagnosis services connecting patients with top experts online

Traditionally, patients have to go to hospitals or specialized treatment facilities for medical examinations and in-person diagnoses. The uneven distribution of medical resources means that top experts are often concentrated in big cities. This often leaves patients in small towns and rural areas without access to accurate diagnostics, resulting in ineffective or delayed treatment.

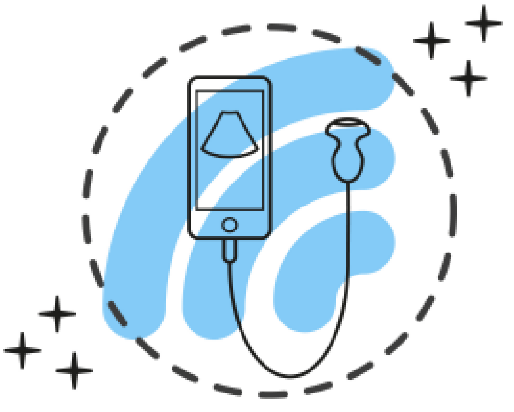
In the near future, the complex processing workloads of imaging devices will be handled in the cloud. Doctors will soon be able to access medical imaging results and AI-assisted diagnostic tools through the cloud. Medical images, examination results, and medical records will be synchronized in real time. This will help doctors provide patients with remote diagnoses and treatment services, wherever they are.

With the application of a "device data collection + 5G + cloud computing" model, medical images can be more easily shared between community hospitals and medical centers. After images are captured on medical devices in community hospitals, they can be automatically or manually uploaded to the cloud. Experts in medical centers can then access the images on the cloud and issue diagnostic reports.

Snapshot from the future: Portable devices that lower the threshold for professional medical examinations

As components get smaller and chip technology advances, large medical devices that previously could only be used in hospitals are now becoming portable, making mobile medical examinations a reality.

Handheld ultrasound scanners are a prime example of this trend. Compact and portable scanners are equipped with the same functions as bulky conventional scanners. This is possible because the functions of conventional ultrasound probes are integrated into a single chip used in portable scanners. In addition, ultrasound information can be collected through smartphone applications. Powered by cloud computing and deep learning, handheld ultrasound scanners can enable powerful functions, such as real-time composite imaging and automatic scanning, that people can use anytime, anywhere. A handheld ultrasound scanner costs only a few thousand US dollars, but has the same functionality of a bulky conventional scanner, on which hospitals often spend more than US$100,000[15].



Conclusion：

Making health computable and bettering quality of life

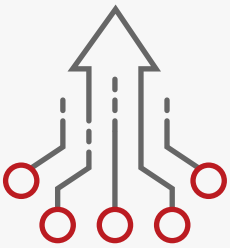
By 2030, we will be able to track our own physical indicators in real time with sensitive biosensor technologies and intelligent devices. We will also be able to build health knowledge graphs to manage our health independently, reducing the reliance on doctors.

Driven by ICT technologies, personalized treatment solutions will become a reality in the future. For example, strong computing power and highly intelligent deep learning systems will be widely used in areas such as precision medicine, adaptive radiation therapy, and rehabilitation robots.

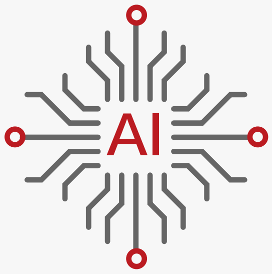
Portable medical devices powered by advanced software and hardware, cloud-edge-device computing, and stable networks will be available in grassroots-level hospitals, communities, and households. These devices will collect medical data in real time and upload the data to the cloud for processing, allowing users to access coordinated telemedicine services and keep track of their health from the comfort of their homes.

By 2030, ICT technology will be enabling access to various applications that will help us stay healthier than ever before. We need a lot of computing power to achieve this.

Huawei predicts that by 2030,



Global general computing power (FP32) will reach **3.3** ZFLOPS, a **10**-fold increase over 2020.



AI computing power (FP16) will reach **105** ZFLOPS, a **500**-fold increase over 2020.

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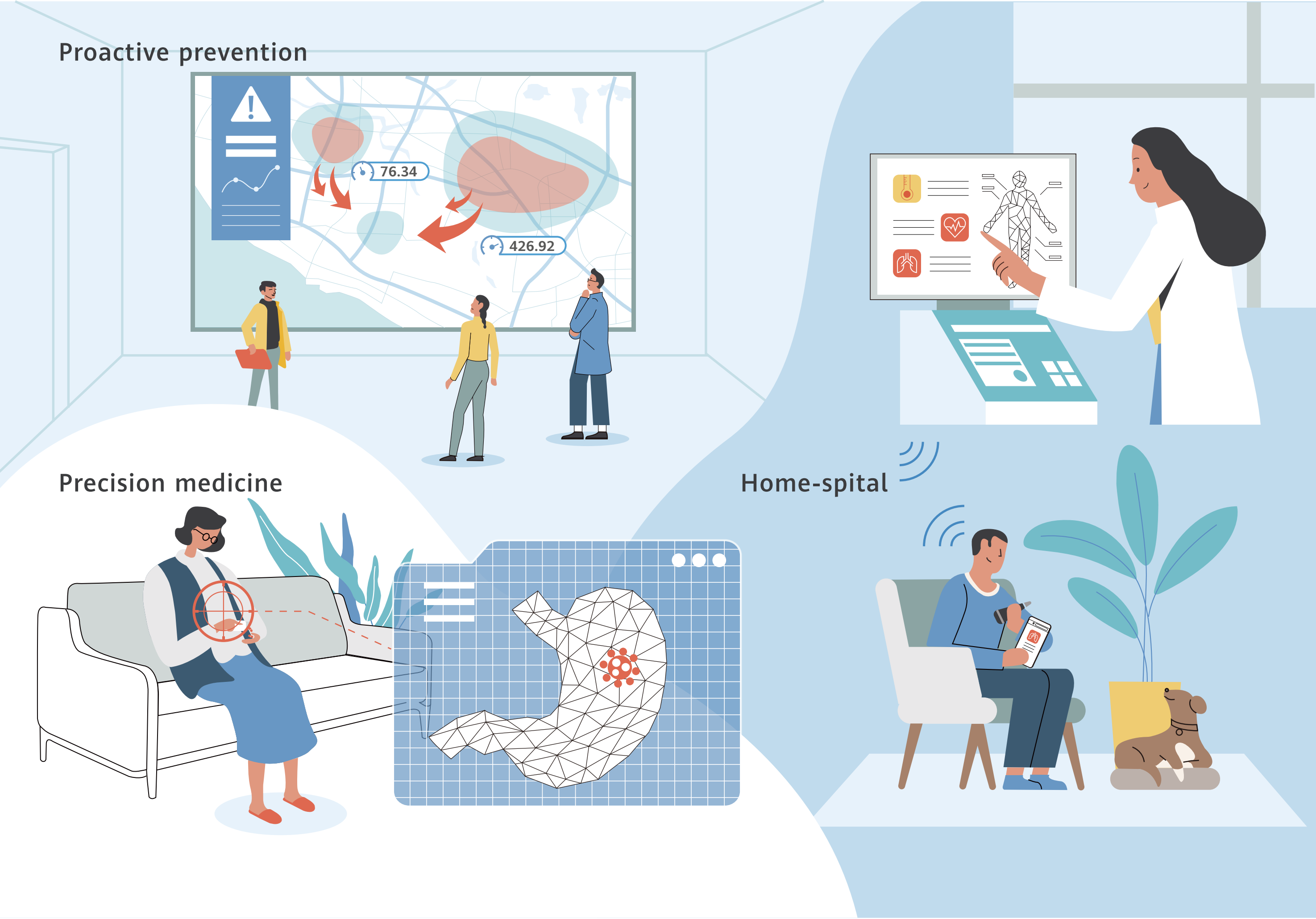

Proactive prevention
76.34
426.92
Precision medicine
Home-spital

Food

Data-driven Food Production for
More Bountiful, Inclusive, and "Green" Diets

Food is a necessity for all, so the UN has made "Zero Hunger" one of its Sustainable Development Goals (SDGs) for 2030. Current estimates show that nearly 690 million people are hungry, and if recent trends continue, the number of people affected by hunger would surpass 840 million by 2030[1].

In the past, food shortages were addressed by focusing on resource insufficiencies, such as poor climate and soil conditions, or labor shortages. However, environmental change and accelerating urbanization mean traditional agricultural technologies and abundant natural resources are no longer enough if we want to achieve the UN's 2030 SDGs[2].

The agriculture workforce is shrinking: According to the International Labor Organization, the proportion of the world population working in agriculture has dropped from 43.699% in 1991 to 26.757% in 2019[3].

Arable land per capita is decreasing: According to World Bank data, arable land per capita has fallen from 0.323 hectares to 0.184 hectares from 1968 to 2018 – a drop of 43%[4].

Overuse of pesticides is causing severe soil pollution: According to statistics, 64% of global agricultural land (approximately 24.5 million square kilometers) is at risk of pesticide pollution, and 31% is at high risk[5].

Simultaneously, the focus of people's diets around the world is shifting from "Does this taste good?" to "Is this good for me?" This has resulted in more nutrition and food safety standards. For example, 13,316 food products in China received some kind of green certification in 2018. This number increased to 14,699 in 2019, up 10.4% YoY[6].

This higher demand for green-certified products results in higher requirements on agricultural conditions and technologies.

As we move towards 2030, our food supply faces new challenges and demands. We can see that technology is key to empowering agriculture, helping it overcome traditional growth constraints, increasing food production across the board, and bringing "green" food to every table around the world.

Direction for exploration: Using accurate data, not experience, to guide cultivation

As the saying goes, there is "a time to plant and a time to uproot". Farmers normally rely on calendars to determine the best times to sow. In addition, they also rely heavily on personal experience to determine when to sow, fertilize, and use pesticides. However, this leaves a lot of uncertainty, and whether any given year yields a good harvest is still ultimately up to fate.

Snapshot from the future: Precision farming based on visualized data graphs

Even within a single crop field, the moisture content, available nutrients, and crop conditions can vary. But with modern tools like sensors and mobile devices, farmers can remotely and accurately monitor soil moisture, ambient temperature, and crop conditions in real-time. This makes it possible to flexibly adjust agronomic measures, like sowing, irrigation, fertilizer, and seed adjustment, based on diverse data sets, to better align crops with the soil available. Take maize, for example. Data-powered adaptive sowing can increase crop yield by 300 to 600 kilograms per hectare of land[7].

Precision agriculture also relies on in-depth analysis of collected data and cloud-based visualized data graphs. Data from these graphs help farmers make informed decisions regarding soil fertility, water, and nutrient delivery across key crop growth stages. These graphs can also help farmers better understand information such as local topographical characteristics, climate conditions, and crop diseases or pests so that they can better estimate crop yields, implement agricultural measures, and adjust budgets accordingly.

Visualized data graphs can also be used to monitor and manage agricultural production in real time, helping farmers make proactive, quick, and precise responses to changes in their environment. For example, in the event of extreme weathers, farmers can use this data to rapidly locate affected areas, develop solutions, and mitigate negative impacts on their yields.

Direction for exploration: Taking a "factory-like" approach to protect agricultural production from environmental conditions

While precision agriculture is an effective tool for increasing agricultural yields, it is not sufficient for meeting the surging food demands caused by population booms, shrinking arable land per capita, pesticide pollution, and worsening climate change. Under precision agriculture, data is used for analysis and calculation so that the best cultivation solution can be found. However, the environment is constantly changing, so data can only be used at the moment it is collected. Therefore, the results of agricultural data analysis cannot be used iteratively.

In addition to precision agriculture, we can also take a more "factory-like" approach to agriculture, creating "vertical farms" in enclosed environments. Not only can vertical farms be used to collect more data, they can also allow farmers to directly adjust parameters to allow crops to grow in an optimal environment. Both countries with little arable land, like Japan, South Korea, and Singapore, and countries with abundant land resources, like the US, are proactively developing vertical farm technologies.

Snapshot from the future: A new form of agriculture in intelligent vertical farms

One typical example of industrialized agriculture is indoor, vertical farms that use data to build standardized growth environments without needing to consider geographical constraints. In vertical farms, every step of the cultivation process, from sowing, to fertilizing, to harvesting, is closely monitored, with farmers precisely controlling light, temperature, water, and nutrient delivery based on the needs of each crop. By controlling every stage of crop growth and adjusting environmental parameters as needed, farmers are able to artificially create the ideal environment for their plants.

Vertical farms have three main advantages:

◎**They don't need pesticides or soil, and reduce agricultural water waste:** Hydroponics and aeroponics, which are common in vertical farms, utilize solutions that are more efficient at delivering nutrients to plants, with any remaining nutrients being recaptured together with water. These methods use less than one tenth of the water used in traditional agriculture, making the entire process more eco-friendly and reducing pollution.

◎**They are not affected by climate, providing consistent and ideal conditions for fresh produce:** As vertical farms create closed environments, automatic control systems can be used to ensure reliable, large-scale cultivation. This makes it possible to grow vegetables in a wider variety of locations and climates. Vertical farms can be built on rooftops, in office buildings, abandoned workshops, and basements, or in deserts, rivers, or seas.

◎**They provide smart agricultural models that are globally replicable:** The ICT control system and data model used in one vertical farm can be used anywhere in the world to achieve almost the same results. The vertical farm model allows anyone to emulate the environment that grew the best wine-making grapes in history, and even arid regions that see little daylight can be used to grow warmth-loving cherries.

Recent pilot programs for vertical farms have found that, if harvested every 16 days, a 7,000 square meters area can yield a staggering 900,000 kilograms of vegetables every year[8].

Direction for exploration: Low-carbon, 3D-printed solutions for meat

In addition to grains and vegetables, meat is an integral part of most dietary traditions. Traditional animal husbandry though is not only inefficient and unable to meet demand, it also has negative environmental impacts. It is estimated that animal husbandry produces about 7.1 billion tons of CO_2 every year, accounting for 14.5%[9] of total anthropogenic greenhouse gas emissions. Methane, a volatile and powerful greenhouse gas, is the second-largest contributor to climate change. Moreover, the majority of methane emissions caused by human activity come from livestock. There are roughly 1 billion cattle worldwide[10].

According to the UN's Food and Agriculture Organization (FAO), the global demand for meat is projected to increase 70%[11]. by 2050 as the global population grows. This makes meat production an area in critical need of proactive solutions. The food industry as a whole has already shown significant interest in artificial meat.

Snapshot from the future: Healthy and sustainable meat supply with 3D printing

Recent applications of 3D printing technologies have successfully improved the quality of artificial meat, making it better tasting and better looking to consumers. It has proven capable of turning both plant proteins and animal cells into artificial meat.

3D printing can use plant-based photoproteins to build fibrous skeletons that closely mimic the texture of real meat. Alternatively, 3D printing can also be used to stack nutrient elements made of real animal cells to create the musculature and fat layers normally seen in animal tissue. Currently, 3D printing can be used to create many types of artificial meat, including pork, chicken, and beef, with the price of artificial beef quickly approaching the market price of real beef.

Conclusion：

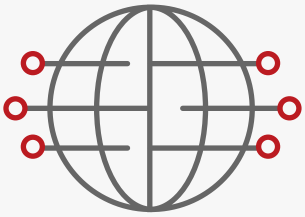
Turning data into food to solve global hunger

In the future, we can use the Internet of Things (IoT) to monitor and analyze soil conditions and crop growth, and to increase yields based on collected data. We can also use historical data to predict changes in the natural environment so as to take proactive intervention measures that reduce the risk of yield reduction. Science-based precision agriculture systems powered by big data, AI, and agricultural know-how would make it possible for farmers to precisely water and fertilize crops and use drones to apply pesticides more accurately.

Intelligent farming models, such as data-based vertical farms will free agricultural production from the constraints of climate dynamics. These models can be replicated worldwide for more inclusive and green diets.

3D printing technologies are also making it possible for people to create artificial meat using their data models based on taste and dietary requirements. By 2030, ICT technology will enable us to connect key agricultural production factors, such as farmland, farm tools, and crops, and to collect and utilize data on climate, soil, crops, etc., to increase yield. Huawei predicts that by 2030, the data generated worldwide will reach 1 YB every year, a 23-fold increase over 2020. There will be 200 billion connections worldwide, and IPv6 adoption will reach 90%. With the wider application of data in agriculture, we will build a more resilient and green food system.

Huawei predicts that by 2030,



There will be **200 billion** connections worldwide.
IPv6 adoption will reach **90%**.

1YB of data will be generated annually worldwide, a **23**-fold increase over 2020.

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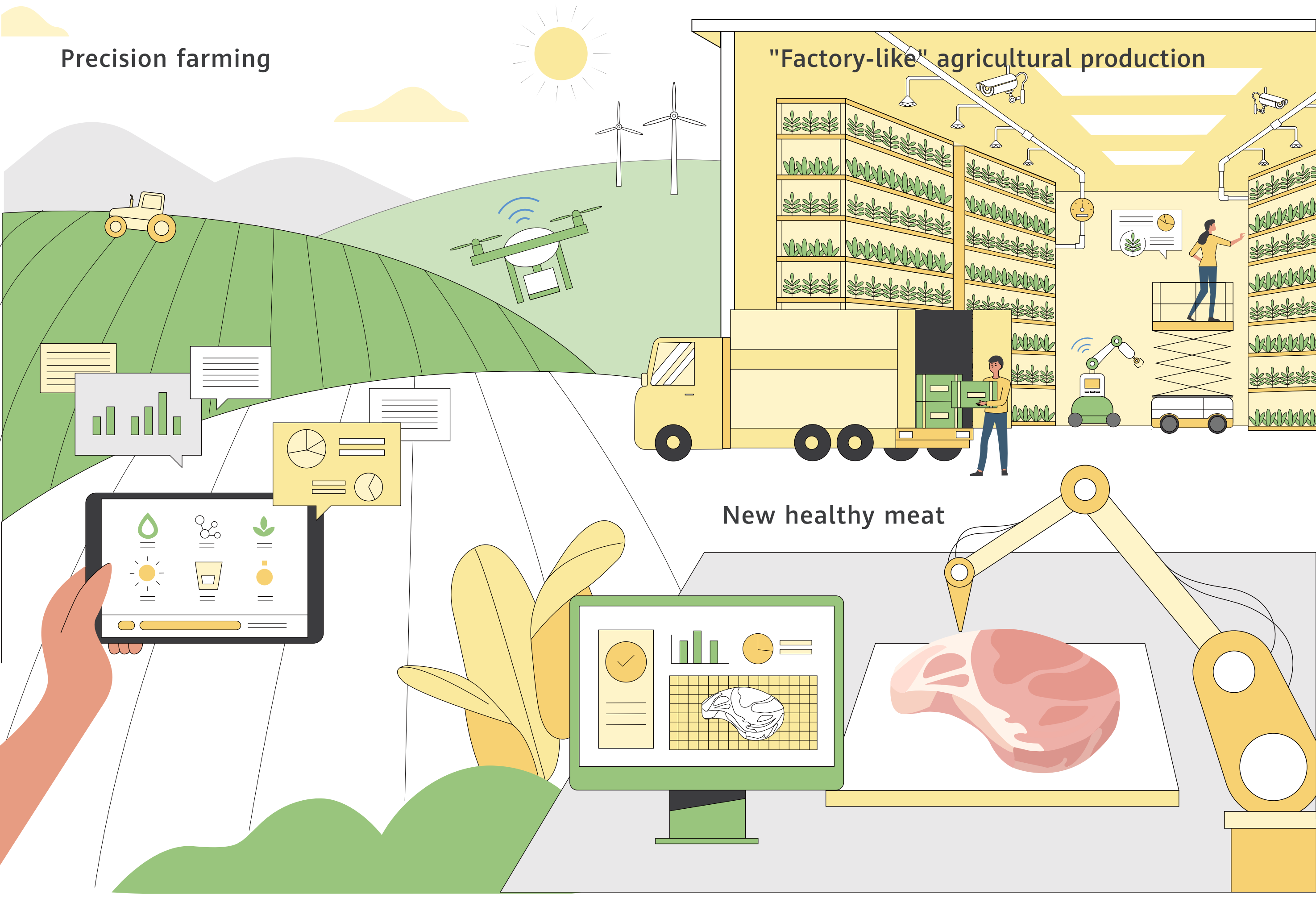
Precision farming
"Factory-like" agricultural production
New healthy meat

Living Spaces

Personalized Spaces with Novel Interactive Experiencess

The spaces people live in have dramatically changed throughout history. Over time, ancient caves have been replaced by modern buildings, and people have moved from rural communities to dense urban districts. The role of living spaces has also transformed. What used to simply be a shelter from the elements has become the vault for our most precious possessions.

Industrial advancements have led to an abundance of material wealth, and while material possessions bring us joy, they have also filled our living spaces to the brim. The average American home has more than 300,000 items[1], and 1 out of every 10 Americans rents offsite storage[2]. Similarly, a British study found that the average 10-year-old child owns 238 toys but plays with just 12 on a daily basis[3]. While many find buying new objects satisfying, the downsides of hyper-materialism are becoming increasingly apparent to society as a whole. This dilemma opens up new possibilities for future home design.

It has been reported that in 2019, CO_2 emissions from the operation of buildings worldwide reached 10 $GtCO_2$, or 28% of total global energy-related CO_2 emissions[4]. Moreover, the number of new buildings all over the world is set to explode. The International Energy Agency estimates that global building stock will rise by 5.5 billion square meters per year on average until 2050[5]. The UN Environment Programme's Global Status Report 2017 predicts that the world will add 230 billion square meters (2.5 trillion square feet) in new construction by 2060, which is almost equal to current global building stock. This means an amount of construction equal the size of New York City will be added to the planet every 34 days over the next 40 years[6]. In response, the World Green Building Council has stated that, if we want to meet the goals of the Paris Agreement, all new buildings should operate at net zero carbon by 2030 and all buildings should achieve this by 2050[7].

As demand for personalized home experiences continues to rise, ICT-enabled smart home technology is gaining popularity. A survey found that about 80% of millennials and 69.2% of baby boomers are interested in smart home technologies.[8] In the UK, 80% of consumers are now aware of smart home technology and it is second only to mobile payments in consumer awareness of a basket of tech trends.

Interoperability has risen as one of the most important buying considerations.[9] Interest in smart living spaces that offer enhanced convenience and safety is also on the rise.

Direction for exploration: New infrastructure provides comprehensive services for communities

Smart doors, smart smoke detectors, falling object alerts, delivery notifications, and many other smart services are becoming increasingly widespread. This means that residents are much more closely connected with their communities and local authorities. In the future, new communities will deliver comprehensive services to residents, powered by the Internet of Things (IoT), Gigabit fiber networks, and other new advanced infrastructure. Services such as virtual community events and smart pet management will make bring residents and their communities more closely together. Groundbreaking new design concepts will also start changing the way our homes look at the household level.

Snapshot from the future: Digital cataloguing and automated delivery for offsite storage

One potential solution to the overwhelming amount of possessions that now fill households is offsite storage. Some proposed solutions include digitalization and cataloguing of all household items, with technologies like 3D scanning, and then storage in local shared warehouses. This would mean when you decide to go to a party, you can flick through a 3D hologram menu to pick out the dress and accessories that you want, and, at the touch of a button, have those items delivered to your door, either by robot[10] or through the building's internal delivery system[11].

A similar system could power a shared "library" of useful household items. For example, in a typical household, electric drills are not needed often, so instead of buying your own, you could search for one in the shared library's online resource catalogue and borrow it for a few days. Automated delivery systems will bring the drill to you and take it back when you are finished.

Direction for exploration: Net-zero-carbon buildings with IoT and intelligent management systems

According to the World Green Building Council, a net zero carbon building is "a highly energy efficient building that is fully powered from on-site and/or off-site renewable energy sources and offsets." Net zero carbon is achieved when the amount of carbon dioxide emissions released on an annual basis is zero or negative. Minimizing building energy consumption through new designs and eco-friendly materials is the first step to achieving net zero carbon.[12] The next step requires not only clean energy sources, but also information and communications technologies (ICT).

One day, net-zero-carbon buildings will be able to automatically interact with their environment through sensors.

- Sensors monitor and generate data about the bu ilding in real time, including its environment and condition.
- The In ternet of Things connects sensors, cloud-based control systems, and core systems such as lighting, electricity meters, water meters/pumps, heaters, fire alarm systems, and water chillers.
- Intelligent, cloud-based systems utilize sophisticated algorithms and real-time data to automatically decide how the building can minimize energy use. For example, a complete automated system could use IoT devices to check the number of people in a building in real time, and then decide when to switch air conditioners and lights on or off in different parts of the building. Such a system would also be able to manage elevators, hallways, and shutters, depending on actual human activity.

In addition to the environmental benefits, net-zero-carbon buildings will also make people's lives more comfortable. Automated systems can keep indoor temperatures at agreeable levels, while soundproofing materials can keep outside noise down to a minimum. There will also be health benefits. Automated systems can decide how much sunlight should pass through a window, to help limit UV exposure, encourage natural sources of vitamin D, support regular sleeping patterns, and combat seasonal affective disorder (SAD).

Snapshot from the future: Automated building management systems for museums

Some key museums are already upgrading their energy systems with automated controls. For example, one museum in Australia installed a building management system that constantly monitors 3,000 different indoor environment data points, and automatically adjusts utilities to provide the right conditions for visitors and the objects on display. Heating, ventilation, air conditioning, lighting, and water efficiency have all been upgraded, reducing the museum's GHG emissions by 35%, and electricity costs by 32%[13].

Direction for exploration: Adaptive home environments that understand your needs

Today, we expect more from our homes than ever before. Homes should be more than just places to live: They should also offer superb experiences. The "homes of the future" will intuitively understand all of our needs. The moment we arrive home after a long exhausting day, the lights, sound systems, air filters, and television will switch on automatically. When we walk into the kitchen, the refrigerator will push healthy meal suggestions adapted to our personalized dietary needs. In the bedroom, air conditioners will check air quality and automatically adjust temperature and humidity based on what we are doing.

There are perceptible and imperceptible factors that determine how comfortable our homes are. Perceptible factors are those we can instinctively feel, such as temperature, humidity, lighting, and ease of access to household items. Imperceptible factors usually include indoor air quality and safety. Both types of factors can be controlled in real time by intelligent automated systems.

Snapshot from the future: Whole-house intelligence that understands usage and creates intuitive experiences

Smart home systems collect data from a wide range of smart home appliances and sensors, over highly-reliable, high-speed networks that reach every corner of your home. They use AI engines to determine what is happening and run appropriate applications. The AI engines, in turn, need distributed processing and computing to understand your behavior, indoor environment, and hardware systems, and then make smart decisions to configure your home appliances. These steps could be taken independently or in collaboration with other systems, to meet your needs. When implemented properly, smart home systems deliver immersive, personalized, and intelligent experiences that evolve as your usage needs change. In the future, the way we interact with home appliances will also change through touch panels, apps, voice commands, and gestures. Sometimes interactions will be so subtle that we won't even be aware of them.

The variety of smart home appliances we will see in the coming years is expected to explode. They will work together to intelligently anticipate and meet your needs in different situations. Everything, from smart beds and pillows to lights and audio devices, will be able to collaborate. A sleep support solution could easily be created for the bedroom by designing a system that automatically adjusts the softness of your mattress and pillow to suit your body and sleeping habits, and changes your bedroom lighting to stimulate the production of melatonin – the hormone that helps you fall asleep. Bedroom speakers could play music to relax you, and air conditioners could keep track of temperature, humidity, and oxygen levels. Such a system could even identify snoring and curb it by rapidly adjusting the softness of your mattress and pillow. Temperature and humidity regulation could also be achieved to stop you from tossing and turning in bed[14].

Conclusion:

Personalized spaces with novel interactive experiences

In the future, new intelligent infrastructure will play an integral role in smart communities. With the help of ICT technologies, community management systems will aggregate massive amounts of data generated by smart equipment, and use that data to holistically manage how communities operate in real time, delivering superior services to residents.

Net-zero-carbon buildings will be made possible by eco-friendly designs and clean energy sources. Passive design for energy conservation cannot achieve zero carbon goals alone, and energy management systems can contribute to these efforts by effectively managing energy sources and accurately controlling indoor environments to minimize energy consumption.

5G and Artificial Intelligence of Things (AIoT) will help smart home systems autonomously adapt to user needs. These systems will rely on superfast network connections and sophisticated algorithms that enable them to promptly sense user needs and provide intuitive services.

In the future, ICT technologies, especially sensors, IoT, and AI, will reshape our living spaces, from communities to buildings to homes. The result will be personalized living spaces that offer all kinds of new interactive experiences: a space that knows you as well as you know it.

At that time, your home may be full of smart appliances that bring a new level of interactivity to your lifestyle and entertainment. The building you live in may be supported by a great variety of smart control systems, and smart functions may be more widely available in your local community. However, none of this will be possible without connections that deliver high bandwidth and extremely low latency. Huawei predicts that by 2030, there will be 1.6 billion fiber broadband subscribers and 23% of homes will have access to 10 gigabit fiber broadband.

Huawei predicts that by 2030,

1.6 billion

fiber broadband subscribers.

23% of homes will have access to 10 gigabit fiber broadband.

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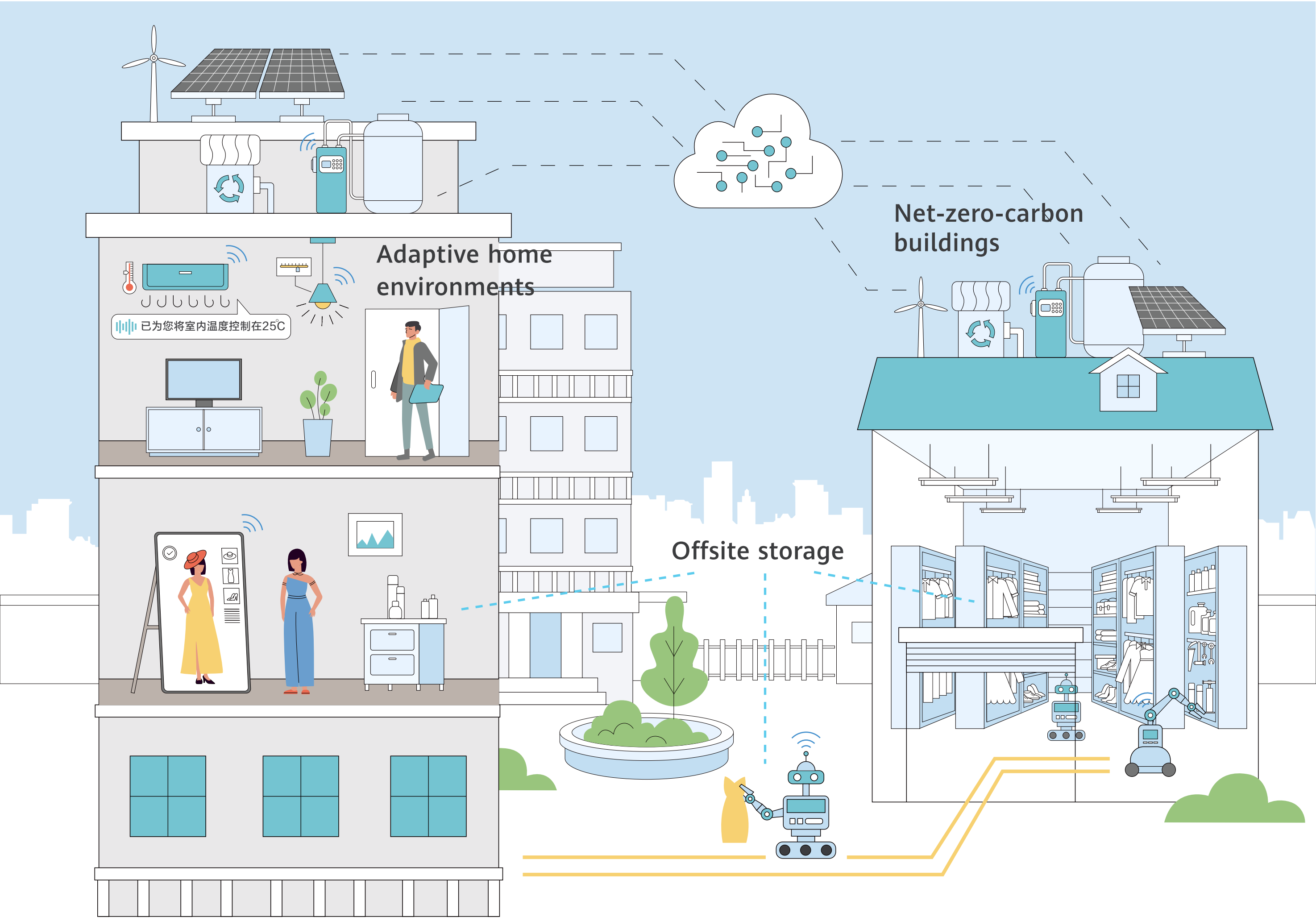

Net-zero-carbon buildings
Adaptive home environments
已为您将室内温度控制在25℃
Offsite storage

Transportation

Smart, Low-carbon Transport Opens up the Mobile Third Space

Travel is an important part of modern life, taking many forms, but particularly private cars. The US has long been known as a "nation on wheels", and in 2020, the vehicle-miles traveled across the US totaled 2.83 trillion miles[1], which is more than 30,000 times the distance between the Earth and the sun. In Europe, vehicles travel more than 12,000 kilometers a year on average[2].As urban areas keep expanding, more and more commuters face the challenge of a long daily commute. In China, more than 10 million people commute for over 60 minutes per day[3].And the trend is continuing: Car-based mobility, in terms of passenger kilometers and predicted vehicle stock, is expected to increase by 70% globally by 2030[4]. Clearly, existing transportation systems will continue to face many challenges.

More congestion, lower efficiency: Traffic jams are becoming increasingly serious and frequent worldwide. Studies have found that the average American commuter wastes 54 extra hours a year in traffic delays[5]. In Colombia's capital Bogota, the world's most congested city, drivers wasted an average of 272 hours in traffic jams during 2018[6], equal to more than 11 days. Congestion also causes significant economic losses. For instance, congestion caused losses of US$88 billion in the US in 2019[7].

Huge demand for travel also poses more serious challenges to the environment: According to the International Energy Agency (IEA), the transportation industry contributed 26% of global carbon emissions in 2020, far exceeding the manufacturing and construction industries. The adoption of circular economy practices combined with accelerated electrification in the automotive industry has the potential to reduce carbon emissions by up to 75% and resource consumption by up to 80% per passenger kilometer by 2030[8], accelerating low-carbon development.

Future transport will not only be congestion-free and low-carbon, but also hassle-free. Travelers will no longer need to think about their route, only about what to do during the journey. They will enjoy a quiet and personal space, where they can watch TV, concentrate on work, or even get an in-seat massage to relax. Commuters will no longer feel exhausted at the end of the journey, instead feeling a sense of satisfaction for making the most of their time. In order to realize these changes, transportation networks will need to be further upgraded. All of the key elements (vehicles, traffic lights, pedestrians, etc.) need to be connected using ICT technologies so that each phase of a journey can be automated.

Direction for exploration: Electric vehicles (EVs) for green transport

As transportation consumes increasing amounts of energy, many countries and regions around the world are making efforts to develop low-carbon travel. Energy saving and emission reductions in transportation have become the key to carbon neutrality. In July 2021, the European Commission officially launched the European Green Deal, specifying the goal of reducing greenhouse gas emissions by 55% by 2030 compared with 1990 levels, and achieving carbon neutrality by 2050. The Deal also proposes to reduce carbon emissions from transportation by 90% by 2050 compared with 2021 levels. Land transport is the focus of this policy as it contributes 20.4% of the EU's greenhouse gas emissions.

To save energy and cut emissions from land transport, countries are vigorously developing vehicles that use renewable energy, including pure EVs, plug-in hybrid EVs, and fuel cell vehicles. Many countries and regions have set timetables for reducing combustible fuel vehicles. For instance, the EU has set the goals of reducing emissions from passenger cars and vans by 55% and 50% respectively by 2030 (previous goals: 37.5% and 31%).
It has also set a new goal of ensuring that by 2035, all new vehicles sold will be zero-emission vehicles, which is equivalent to banning the sale of combustion-engine vehicles from 2035[9].
Japan plans to increase the share of EVs in domestic sales from 50% to 70% by 2030[10]. China has suggested that traditional fuel vehicles will be phased out of its market from 2030[11].

Snapshot from the future: Renewable energy boosts green mobility

The adoption of new energy vehicles in urban public transportation, including buses and taxis, started early and is now well-advanced in many cities. For example, every one of Shenzhen's 16,000 buses were electric by 2017, making it the world's first city with a 100% electric bus fleet[12]. In Europe, EVs make up over 78% of Denmark's new buses, and about two-thirds of new buses are emission-free in Luxembourg and the Netherlands[13].

There are two reasons for the fast progress in public transportation. First, public transport vehicles are replaced at a relatively fast rate, providing the opportunity to plan and quickly implement the adoption of EVs. Government subsidies plus efficient O&M solutions can also reduce the operating costs

of electric fleets to levels close to or even lower than conventional vehicles. These factors reduce the obstacles to introducing new energy vehicles.

Second, these publicly-owned vehicles are centrally stored and maintained in specialized facilities that can easily be upgraded into multi-functional spaces with charging piles for EVs. Therefore, the charging problem is not a major obstacle for the electrification of public transportation.

Public transport vehicles also travel longer distances every day and generate more carbon emissions than private vehicles. Therefore, the wide adoption of electric public transport is a highly efficient way of reducing vehicle emissions. In Beijing, for example, 71,000 private pure EVs saved 89 million liters of gasoline and 199,000 tons of CO_2 emissions in 2018. By contrast, just 9,400 electric taxis in Beijing made a similar contribution, saving 65 million liters of gasoline and 145,000 tons of CO_2 emissions[14].

According to the IEA, although the global automotive market shrank by 16% in 2020, following the COVID-19 pandemic, the number of newly registered EVs hit a new high of 3 million, up 41% from the previous year. The number of EVs in use worldwide in 2020 exceeded 10 million, and that strong momentum has continued. The sales of EVs in the first quarter of 2021 were almost 1.5 times higher than Q1 2020. Moreover, consumer spending on EVs grew by 50% in 2020, reaching US$120 billion, while government subsidies were just US$14 billion. Government subsidies as a percentage of the total spending on EVs have declined for five years in a row. This indicates that although government subsidies can stimulate the market, sales of EVs are increasingly driven by consumers' own choices.

The number of electric cars, vans, heavy trucks, and buses on the road worldwide is expected to reach 145 million by 2030. If governments accelerate efforts to achieve global climate and energy goals, then the global EV fleet will reach 230 million vehicles by 2030[15]. The IEA also predicts that more than 300 million EVs will be put into service by 2040, reducing oil consumption by 3 million barrels per day[16].

Snapshot from the future: Clean energy aircraft trials

The aviation industry is actively developing clean energy aircraft, both small local planes and larger passenger aircraft, in an effort to protect the environment, reduce pollution, and cut O&M costs. The continuous development of urban air mobility (UAM) is also driving the aviation industry to increasingly use electric power, setting it on a greener path.

In terms of carbon emissions, the aviation industry contributed about 2% of global anthropogenic CO_2 emissions in 2019. If such emissions are not effectively curtailed, this percentage is expected to increase to 25% by the middle of this century[17].

In terms of O&M and fuel expenses, global maintenance, repair, and operations (MRO) costs were US$69 billion in 2018, accounting for 9% of airlines' total operating costs. Maintenance costs for engines accounted for 42% (US$29 billion) of total MRO costs. Fuel costs for the global aviation industry were US$188 billion in 2019, accounting for 23.7% of total operating expenses. It is expected that MRO costs will grow to US$103 billion in 2028[18].

At present, three main types of clean energy aircraft are being developed: hybrid-electric, pure electric, and hydrogen-powered. In addition to improvements in increasing energy efficiency and reducing pollution and noise, clean energy aircraft also represent an opportunity to try new designs, such as blended wing body aircraft. This design can significantly reduce aircraft's drag and energy consumption, and improve flight performance. In addition, this design can increase the amount of space in the aircraft cabin, which is very valuable as it increases the aircraft's carrying capacity.

n June 2020, France announced an investment of EUR15 billion that included EUR1.5 billion for the development of large clean energy passenger aircraft. France plans to complete the maiden flight of the aircraft by 2035, and more than 1,300 companies in the industry will participate in the plan. For this, France has drawn up a clear roadmap which starts with a revamp of Airbus's A320 product line to develop a hybrid electric "successor" model to the A320. The prototype of this new model will be unveiled between 2026 and 2028, and make its maiden flight by 2035.

Direction for exploration: Autonomy opens up the mobile third space

From horse-drawn carts to modern cars, humans have developed many generations of vehicles to help us move faster than we could ever run. However, the upcoming autonomous driving era means that humanity will soon equip vehicles with their own brains. As an important factor for the way we travel, autonomous driving technology will reshape our travel experience, and thoroughly transform business models in the transportation industry.

As artificial intelligence replaces the human brain to make decisions for vehicles, drivers' hands, feet, and eyes will be freed during travel. This will enable new mobile entertainment, social engagement, shopping, and work scenarios on the road, turning vehicles into our mobile third space.

Autonomous driving technology is classified into six levels, L0–L5, by the standards of the US Society of Automotive Engineers and the US National Highway Traffic Safety Administration. Specifically, L0 refers to traditional human driving with no automation; L1–L3 include AI-assisted driving with low or moderate automation; and L4–L5 represent that a vehicle can be completely controlled by the AI system, with no human operation needed.

Autonomous driving technology involves multiple industries, such as ICT, manufacturing, and transportation. Its development requires cross-industry collaboration, which can in turn stimulate economic growth. After being deployed at scale, autonomous driving will significantly improve road safety and transport efficiency, and create positive social and economic benefits in terms of energy saving and emission reductions. Autonomous driving is expected to create about US$3.2–6.3 trillion in economic benefits for the US by 2050, leading to nearly US$800 billion in annual social and consumer benefits[19].

In the report titled On the road to automated mobility: An EU strategy for mobility of the future, the European Commission sets out the goal of making self-driving vehicles commonplace across the EU by 2030. The strategy states that the deployment of driverless mobility, when fully integrated in the whole transport system, is expected to contribute significantly to achieving the Vision Zero, i.e. no road fatalities on European roads by 2050[20]. In China, 11 ministries including the National Development and Reform Commission jointly issued the Smart Car Innovation and Development Strategy in February 2020. The strategy proposed to have conditional autonomous vehicles in large scale production and high-level autonomous vehicles commercialized for specific environments by 2025, and to build a mature, standardized intelligent vehicle system by 2050[21].

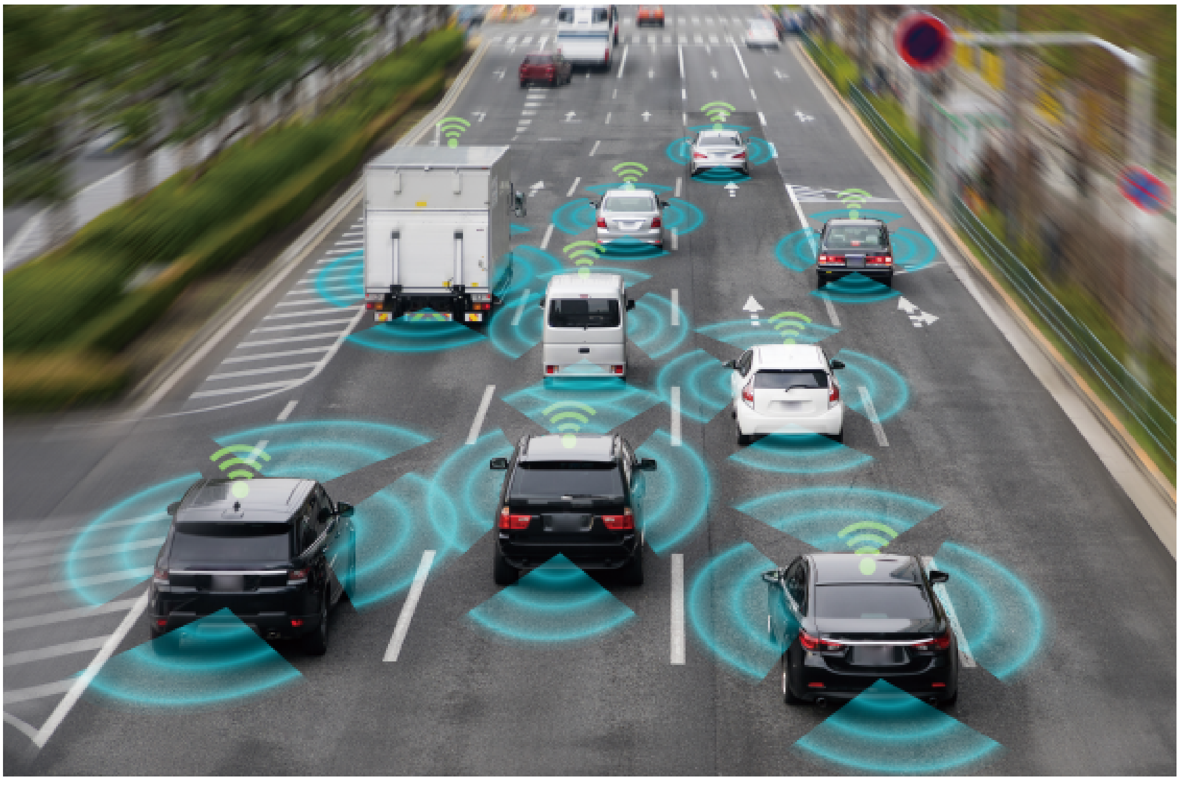
Snapshot from the future: Self-driving vehicles in the fast lane

Self-driving vehicles are achieving higher levels of automation, from L2 and L3 to L4 and L5. Buses, taxis, low-speed logistics, and industrial transport (logistics and mining) will be the first commercial applications of autonomous driving.

Low-speed public roads: Self-driving vehicles have delivered positive results in fields such as logistics and distribution, cleaning and disinfection, and patrolling. Unmanned vehicles for logistics and distribution can successfully drive at low speeds on roads with less complicated conditions. This means they can provide safe unmanned delivery services on public roads. Low-speed unmanned vehicles have provided valuable support during the fight against COVID-19, especially in the transportation and distribution of medical supplies, cleaning and disinfection, patrolling, and checking temperatures. These vehicles have proved their practical value, laying a foundation for their adoption in other markets.

High-speed semi-closed roads: Heavy trucks are expensive, so the price of sensors is not a limiting factor. Sensors such as lidar can be installed in these trucks for better sensing of their environment. Heavy trucks are mainly used in high-speed cargo transportation, ports, and logistics parks, which means the driving environment is less complex and routes are generally-fixed. Heavy trucks are rarely seen on complex urban roads. This reduces the complexity of the driving environment that autonomous driving systems have to handle. Truck drivers are expensive, and they frequently breach rules by overloading their vehicles and working overtime. So autonomous driving of heavy trucks would quickly help industries cut costs and work more efficiently, making this a compelling business case. According to a Deloitte report on smart logistics in China, technologies like unmanned trucks and artificial intelligence will mature in a decade or so, and will be widely used in warehousing, transportation, distribution, and last mile delivery[22].

Special non-public roads: Autonomous driving is playing an increasingly important role in environments like mines and ports. Some companies are working with ports to test self-driving container trucks. We have already seen unmanned trucks working in multiple fleets and even during night shifts at mines. At the Yangshan Port in Shanghai, 5G-powered L4 smart-driving heavy trucks can drive at speeds of up to 80 km/h, and the distance between vehicles can be shortened to 15 meters. Thanks to the centimeter-level precision of the Beidou GPS system, the vehicles can come to a stop within 15 seconds of a command, with an error of only 3 centimeters. The use of autonomous vehicles has brought a 10% improvement in vessel loading/unloading times[23].



With its high level of safety and efficiency, autonomous driving will first demonstrate its commercial value in mining. While working autonomously, many mechanical vehicles, such as mining trucks, excavators, and bulldozers can work together. In the past, one driver took care of each mining truck, but now a commander will take care of an entire group of trucks. In the event of a fault or danger, the commander can remotely pilot the vehicle to a safe area from the control center, and send warnings to nearby vehicles.

Public roads: Robotaxis are an obvious business model for self-driving companies, and are one of the best ways to get returns from their initial investment. According to one study, robotaxis could replace 63% of carshare and taxis and 27% of public transport[24].

Autonomous driving technologies will lead to more innovative changes in the designs of car bodies. All possible configurations will be explored and exploited. Cars can become the mobile third space, catering to many different scenarios. This will disrupt the business models of existing industries like catering. Self-driving food trucks may become the standard of the future, and dinner with friends and family may take on a whole new form: After you book a lunch, a self-driving food truck will pick you up and carry you along whatever scenic route you choose. You can enjoy the views while dining and chatting, all within a private space. This model would eliminate the need to visit restaurants and ensure privacy during the meal. For a restaurant, the size of the premises would no longer be a limiting factor for the size of its business, and location would no longer restrict the clientele it could attract. Business results could be disconnected from footfall.

Snapshot from the future: Urban air mobility

In the future, airspace will become an important resource for urban transportation. An efficient air-based urban transportation network will greatly free up roads, reduce travel times, and improve the efficiency of logistics and emergency services.

As defined by NASA in the Urban Air Mobility Airspace Integration Concepts and Considerations, safe and efficient air traffic operations in a metropolitan area for manned aircraft and unmanned aircraft systems consist of aircraft, a command and dispatch platform, a navigation and positioning system, a charging system, and a tarmac.

The development of electric vertical take-off and landing (eVTOL) aircraft has attracted investment from innovative companies around the world, and their performance has seen solid progress. Currently, four-seat aircraft made by several companies can deliver a cruising range of about 100 kilometers[25]. Some companies are working on eVTOL aircraft with seven seats or more[26]. Some are exploring hydrogen-fueled aerial vehicles[27] for longer ranges (more than 600 kilometers). These new aircraft may be used in various scenarios, including emergency medical services, urban air mobility (UAM), regional air mobility (RAM), freight transport, and personal aircraft.

Air emergency rescue systems: Over the past decade (2010–2020), skyscrapers have sprung up in major cities around the world. The number of skyscrapers will continue to grow over the next decade as global urbanization continues. The rapid rise of skyscrapers may make for impressive skylines, but they also create safety risks. Firefighting and emergency medical services in skyscrapers will be a new challenge for cities. Air emergency rescue offers a new solution to these challenges, allowing firefighters and medical personnel to better protect lives and property by quickly reaching higher floors to put out fires or assist people.

Air metro/air taxis: Convenient and efficient transportation is a core need of urban residents. Batteries with higher energy density are enabling electric aircraft to work longer and have a larger capacity. eVTOL will prove to be an effective tool to improve the urban transport experience. Pilot projects have begun for air passenger transport services. In 2019, a Chinese company launched the world's first urban air mobility service in Zhejiang, cutting road trips that normally took 40 minutes to a five-minute air hop[28]. According to NASA's projections, air metro will support 740 million passenger trips by 2030.

Of course, these scenarios require a fast and stable space-air-ground integrated network and positioning system, cost-effective and reliable visual sensors and lidar, secure and stable automatic flight algorithms, and an efficient, real-time command and dispatch platform.

Direction for exploration: Sharing vehicles for faster, low-carbon transport

When a centralized transport management system schedules the vehicles and resources, passengers can be provided with tailored mobility solutions based on their individual needs; at the same time, the vehicles will be used much more efficiently. The shared vehicle model avoids wasteful, carbon-intensive transport where a single passenger takes a vehicle to a single destination.

Snapshot from the future: Mobility as a Service (MaaS) available on demand

According to the International Road Transport Union, MaaS is to put the user at the core of transport services, offering them tailor-made mobility solutions based on their individual needs. MaaS is the integration of various forms of transport modes into a single mobility service accessible on demand. It combines all possible transport modes, enabling users to access services through a single application and single purchase[29].

The key objective of MaaS is to provide integrated and convenient public transport services and develop green transport. MaaS systems aim to integrate local transport (e.g. buses, rail, shared cars, and shared bikes) and intercity transport (e.g. planes, high-speed rail, and long-distance coaches) and provide useful local information like dining, accommodation, shopping, and local tourist attractions. These systems will build on the intelligent scheduling functions of public transport systems, and identify passenger travel models while prioritizing green transport. With online payment functions integrated, MaaS systems can offer travel booking, one-tap itinerary planning, seamless connections between different transport modes, and one-tap payments. MaaS will improve satisfaction with transport services while providing green transport options.

Many EU cities are building MaaS showcase projects. Different cities have different levels of integration in terms of facilities, fares, payments, information, communications, management systems, and transport services. Gothenburg, Hanover, Vienna, and Helsinki were the first cities to explore MaaS. These cities have made full use of digital technologies to optimize their transport systems, including buses, shared cars, bicycles, and urban deliveries. This will help them incubate emerging transport service providers and drive urban decarbonization[30].

MaaS can bring tangible benefits: Individuals can cut their transport costs while enjoying better safety and a better experience. Governments can optimize their investment in transport infrastructure for more sustainable urban management and higher citizen satisfaction. In addition, MaaS will create more opportunities for transport service providers, as they can cut service costs and expand their services. After MaaS is widely deployed, we will see integrated scheduling of transport resources, better shared resources, a user-centric experience, and low-carbon transport.

Direction for exploration: Connected vehicles for safer, faster,and larger-scale autonomous driving

Intelligent and self-driving vehicles that are unconnected face challenges in areas like target detection, trajectory prediction, and driving intention prediction, especially when visibility is limited or weather conditions are harsh. However, when vehicles are connected, there will be well-coordinated information exchange, sensing, and decision control. This will give each individual vehicle a much greater ability to sense what's around it. The introduction of new intelligent resources like high-dimensional data will make collective intelligence a reality. This means that the technical challenges facing individual vehicles in autonomous driving will no longer exist, and these vehicles will become safer, better drivers. As a result, the operation design domain (ODD) of autonomous driving will expand. ODD means the operating conditions under which a given driving automation system is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics.

Affordability is a major challenge in the large-scale commercialization of autonomous driving. High-level autonomous driving requires a large number of on-board sensors. Generally, an L4 self-driving vehicle requires 6–12 cameras, 3–12 millimeter wave radars, 5 laser radars, 1–2 global navigation satellite systems (GNSSs) or inertial measurement units (IMUs), and 1–2 computing platforms. This means that costs are high for each vehicle. If the vehicles are connected and supported by roadside sensing and scheduling, the cost per vehicle will go down. This is how intelligent vehicles will evolve, and the only way to deploy automated driving systems on a large scale[31].

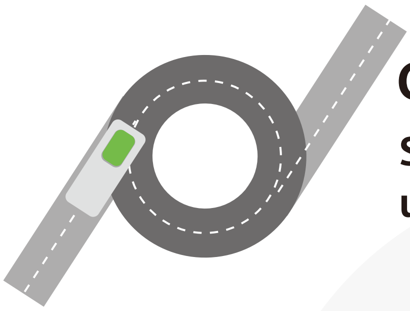
Connecting vehicles requires continuous network coverage. Currently, global mobile communications services cover only about 20% of the land area (land only covers 29% of the earth's surface), and less than 6% of the earth's surface. For example, more than 95% of the sea area of China is not covered by terrestrial mobile communications networks[32].So a space-air-ground integrated network is needed to provide continuous coverage. As in-vehicle and in-flight entertainment on large screens and holographic conferences are becoming more popular, terrestrial networks alone will not give users the consistent experience they demand in their entertainment and work. A space-air-ground integrated network will be needed to provide large bandwidth and high availability.

Snapshot from the future: Safer, more efficient dispatch services

In the past decade, pioneers have begun exploring the use of elevated rails to transport containers in busy ports. Containers are sent to rails similar to cable railways. The railway system dispatches the containers based on their destination and sends them to railway stations, truck warehouses, or even waterless ports in inland cities. This makes container transportation much faster at a very low cost. In the future, space-air-ground integrated networks will support the dispatching of unmanned vehicles and drones, providing safer and more efficient dispatching services for each vehicle and aircraft, and making large-scale autonomous driving a reality.

Snapshot from the future: Broadband in the air, just as at home

Moving forward, broadband coverage will extend beyond the ground into the air and beyond. Broadband connections will be available to devices at various heights, such as drones less than 1 kilometer above the ground, aerial vehicles 10 kilometers above the ground, and low-orbit spacecraft hundreds of kilometers above the ground. The integrated network will consist of small cells covering hotspots with a radius of 100 meters, macro cells with a radius of 1 to 10 kilometers, and low-orbit satellites with coverage over a radius of 300 to 400 kilometers, providing users with unbroken access to broadband of up to 10 Gbit/s, 1 Gbit/s, and 100 Mbit/s, respectively[33].



Conclusion：

Smart, low-carbon transport opens up the mobile third space

Future transport will be a multi-dimensional innovative system. The shift to electric, autonomous, shared, and connected vehicles will create an intelligent, convenient, low-carbon transport experience. To make this happen, we need innovative applications of new energy technologies; secure and stable autonomous driving algorithms; cost-effective, reliable sensors; a high-speed, stable space-air-ground integrated network; and a traffic management brain based on great computing power.

The mobile third space will reshape the transport experience, incubate innovative mobility services, and drive the emergence of new business models. An intelligent urban transport management system can optimize resource allocation, enable more efficient sharing of transport resources, alleviate traffic congestion, and reduce the environmental pollution caused by traffic. This is how we will resolve the conflict between the surging demand for transport and the urgent need to decarbonize.

Huawei predicts that by 2030, 50% of new vehicles sold globally will be EVs, and 20% of new vehicles sold in China will be autonomous vehicles. In addition, by 2030, the whole-vehicle computing power will exceed 5,000 TOPS, and 60% of new vehicles sold will support C-V2X.

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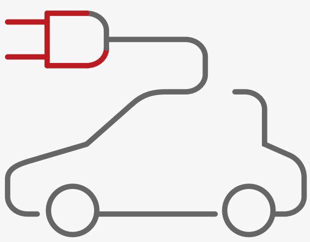
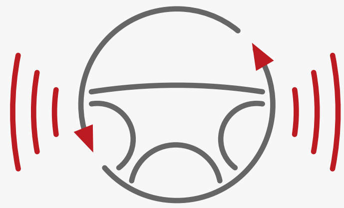
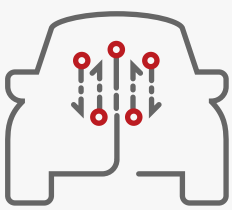


50% of new vehicles sold will be electric vehicles.



20% of new vehicles sold in China will be autonomous vehicles.



Whole-vehicle computing power will exceed **5,000** TOPS.

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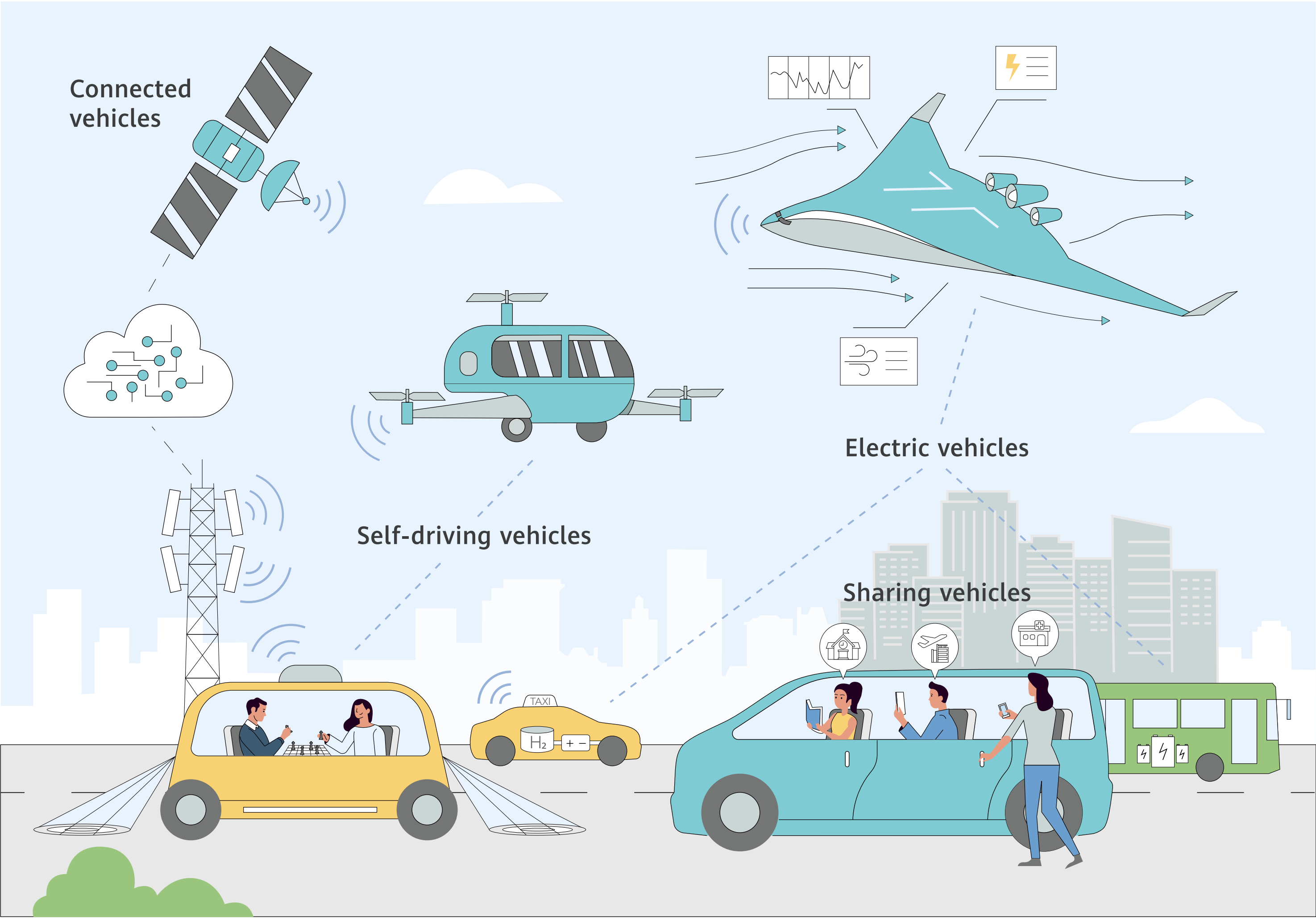
Connected vehicles
Self-driving vehicles
Electric vehicles
Sharing vehicles
TAXI

Cities

New Digital Infrastructure Makes Cities More Human and Livable

Urbanization is a global mega trend of this century. More than half of the world's population now lives in urban areas, and this figure is expected to rise to 60% by 2030.Take China as an example: Morgan Stanley projects that the percentage of China's population in urban areas could increase from 60% currently to 75% by 2030[1], translating into 220 million new urban dwellers[2].China will form five super-city clusters, such as the Guangdong–Hong Kong–Macau Greater Bay Area and the Yangtze River Delta[3]. In 2030, there will be 43 megacities with populations of 10 million or more[4].

As urbanization accelerates, cities worldwide will be forced to negotiate the contradiction between increasing size and limited resources. Typical urban problems, such as high energy consumption, pollution, traffic jams, and unequal access to digital infrastructure, will become even more pressing.

Urbanization is a global mega trend of this century. More than half of the world's population now lives in urban areas, and this figure is expected to rise to 60% by 2030.Take China as an example: Morgan Stanley projects that the percentage of China's population in urban areas could increase from 60% currently to 75% by 2030[1], translating into 220 million new urban dwellers[2].China will form five super-city clusters, such as the Guangdong–Hong Kong–Macau Greater Bay Area and the Yangtze River Delta[3]. In 2030, there will be 43 megacities with populations of 10 million or more[4].

As urbanization accelerates, cities worldwide will be forced to negotiate the contradiction between increasing size and limited resources. Typical urban problems, such as high energy consumption, pollution, traffic jams, and unequal access to digital infrastructure, will become even more pressing. According to UN-Habitat, cities consume about 75% of global primary energy and emit between 50% and 60% of the world's total greenhouse gases[5].

By 2030, the world is expected to generate 2.59 billion tonnes of waste annually[6]. Up to 53 million tonnes of plastic could end up in rivers, lakes, and oceans every year by 2030[7]. Another worrying statistic is that air pollution kills an estimated seven million people worldwide every year[8].

The conflict between growth and limited resources will be the biggest headache for cities. They will need to make the most efficient use of their resources. Rapid advances in new technologies, such as 5G, cloud, AI, blockchain, and intelligent sensing are opening up more possibilities for cities, which represent the best places to create and incubate new applications for these technologies.

Over the past decade or so, countries across the globe have been making their cities more digital and exploring ways to leverage technologies to support sustainable development. In 2020, nearly 1,000 exploratory smart city projects were underway worldwide. China was home to about 500 of these, with 90 in Europe and 40 in the US[9]. Global spending on smart city initiatives is increasing year by year. In 2020, this spending totaled nearly US$124 billion, an increase of 18.9% over 2019[10]. Advancing digital transformation has become one of the key pathways to sustainable development for the world's leading cities.

Direction for exploration: New digital infrastructure is the engine of digital cities

The unstoppable expansion of cities is putting great pressure on the environment and on our limited resources. The biggest challenge for the future of urban development is how to use technology to significantly improve urban governance. Cities need advanced, refined systems that deliver sustainability while minimizing resource use.

In the past, cities provided physical public infrastructure, including water, electricity, gas, and road networks, to support rapid industrialization. Moving forward, a major direction for exploration will be new digital infrastructure that supports the development of digital and intelligent urban systems.

We believe that new digital infrastructure will consist of four layers. The bottom layer is an intelligent sensing system that can accurately sense dynamic situations and the heartbeat of the city in real time. The second layer is intelligent connectivity. High-speed wired and wireless connections will connect the city, creating an organic whole. The third layer is an intelligent hub, which will serve as the city's "brain" and decision-making system. This layer aggregates massive data and enables city-wide data sharing so that AI systems can deliver the maximum possible value, making granular, data-driven, highly-automated city governance a reality. The fourth and top layer is smart applications. A comprehensive ecosystem of smart applications will be built on top of the digital infrastructure, covering the "last mile" of service delivery and creating infinite possibilities for smart urban growth. These four layers will interconnect and support each other, ultimately producing a smart city that embodies the new goal of ubiquitous intelligence.

Snapshot from the future: Nanosensors track the pulse of the city

Digital cities depend on data, which comes from a wide array of sensors scattered throughout the city. Just as people perceive their surroundings using their senses of sight, hearing, smell, taste, and touch, a city needs its own sense organs, deployed around the city, to sense what is changing. These sensors will provide the data that underpins the growth of a digital city.

The MIT Technology Review listed Sensing City as one of the 10 Breakthrough Technologies 2018. We believe that in the cities of the future, restricted sensing systems will merge into a comprehensive sensing network. Sensors across a city will be connected using a range of different transmission systems. Analytics using these massive flows of comprehensive data will generate a more accurate picture of the latest developments within a city. Breakthroughs and advances in sensing technology will drive leapfrog advances in sensing cities.

One particularly cost-effective and disruptive technology – nanosensors – is expected to drive the next revolution. Nanosensors have huge potential and can be deployed in massive numbers to form a wireless nanosensing network. This will greatly enhance a city's ability to sense, leading to major advances in climate monitoring, health monitoring, environmental protection, and other domains.

Nanosensors are very small and precise, and will vastly improve sensing performance. Working at the atomic scale, they are expanding our understanding of what sensors can be, driving new advances in sensor manufacturing, and opening up new fields of application. Early applications of nanosensors cover many different fields, including biology, chemistry, mechanics, and aerospace.

Graphene gas nanosensors are ultra-sensitive to odors. A nano-coating on the sensor's surface where it makes contact with the gas improves sensitivity and performance. The sensor collects odor molecules with a metal-organic film, and then amplifies the chemical signals using plasma nanocrystals. The most common application is for detecting carbon dioxide, but the sensor can also quickly detect hazardous and toxic gases. An American university has created a novel type of nano-coating using graphene, and when the coating is applied as a nanofilm on gas sensors, it delivers a 100-fold increase in molecular response compared to the best available sensors that use carbon-based materials[11].

In the near future, these sensors will be able to accurately identify hazardous, toxic, or explosive gases in the air, thereby greatly improving safety in scenarios like factories and at customs inspections.

Nanocrack-based acoustic sensors are able to recognize specific frequencies of sound. They are

more sensitive than other acoustic sensors, as the spacing between cracks in nanocrack-based sensors can be as little as just a few nanometers. Researchers build the sensor frame by adding a 20-nanometer-thick platinum layer to the surface of a viscoelastic polymer. When the platinum layer deforms and stretches, it pulls apart from the underlying polymer. Researchers then measure the conductivity of the sensor surface. In an environment with 92 decibels of noise, the nanocrack sensor performed far better than conventional microphones at separating out sounds in a given frequency range. For example, when these nanosensors are placed on the surface of a violin, they can accurately record every note of a tune and "translate" it so that a connected device can accurately recreate an electronic version of the tune. When this kind of sensor is worn on the wrist, it can accurately monitor a person's heartbeat. Breakthroughs in this technology will greatly enhance acoustic monitoring in urban infrastructure[12].

Snapshot from the future: All-optical, 10 gigabit cities

The digital transformation of cities will require massive flows of information. The newest generation of connectivity technologies, such as 5G, F5G, and gigabit Wi-Fi, is enabling high-speed networks with universal coverage in urban spaces. High speed information flows require optical networks. With optical networks as the foundation, cities will be able to merge their operational infrastructure into their communications infrastructure. As a result, new types of people-centered government services will be accessible and affordable to every person, home, and organization.

Several major cities have already conducted preliminary research into this area and found tentative signs that all-optical cities will unleash tremendous value and growth potential.

In April 2021, Shanghai became the world's first all-optical smart city. Owing to its F5G optical network, the city is able to deliver stable connections with latency below 1 millisecond anywhere in the urban area. The deployment of this high-speed optical network has laid a solid foundation for Shanghai's future digital transformation[13].

In Adelaide, Australia, 1,000 buildings are now connected to 10 gigabit networks. Companies in these buildings can access cloud services at a speed of 10 Gbit/s, creating huge opportunities for industries such as education, video, IT, and software engineering[14].

We believe that all-optical infrastructure will drive leapfrog improvements in the communications networks of future cities, in terms of capacity, bandwidth, and user experience: Uplink and downlink rates will reach 10 Gbit/s; latency will be reduced to microseconds; and the number of connections will see a 100-fold increase.

By 2030, many leading cities will have 10 gigabit connectivity, with 10 gigabit wireless services available to organizations, homes, and individuals.

The future architecture of an all-optical city will consist of four parts:

All-optical network access: All network connections will be optical, including homes, commercial buildings, enterprises, and 5G base stations. The all-optical transmission network will be extended into edge environments like large enterprises, commercial buildings, and 5G base stations. This will enable the digital transformation of many different industries, and support the development of F5G+X and 5G2B industrial applications.

All-optical anchors: Connections originating in home broadband, enterprise broadband, 5G networks, or data centers will be routed and transmitted through all-optical networks; optical networks will support multiple different fixed access technologies and provide one-hop connections to the cloud.

All-optical switching: One-hop access to services through urban optical networks. All-optical cross-connect technologies are used to build multi-layer optical networks that support one-hop access to services; high-speed inter-cloud transmission; and high synergy between cloud and optical networks.

Fully automated O&M: Real-time sensing of network status with proactive, preventive O&M. This supports elastic network resources, and automated service provisioning, resource allocation, and O&M.

Snapshot from the future: Intelligent hubs cut out the human factor from urban management

During the digital transformation of cities, data barriers will be broken down, and all data will ultimately form a single data lake. AI will play an increasingly important role, and many public service and regulatory issues will be decided by expert algorithms instead of being left up to human judgment. Narrow AI applications will expand until they can deliver data-driven wisdom for all city governance scenarios.

Technological advances are driving important changes in the approach to city governance. For example, there is a shift from reactive services to proactive services, from broad-brush to granular regulation, and from post-hoc response to real-time response and even incident prediction and prevention.

These changes will pose new challenges: For example, AI will lead to the creation of new regulatory authorities. Supported by massive data and the superior performance of algorithms, AI will itself become a part of city governance, and will then use its position to drive further changes. AI will be integrated into more and more sectors of government, connected to all the various sensors deployed across the city, so that it can support the accurate and efficient provisioning of urban resources. AI ethics and the principles of humanism and fairness must be constantly deployed to correct any deviations as the technology evolves.

Huawei believes that as the goals of city governance evolve, cities will need powerful, intelligent hubs. These hubs will help us overcome the challenges of technology, and will aggregate data and support applications. They will also have the capacity to iterate and improve themselves. These hubs will aggregate massive amounts of data from every corner of a city, and mine that data for insight to support better city governance. This will benefit every industry and greatly improve the efficiency of city governance and the experience of users of government services.

Early-stage explorations by Toyota: In Toyota's plan for the city of the future, each house, building, and vehicle will be equipped with sensors. Data from these sensors will then be aggregated into a city's data operating system, through which people, buildings, and vehicles are all connected. When the data is aggregated to the intelligent hub, AI will be used to analyze people's surroundings and then guarantee the safety of pedestrians and drivers by keeping them separated. In addition to new technologies like indoor robots, citizens can use AI to check their health at home. Wearable medical sensors for home use will transfer data to the data operating system, which will provide instructions for healthcare[15].

Snapshot from the future: Smart ecosystems spread intelligent services across all use cases

When cities have ubiquitous, high-speed connectivity, intelligent hubs, and massive, real-time data from city sensors, smart applications will emerge in every aspect of urban life. Starting with government services, AI will expand to industry support and smart lifestyles. The key to this process will be an ecosystem for innovation in smart applications that bridge the last mile in citizen services. These services will be vital to unleashing the value of new digital infrastructure.

Some major cities are already early adopters of this idea. In China, Huawei has partnered with Guangming District in Shenzhen to build a green, all-optical, smart district as a showcase. Once kicked into full gear, this project will accelerate the innovation in services to key urban industries, such as smart manufacturing, life sciences, and optical networks.

Huawei and Guangming will build China's first innovation center for life sciences and intelligent manufacturing. It will include two service platforms – EI Health and Fusion Plant. By bringing together both upstream and downstream players to serve their respective industries, Huawei and Guangming will accelerate their modernization and use of AI.

The industry platforms will provide services to support business innovation: a powerful public cloud computing platform and massive storage. For the life sciences, they will provide trained algorithms for image analytics, gene analysis, and drug R&D data analytics. For manufacturers, they will offer industrial Internet services. This will accelerate digital transformation for biomedical and industrial enterprises, and support the emergence of smart applications and application providers.

Thanks to new digital infrastructure, cities will be able to create their own smart innovation ecosystems. These ecosystems, in turn, will take advantage of infrastructure to bridge the gaps in digital innovation. We expect to see the ecosystems serve industries and the industries give back to and nurture the ecosystems. This will unleash the tremendous value of digital infrastructure across cities, benefiting countless industries. Smart ecosystems are key to spreading intelligent services across all use cases.

Direction for exploration: Smart government services make cities more human

In China, accessing government services used to involve many visits to different agencies and administrative departments. Today, most Chinese cities have government service halls and most government services can be delivered within a single hall. Since the outbreak of COVID-19, more government services have been delivered through smartphones, and most people no longer even need to visit service halls.

Government service designed for people is an approach being progressively implemented in China and certain leading cities worldwide. At the same time, emerging technologies such as cloud, AI, and blockchain are all evolving. What will these developments bring to cities? They can guarantee swift and easy access to government services and make our cities friendlier places to live.
This is one of the major directions of development for our cities.

Snapshot from the future: Proactive, precise provision of government services

Machine recognition technology makes contactless services possible. Today, in most of China's developed provinces, citizens do not need to go to government offices to access government services. They can now access them directly through their smartphones. Over the next decade, the digitalization of government services will be taken to the next level.

1. Digital identity authentication will be widely adopted. The ID cards, drivers' licenses, social security cards, and bank cards that people carry at all times will be digitalized. It is estimated that the total addressable market for global electronic identity authentication services will be worth US$18 billion by 2027[16].

2. Digital credit will underpin and restructure many public service processes and the customer experience. It will be one of the founding technologies for digital government. Most citizens are already familiar with forms like electronic library cards, social security cards, and car rental services that require a credit rating. As these services continue to improve, they will deliver a better experience to millions of citizens.

3. Universal access to one-stop, e-government services will soon be realized. In the future, all government services will be remotely accessible and government service halls may cease to exist. Technological advances will give rise to new digital government practices and government services. Today's centralized digital government model is a great example. In many Chinese cities, the local government has created a single

network. This model uses big data and IoT, and enables complex operations involving multiple different departments, regions, and levels of government. It offers an architecture that addresses the needs of the municipal government and of local residents. In the future, as governments aggregate more massive data and their AI technologies mature, they will be able to deliver government services in a more precise and proactive way; manage their municipalities more efficiently; and improve their service experience.

Let's look at smart care for the elderly as an example. Communities in Shanghai have installed smart water meters for elderly people who live alone and agree to the installation. If the total water used within a 12-hour period falls below 0.01 cubic meters, the meter will send an alarm to the central network and community workers. These workers will then visit the elderly person in question to check whether everything is normal. Such attentive care demonstrates a real human touch and concern for the elderly[17].

Snapshot from the future: Blockchain-based data sharing

Data is the most important element in the digital transformation of cities. However, data sharing services have been confined to a single center, which is not conducive to broad sharing or openness. There are also many other challenges, including data security risks during data exchanges, flaws in standards and specifications, information silos, and inconsistent solutions for data access control, encryption, and access audits. Together, these challenges make it difficult to share data effectively between government departments or between governments and private companies.

Blockchain technology can be fully integrated with emerging information technologies such as cloud computing, big data, and AI. It offers a solution to the problems of trust in data transmission, sharing, and use that arise in digital cities. Blockchains are maintained by multiple parties, and use multiple cryptographic technologies to ensure secure transmission and access. They meet the needs of many different government data applications. Blockchain technology uses hash pointers to prevent data tampering, and is a secure and trustworthy medium for data sharing. In a complex service environment such as digital government services, blockchain could be used to establish trust among government departments and dramatically increase the efficiency of data sharing.

The application of blockchain as a base technology in digital government will support the provi-

sioning of government services. We can examine how the technology could be used in different scenarios. Clear use cases include information infrastructure, smart transportation, and energy sectors such as electricity.Dubai is one of the world's fastest adopters of digitalization. This city is applying some of the most innovative ideas to real-world scenarios, aiming to become a smart metropolis powered by blockchain. Within its smart city program, one pilot initiative is garnering much public attention. The initiative in question plans to use blockchain technology to track, transport, and deliver import and export goods. By integrating this initiative into the city's administration of foreign trade.

Dubai plans to create a secure and transparent platform. This blockchain-powered system will give a huge boost to document processing efficiency and is predicted to save US$1.5 billion and 25.1 million working hours. Once this system is launched, citizens will no longer need to wait in long queues to access government services[18].

Direction for exploration: Intelligent environmental protection for livable cities

The growth of a city always puts pressure on the environment. Cities cause air pollution, carbon dioxide emissions, solid waste, and water pollution. Infrastructure for protecting the environment usually lags far behind the economic development and population growth of a city. Therefore, a key aspect of constructing future cities relates to addressing the conflict between city growth and the environment. This leads us to examine how digital and intelligent technologies can be used to protect the environment more efficiently and make cities more livable for every resident.

Snapshot from the future: Automatic waste disposal makes zero waste cities

Cities produce huge amounts of solid wasteevery-day, and effective waste disposal has always been a daunting challenge for city administrations. The zero waste city is a concept that emerged from building innovative, green cities, and sharing the benefits of city development. Under the zero waste city initiative, cities will grow and live in a green way, reduce solid waste, use resources more efficiently, and minimize the impact of solid waste on the environment.

"Zero waste city" initiatives have been launched around the world. For example, the European Union (EU) has kicked off the European Green Deal. Key elements of the waste proposal in this deal include:

·A common EU target for recycling 65% of municipal waste by 2030;

·A common EU target for recycling 75% of packaging waste by 2030;

·A binding landfill target to reduce landfill to a maximum of 10% of all waste by 2030;

·A ban on landfilling of separately collected waste;

·Concrete measures to promote re-use and stimulate industrial symbiosis – turning one industry's by-product into another industry's raw material[19].

The C40 Cities issued an Advancing Towards Zero Waste Declaration, pledging to achieve zero waste cities by:

·Reducing municipal solid waste per capita by at least 15% by 2030 compared to 2015;

·Reducing the amount of municipal solid waste disposed through landfills and incineration by at least 50% by 2030 compared to 2015; and

·Increasing diversion away from landfill and incineration to at least 70% by 2030[20].

In 2019, China started piloting its zero waste city initiative in 11 + 5 cities[21], exploring ways to construct a solid waste classification and recycling system.

With countries setting goals to construct zero waste cities, solid waste processing technologies and innovations are set to develop rapidly, generating many new methods and best practices in this sector.

The Songdo Smart City Hub in South Korea has introduced an automated waste disposal system[22], which uses negative pressure to suck domestic waste to a waste processing center through underground pipes. In Malaysia, a company has developed a waste disposal system that transports municipal or domestic solid waste through underground pipes at high speeds, taking the waste from waste chutes and outdoor load stations into sealed containers located up to 2.5 km away. Once the containers are full, they are collected at specific times by a flatbed armroll truck. This system dramatically speeds up the entire waste collection process whilst reducing manpower.

A company in Europe has developed an automated waste sorting robot. Powered by AI, this robot can automatically identify different types of waste on a conveyor belt, classify the waste as required by customers, and then process and recycle the waste. The robot can sort waste several times faster than a normal worker and can work 24/7, significantly speeding up the entire waste sorting process. In the future, with the help of such intelligent waste sorting robots, waste sorting in cities is set to be much faster, as it becomes fully automated and unmanned.

With the help of AI, the entire waste management process in a future city, from collection and transportation to sorting and processing, will be automated and intelligent. Intelligent waste recycling bins, driverless garbage trucks, automated waste sorting robots, automated garbage recycling devices, and other innovative applications will emerge one after another. Hopefully, this will help to make more and more zero waste cities possible.

Snapshot from the future: Optical detection makes water sources safer

The uneven distribution of water resources and water pollution have long been problems for cities. Many face water shortages. At present, slightly less than one half of the global population, amounting to about 3.6 billion people, live in areas that suffer from water scarcity at least one month each year[23]. Industrial wastewater and agrochemical water pollution are far more serious today than in the past.

The management and use of water resources in most cities worldwide is still split across several different industrial sectors, siloed, and lacks any kind of overview. In the future, cities will need to properly manage their full water cycle, from intake and use to discharge. A holistic, AI-managed system will be introduced to manage water resources, while cities rebuild their water facilities.

An AI system will be able to maximize the use of water resources within a city by refining every stage of water intake, use, and discharge, using forecasts for the weather and water consumption.

This process will also involve precise, scheduled use of water resources and a reduction in the total energy consumed.

Water quality monitoring, especially regarding the treatment of industrial wastewater, is another key concern for the conservation of city water resources. The latest technologies can be applied in this sector. Wastewater often goes through a chemical treatment process.

However, this approach usually takes a long time and has many restrictions. In contrast, a new optical detection technology does not suffer from any of the drawbacks of chemical treatment.

Each substance produces a unique spectral pattern. Leveraging this feature, the new technology could be used to monitor water quality in real time throughout the entire process, detecting wastewater whenever it is present.

A research team in the US has developed optical sensors to detect sewage contamination in the Great Lakes. Statistical relations between optical properties and genetic bacteria markers will be used to calibrate field sensors for the detection of sewage contamination, including the sources and timing of contamination[24].

Optical technologies can also be further integrated with analytics from the IoT, AI, and cloud computing. Sensors for water quality and deep data analytics will move us closer to 24/7, efficient, real-time, automated, intelligent water quality monitoring. This will provide quick warnings in cases of water contamination.

Optical technology can be used alongside AI to explore the hidden relationships between water quality parameters and treatment processes, so as to upgrade and transform urban sewage treatment processes more methodically.

We will thus form a closed loop of prevention, control, monitoring, treatment,
and better prevention.

Snapshot from the future: Real-time AI air quality monitoring

Over recent years, air pollution has posed an increasing threat to people's health, and urban air quality is attracting more attention than ever before. According to the World Health Organization, nearly 90% of cities worldwide fail to meet its air quality standards. This problem is currently only getting worse. Industrial exhaust, coal burning, automobile exhaust, and other types of air pollution have all become major challenges to public health.

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and urban air quality is attracting more attention than ever before. According to the World Health Organization, nearly 90% of cities worldwide fail to meet its air quality standards. This problem is currently only getting worse. Industrial exhaust, coal burning, automobile exhaust, and other types of air pollution have all become major challenges to public health.

Most cities will opt to deploy cost-effective and reliable air quality sensors and build a monitoring network. This way, they can monitor air quality and weather across the entire city and take targeted measures to improve air quality and the urban environment. One company has developed a highly-integrated, real-time air monitoring system[25].The integrated sensors and software can monitor the concentrations of environmental pollutants in urban environments, such as PM2.5, PM10, CO, NOx, SOx, and O_3, as well as other environmental parameters such as noise, temperature, humidity, air pressure, rainfall, and floods. Data is transmitted to the cloud platform in real time through wireless connections. The cloud platform provides a real-time visual dashboard for clear monitoring and management of the overall environment in key areas of the city.

In the future, we can consider integrating sensors with AI. Supported by machine learning, sensors will be trained to detect their surroundings and make preliminary judgments regarding potential changes. This intelligent upgrade of sensors will substantially improve the ability of cities to automatically sense environmental changes in real time.

The use of AI-powered sensing technology in the fight against COVID-19 is a prime example of how the technology can be applied. Every time a person exhales, small droplets are released into the air. If someone is infected, droplets in the air can transmit the virus to others. The lower the humidity or temperature, the longer the infectious aerosol can stay in the air and the higher the probability infecting another person. An AI sensing system can monitor volatile organic compounds, humidity, and air temperature, and determine whether the environment is conducive to virus transmission. In addition, the system can automatically and centrally control ventilation and air conditioning systems to reduce the risk of infection.

Novel applications in this sector will boost the ability of cities to monitor and improve air quality and simplify the process of managing our atmospheric environment.

Conclusion:

New digital infrastructure makes cities more human and livable

ICT technologies like 5G, optical networks, AI, cloud, and blockchain will all be rolled out rapidly over the next decade. Cities will soon welcome a period of 10 gigabit connectivity, with 10 gigabit wireless services becoming available to organizations, homes, and individuals. Huawei predicts that by 2030, 40% of companies and 23% of homes worldwide will have access to 10 gigabit Wi-Fi networks.

The application of these ICT technologies in cities will significantly boost our ability to make use of limited resources, to manage our cities efficiently, and to give citizens a positive experience. ICT technologies will help cities achieve their sustainable development goals, and make our cities more human and livable.

Huawei predicts that by 2030,

40% of companies will have access to 10 gigabit Wi-Fi networks.

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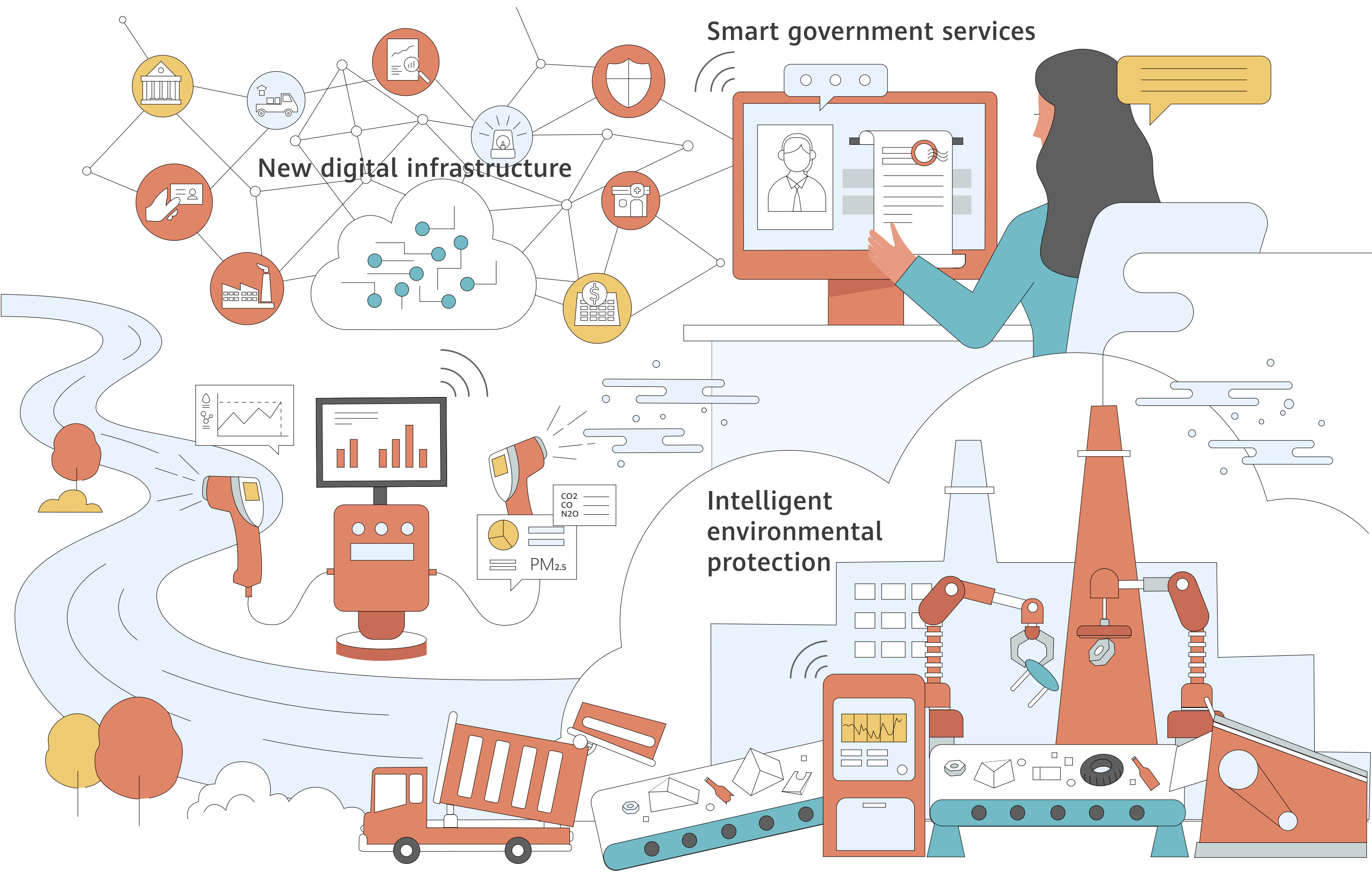
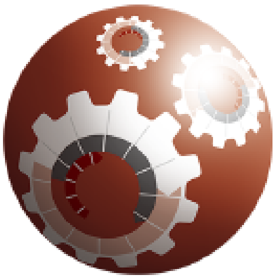

Smart government services
New digital infrastructure
Intelligent environmental protection
CO2
CO
N2O
PM2.5

Enterprises

New Productivity,
New Production Models, New Resilience



Over the next decade, the world's population will age significantly and irreversibly. According to a report published by the UN[1], the global population aged 65 and over is projected to exceed 12% of the total population by 2030, while the global population aged under 25 will decrease from 41% in 2020 to 39% in 2030.

Population ageing will lead to a huge worldwide labor shortage. By 2030, we can expect a deficit of 85.2 million workers around the world – more than the current population of Germany[2].
The size of the workforce is an important factor in economic growth for every country.
Take manufacturing for example. By 2030, this sector is estimated to face a global labor shortage of 7.9 million workers, leading to unrealized output of US$607.14 billion[3].

Consumer demand is set to become much more diverse, which will profoundly change production models, forcing businesses to innovate.

Companies that aim to grow and expand their business will need to capture, stimulate, and nurture the increasingly diverse consumer demand. Companies of the future must rapidly respond to new consumer demands by launching products with innovative functions. For example, as the "singles economy" gains traction, companies can rapidly adjust their products by targeting solo dining, small home appliances, and mini karaoke booths. In addition, companies need to take the initiative and stimulate demand through emotional appeal, and rapidly produce combinatorial designs for product appearance, images, and implications. For example, they can customize limited-edition products or launch co-branded products within the shortest time possible.

Black swan events pose new challenges to business continuity. For example, the global spread of COVID-19 has had a negative impact on the economy, resulting in factory shutdowns, material shortages, and disruptions to global logistics and supply chains. Due to the pandemic, it is estimated that global GDP suffered US$3.94 trillion in lost economic output in 2020[4]. According to a survey by McKinsey, although economic recovery is gaining momentum in many parts of the world, supply chain disruptions are the most-common risk to company growth, which respondents now say pose a greater risk than when asked in prior surveys[5]. Therefore, determining how to enhance supply chain resilience is now a vital challenge that companies must take very seriously.

Direction for exploration: Bringing unmanned operations to manufacturing and services to make up for labor shortages

In order to expand, companies need to promptly seize business opportunities. When they receive a large order, they must quickly expand their production capacity.

However, more and more companies are missing out on opportunities due to labor shortages. This is where new forms of productivity come in.

People are also trying to introduce new forms of productivity to help solve chronic issues in education, healthcare, and many industries, such as unequal distribution of resources and shortages of professional talent.

Snapshot from the future: Collaborative robots

Collaborative robots are a type of industrial robot. They were initially designed to meet the customized and flexible manufacturing requirements of small- and medium-sized enterprises, and perfectly align with the development trends of the manufacturing industry. Collaborative robots are suitable for jobs that people are unwilling to do, such as highly repetitive work like sorting and packaging. Collaborative robots have several unique advantages:

Safer: Collaborative robots are compact and intelligent, and their sophisticated sensors enable them to stop in an instant. Unlike traditional industrial robots, collaborative robots do not need to be isolated by physical fences. The scope of their movement is restricted by virtual digital fences. This means they can be placed at any

location along a production line on demand, and work closely together with human workers on the production line to get the work done.

Faster and more flexible deployment: Traditional industrial robots require professionals to plan and program their movement paths and actions, so they take a long time to deploy and are very costly. In contrast, collaborative robots feature user-friendly programming, such as programming by demonstration, natural language processing, and visual guidance. They can be placed in new positions at any time, and programing and commissioning can be completed rapidly, so they can start working very quickly.

Lower total cost of ownership (TCO) and shorter payback period: The price and annual maintenance cost of collaborative robots are significantly lower than those of traditional industrial robots. According to China's Forward Industry Research Institute, the average selling price of collaborative robots has halved over the past several years[6]. As collaborative robots are adopted more widely, their price will fall even further, meaning that investment in these robots will quickly turn cash flow positive.

Collaborative robots are currently most widely used in the manufacturing of computers, communications equipment, consumer electronics products, and automobiles. They are also starting to be used in the medical industry for analysis and testing, liberating medical professionals from repetitive and time-consuming procedures (e.g., urinalysis) and reducing the risk of infection among medical workers by taking care of tasks like throat swabs.

Snapshot from the future: Autonomous mobile robots

Autonomous mobile robots (AMRs) are a key enabler to help the manufacturing industry become flexible and intelligent. They will reshape the production, warehousing, and logistics processes.

AMRs generally need rich environmental awareness. They feature dynamic route planning, flexible obstacle avoidance, and global positioning. The AMRs used in industrial manufacturing and logistics are mainly powered by the simultaneous localization and mapping (SLAM) technology to enable autonomous navigation. Their environment does not need to be tagged to enable them to navigate[7].

On production lines, AMRs make automated and unmanned logistics possible. This includes unmanned execution; unmanned interaction between AMRs and other equipment for material collection, feeding, and unloading; and unmanned material handling.

In warehouses, AMRs implement goods-to-person picking, executing intelligent picking, movement, and stock-in and stock-out procedures. In this model, the control system receives an order and assigns an AMR, which then lifts the shelf containing the required goods, moves it to the operator console, and unloads the goods to complete the order. After picking is completed, the robot moves the shelf back to its original position.

The distribution and picking of materials are not confined to factory buildings; AMR systems can be expanded to an entire campus. For example, when goods are unloaded, robots can automatically move them into their designated warehouse. Goods will be automatically logged into and out of warehouses, and the movement of goods between factories or warehouses will be automatically registered. These functions require the robots to support outdoor autonomous navigation, using features such as laser navigation, visual navigation, and satellite positioning.

Snapshot from the future: AI-powered adaptive teaching

Conventional education uses the same model to deliver the same course content to different students. AI can transform this industry. It analyzes learning models and individual differences between students. This improves the quality of education and makes it possible to teach students in accordance with their aptitudes.

For example, as technologies such as big data, cloud computing, Internet of Things (IoT), virtual reality (VR), and augmented reality (AR) evolve, AI-assisted education will break down learning and teaching behavior in a more granular way and build more robust and precise education models. VR and AR technologies can be used to present materials in a more engaging way and deliver interactions that suit students' personal preferences, helping students better master their course content.

AI liberates teachers from the repetitive and tedious grading of exam papers and administration, allowing them to focus on the creative work of educational research and one-to-one communication with students. With the support of huge amounts of data generated through educational activities, AI will help teachers better understand the educational needs of their students, and provide key recommendations on the most effective teaching methods and the best way to organize course content.

In schools, AI can be deployed anywhere, and can simulate the best teachers of every subject, bringing the highest-quality education and content to the most remote schools. AI-based education offers multi-channel engagement with students, including video and audio, which can help make up for the scarcity of teaching resources in some areas (for example, in understaffed schools, a teacher may have to teach four or even five different subjects). In this way, AI promotes educational equity[8].

Direction for exploration: Bringing unmanned operations to manufacturing and services to make up for labor shortages

The role of consumers in the production process is changing remarkably. Consumers are being given more say in upstream activities, and can engage in more and more steps during the production process. Under the old model, large-scale production is the norm, where companies design and manufacture products on their own, and consumers can only choose what they want from a range of finished products. With companies now better understanding what consumers really want, they offer more and more product categories to provide consumers with more choices, but this often results in overstocking.

New models such as e-commerce and livestreaming enable companies to more directly and accurately assess customer demand and promptly adjust the size of their production runs to avoid overstocking. Companies can even plan how many resources they will need in advance to avoid overcapacity.

In the future, consumers will become directly involved in design processes. They will be able to express their opinions and even make design decisions. For example, modular designs in the flexible manufacturing process can allow consumers to mix and match and decide on the form factors or style of the products they want. Companies only start production once the customer has made their choice. This means the whole production model will become truly personalized. As modular manufacturing offers more options, consumers will be given more freedom to choose exactly what they want, ultimately leading to a fully personalized production model.

Snapshot from the future: ICT-powered flexible manufacturing

To respond to changing market conditions and set themselves apart in the face of fierce competition, companies must take the initiative and embrace new production models. That's why an increasing number of companies are looking to concepts like flexible manufacturing.

Flexible manufacturing is an advanced production model characterized by on-demand production. It helps companies become more flexible and enables them to rapidly respond to ever-changing market demand. In addition, flexible manufacturing shortens the R&D cycle, cuts R&D costs, and ensures equipment is not left idle, while reducing inventory risks and speeding up capital turnover. Therefore, it allows companies to seize market opportunities and grow sustainably. Flexible manufacturing involves the following areas:

Flexibility of product design and production line planning: After receiving an order for a new category of product, companies need to quickly conduct R&D and design, and rapidly adjust factors such as production line equipment, working procedures, processes, and batch size. This is where ICT comes in. Simulation, modeling, VR, and other ICT technologies can be used to simulate the entire new manufacturing process. This will reduce the cost of new product development and design, and support more accurate adjustment cost projections and capacity projections.

Flexibility of process: In flexible manufacturing, companies can design products based on the personalized needs of customers, or invite customers to directly participate in product design (e.g., using modular systems to enable customers to define what a product will ultimately look like). Both models require an intelligent scheduling system. The system makes automatic adjustments and provides an optimal production plan based on known features such as the factory's production capacity, order complexity, and delivery deadlines.

After a company receives an order, the scheduling system will automatically identify all universal components, custom components, and procedures and materials required to manufacture these components. By coordinating production tasks and the provisioning of materials and tools, this

scheduling system maximizes the productivity of all equipment and workers in the factory so that no component will become a bottleneck in order delivery.

Flexibility of equipment: As the number of customizations and small-batch orders increases, factories must be able to switch between production processes in real time. Conventional manufacturing equipment can generally only be reconfigured by trained engineers using specific programming devices and languages. This makes switchover processes time-consuming, and does not support the kind of rapid responsiveness that companies need. In the future, ICT technologies such as visual programming, natural language interaction, and action capture will help factories reprogram equipment quickly and easily. This will help companies promptly meet consumer demand for flexible manufacturing.

Flexibility of logistics: One of the keys to flexible manufacturing is modularization, through which a large number of finished components are manufactured. This requires automated ICT technology to effectively manage warehousing and logistics, which prevents omissions and other errors in the shipment process. Take furniture producers as an example. With large-scale customization, every board, decorative strip, and handle may need its own identification code or radio frequency identification (RFID) tag to facilitate automated packing and loading, and to support traceability throughout the whole transportation and distribution process.

Traditional manufacturing followed a "product > place > people" model that forced sales to start with the site of production. As manufacturing becomes flexible, we can reverse that model to "people > place > product" so that production is based on demand, or even reduce it to a "people > product" approach. This will create a new, truly "people-centric" production model.

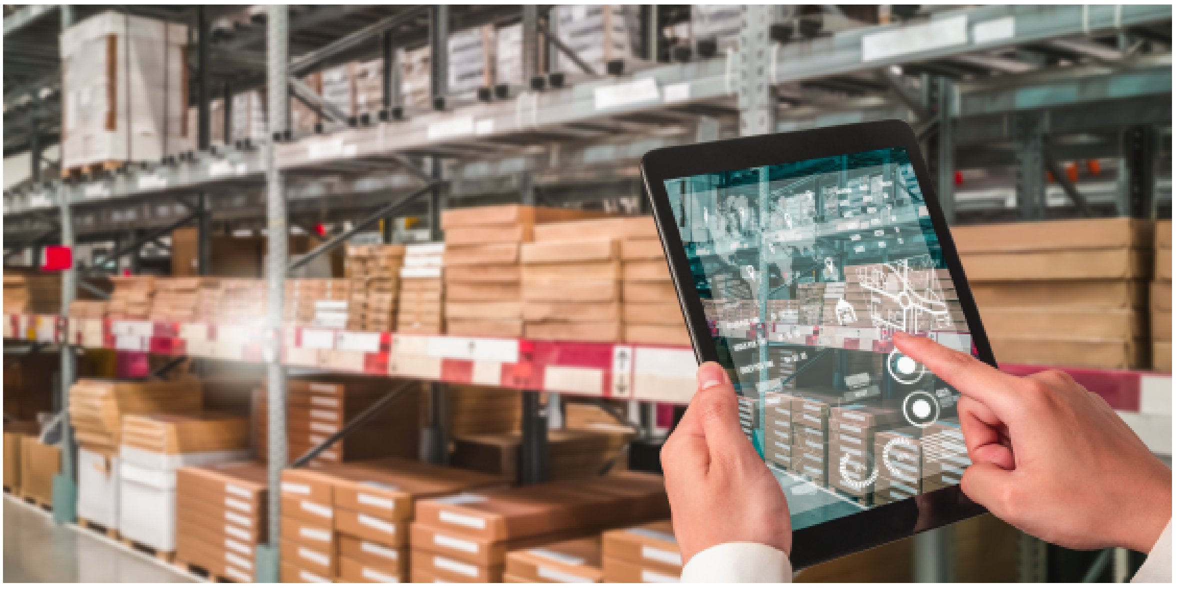
Direction for exploration: Resilient and intelligent supply chains that help enterprises respond to crises

Recent years have seen frequent black swan events, which pose new challenges to the traditional supply chain. Facing constant uncertainty, companies want to consolidate their supply systems to enhance their resilience and ensure business continuity. A global supply chain survey conducted by Allianz Research found that 94% of companies reported disruptions to their supply chains because of COVID-19, and 62% of companies said they were considering looking for new suppliers in the long term[9], more and more companies regard building a resilient and intelligent supply chain as one of their most important strategic priorities.

Snapshot from the future: Supply chain visualization powered by digital technologies

Supply chain visualization is about using ICT technology to collect, transmit, store, and analyze upstream and downstream orders, logistics, inventories, and other related information on the supply chain, and graphically display the information. Such visualization can effectively improve the transparency and controllability of the whole supply chain and thus greatly reduce supply chain risks.

Supply chain visualization supports the tracking of materials and equipment in upstream activities. Logistics information is displayed in real time, including information on packing, goods logged



in, goods logged out, and inspections; goods can even be traced throughout the production process.

With supply chain visualization, the operation data of various transportation vehicles in the logistics system is also available, and the status of these vehicles can be displayed in real time. GPS, AI, 5G, IoT, and other technologies are used to monitor the transportation process and the status of goods when they are in transit. There is a visualized scheduling center that enables the consolidation or splitting of orders at any time, and the optimization of transportation resources and routes. This enables companies to detect and rapidly respond to any logistics emergency by promptly adjusting logistics routes to ensure the timely and safe delivery of goods.

A remote monitoring system monitors the environment in warehouses in real time. This system uses various sensors to graphically display operations and maintenance (O&M) information such as temperature, humidity, dust, and smoke. This allows the timely detection of any signs of fire or water leakage, which enables prompt intervention and prevents material losses. Goods can be tracked in real time as they are logged into and out of warehouses. With the movement of goods, IoT, RFID, and QR code technologies are used to automatically identify and register goods, and the warehousing status data of goods can be accessed remotely in real time.

Snapshot from the future: From supply chain to supply network

In the traditional supply chain model, each link on the chain depends on the previous link delivering as expected. Every link could be a bottleneck that prevents the normal flow of goods down the chain. For example, if the supply of an upstream raw material provider is disrupted, downstream manufacturers will definitely be affected, resulting in inefficient operations or even a standstill for the entire supply chain[10].

With the adoption of ICT technologies such as cloud computing, IoT, big data, and AI, the supply chain will transform into a supply network. In this network, the upstream materials required by every link have multiple alternative sources, and they can be sourced through multiple routes. A multi-contact collaborative supply ecosystem will be created by enhancing the internal and external interconnectivity of enterprises. The failure of any single link will not result in paralysis across the whole supply network.

Conclusion:

New productivity will reshape production and enhance resilience

By 2030, digital technologies will be transforming companies. Technologies such as AI, sensors, IoT, cloud computing, 5G, and AR/VR are poised to become new drivers of productivity. They will help make up for labor shortages, so that companies can seize new business opportunities and expand their possibilities.

Huawei predicts that by 2030, every 10,000 workers will work with 390 robots, and the number of VR and AR users will reach 1 billion. Also, one million companies are expected to build their own 5G private networks (including virtual private networks). In addition, cloud services are forecast to account for 87% of enterprises' application expenditures, while AI computing will account for 7% of a company's total IT investment.

In the future, product design, process design, equipment functions, logistics, and distribution will all be reshaped to become more flexible and serve new people-centric production models. As 3D printing advances and becomes more widely adopted in commercial settings, mold manufacturing, production line adjustment, and many other activities can be eliminated. This will give consumers a much bigger voice in the design and production process, and brand-new personalized production models will be created. Powered by digitalization, supply chains will be visualized and expand into supply networks. This will enable companies to become more resilient than ever and more capable of responding to volatile markets.

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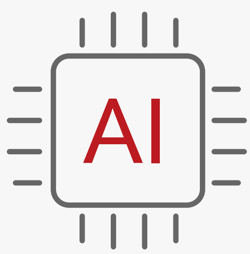

AI computing will account for **7%** of a company's total IT investment.

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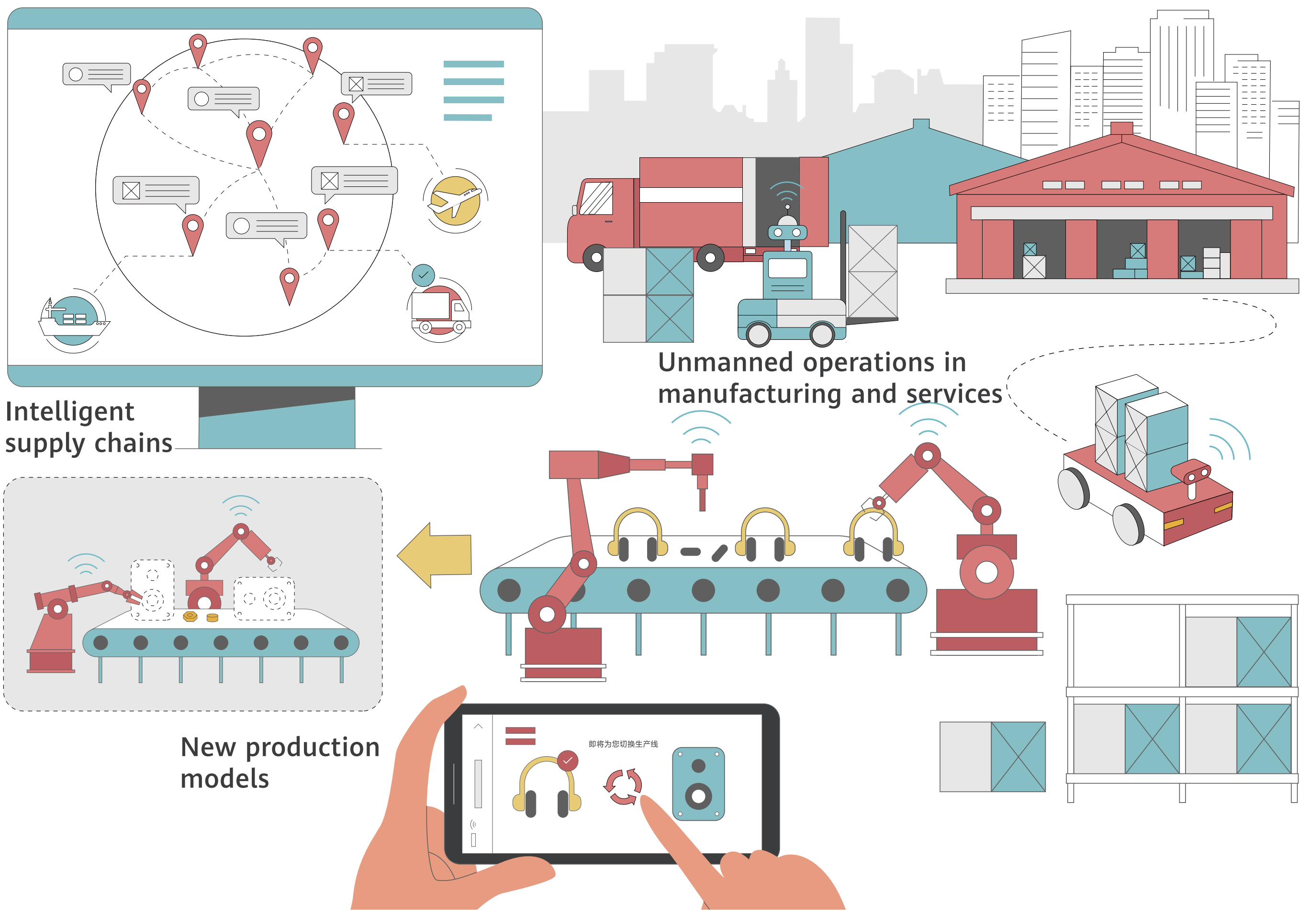

Intelligent supply chains
Unmanned operations in manufacturing and services
New production models
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Energy

Intelligent,
Green Energy for a Better Planet

Climate change is becoming more serious every day. The past decade (2011–2020) was the warmest on record, with the global mean temperature 1.2°C above pre-industrial (1850–1900) levels[1]. Global temperatures have now risen to the point where it has begun to threaten human society. Global carbon dioxide (CO_2) concentrations have reached new highs[2] , with globally averaged mole fractions of CO_2 at 410 parts per million (ppm). This means that CO now makes up more than 0.04% of the atmosphere. The oceans are absorbing around 23% of anthropogenic emissions of CO_2, and the resultant acidification of the oceans impacts oceanic organisms and ecosystems[3] .

In a large region of the Siberian Arctic, the temperature in 2020 was 3°C above average. In Verkhoyansk, Russia, the mercury climbed to 38°C, setting a new record high temperature for the Arctic Circle[4]. Over the 2010–2019 period, weather-related events triggered an estimated 23.1 million displacements of people each year[5].

Climate change is taking its toll on economy as well. The International Monetary Fund found that for a medium- or low-income developing country with an annual average temperature of 25°C, the effect of a 1°C increase in temperature leads to a growth decrease of 1.2%[6].

Climate change is a global challenge, and many countries have come together to tackle it. At the UN Climate Conference (COP 21) in 2015, parties to the Paris Agreement agreed to intensify efforts to limit global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels, and set the goal of reaching net zero CO_2 emissions globally around 2050. In other words, by the midpoint of this century, the CO_2 emitted by human activities needs to be matched by the CO_2 deliberately taken out of the atmosphere. At the 75th UN General Assembly in September 2020, China pledged to peak its carbon emissions by 2030 and achieve carbon neutrality by 2060.

However, the Emissions Gap Report 2020 by the

UN Environment Programme (UNEP) shows that annual emissions need to be 15 gigatons of CO_2-equivalent (GtCO2e) lower than current unconditional Nationally Determined Contributions (NDCs) imply for a 2°C goal by 2030. Limiting the rise in global temperatures to 1.5°C would require an even greater decrease in global emissions by 2030[7].

Concerted efforts are needed to combat climate change and drive the transformation of the global energy mix in three areas: energy supply, consumption, and carbon fixation. On the supply side, renewable energy should be used wherever possible as a cleaner alternative to fossil fuels, for power generation and hydrogen production. This means a shift in the energy production model. It is estimated that the renewable energy share in power generation, which currently stands at 26%, will increase to 42% by 2030[8]. On the consumption side, fossil fuels will need to give way to electricity in the transport, industrial, agricultural, and construction sectors, changing the way energy is used. The share of electricity in final energy consumption is expected to increase from 20% to 30% by 2030[9]. Carbon fixation is another option. If some carbon emissions prove unavoidable, technologies such as soil carbon sequestration and carbon capture and storage can be harnessed, alongside ecological improvement efforts, to remove that carbon from the atmosphere.

As the share of renewables in energy networks continues to increase, challenging the conventional architecture of the energy industry and energy supply chains, a paradigm shift is occurring. With the increasing complexity of energy networks and the increasing digitalization of the energy sector, ICT technologies have become an important part of de-carbonization solutions. The key questions for global warming now are: How can we further increase the share of renewables in the energy mix? How can we adapt to the new energy mix? And how can we fully harness the power of ICT technologies?

Direction for exploration: Renewable electricity generation: Floating power plants

In 2020, the worldwide energy installed capacity from renewable sources increased by 280 gigawatts (GW) or 45%. Of this, 162 GW was contributed by solar power, an increase of 50%, and 114 GW by wind, an increase of more than 90%[10]. By 2050, solar and wind power will account for 60%[11] of the world's total electricity generation. It is estimated that in China alone, the total installed capacity for solar and wind power will reach above 1.2 billion kWh[12] , and 50% of the country's total generation in 2030 is expected to come from non-fossil sources[13]. The German Renewable Energy Federation (BEE), updating its 2030 scenario, calculates that a 77% renewables share of gross electricity demand is required in 2030, in order to achieve climate targets[14] .

The rapid development of inland wind and solar projects is forcing us to confront problems such as shortage of land, distance from electrical load centers, reduced efficiency of solar photovoltaic (PV) systems under high temperatures, and biodiversity loss. A new trend for the future, particularly apparent in island nations, is building wind and solar power installations offshore to take advantage of the excellent geographical features and abundant space of near-shore locations.

Snapshot from the future: Offshore wind, a promising energy source for the future

Some European countries are actively exploring offshore power generation. In 2020, the installed offshore wind capacity in the UK and Germany exceeded 18 GW, accounting for 51% of the world's offshore wind capacity[15]. Denmark is also an active player, with 15% of its electricity generated by offshore wind in 2018. Offshore wind energy still provides only 0.3% of the electricity globally[16] , and there is huge room for expansion. Thanks to a large number of technology innovations that have reduced the installation and operating costs of offshore wind farms, offshore wind is set to grow rapidly.

Offshore locations offer higher wind intensity and offshore wind turbines are productive for a greater proportion of the time. Thanks to new technologies, offshore wind turbines can be larger than their onshore counterparts, and consequently have a higher capacity factor.

$$P=1/2\ \rho A V^3\ C_P$$

The equation above is used to calculate the power output of a wind turbine. The generated power, P, is proportional to both the cube of the wind speed, V, and to the swept area of the turbine, A. Offshore wind is better than inland wind, because when wind flows over rough ground surfaces or obstacles, it changes speed and direction. Sea surfaces are less rough and there are fewer obstacles. On average, the wind 10 km offshore is 25% faster than wind at the shoreline[17].
In addition, offshore wind is less turbulent and wind direction is more consistent. As a result, turbines suffer less fatigue, and the service life of offshore wind power equipment is longer.

The swept area of a wind turbine depends on the diameter of the rotor. In 2021, offshore wind turbines with a rotor diameter of 164 meters and a capacity of 10 megawatts (MW) became available. By 2030, an offshore wind turbine is expected to have an average rotor diameter of 230–250 meters and a capacity of 15–20 MW[18]. In contrast, inland wind turbines in 2021 have a rotor diameter of approximately 158 meters and a capacity of 5.3 MW, and are expected to reach a diameter of 170 meters and a capacity of 5.3 MW by 2025[19]. The capacity of offshore wind turbines can be 3 to 4 times[20] greater than that of inland wind turbines.

There are fewer calm periods at sea, so offshore wind turbines can generate power for 3,000 hours a year, compared to 2,000 hours a year for inland counterparts[21], which makes for more efficient use of generator capacity. With technology advances, the capacity factor of offshore wind power can be 40–50%, higher than that of inland wind and twice that of PV systems. In many areas, the capacity factor of offshore wind is close to that of natural gas and coal[22] ,
so offshore wind has the potential to be a baseload technology[23].

Currently, offshore wind turbines are mainly deployed in shallow water areas less than 40 meters deep, within 80 km of the coast. They are fixed by single piles[24]. New floating turbine technologies offer a new alternative with simpler installation and lower cost[25]. Floating turbines can be installed in water up to 60 meters deep. And the new high-voltage direct current (HVDC) technology offers a more cost-effective solution for transmission at a distance of 80–150 kilometers from the coast. These innovations have greatly expanded the potential of offshore wind.

Other innovations have led to a significant reduction in the cost of offshore wind installations, and the offshore power generation cost in 2040 is expected to be 60% lower than in 2019[26]. In Europe, offshore wind will soon outperform natural gas in terms of cost and be on par with solar PV and inland wind[27]. The Global Wind Energy Council (GWEC) forecasts that global offshore wind capacity will increase from 29.1 GW today to 234 GW by 2030[28].

Annual installations of offshore wind capacity are expected to grow at 31.5% per year over the next five years[29]. The IEA forecasts that offshore wind will become Europe's largest single source of electricity by 2040[30]. This is a boom time for offshore wind power.

Snapshot from the future: Floating PV, the latest trend in Solar PV

According to the Snapshot of Global PV Markets 2021 by the IEA, the total installed capacity of photovoltaics at the end of 2020 was 760.4 GW[31]. In 2020, solar PV accounted for approximately 42%[32] of the total power generation from all new renewable energy sources. Large inland PV power plants are the most common form of PV installation, but there are a number of problems associated with inland solar farms: land acquisition, high costs, and poor performance under high temperatures. Floating PV (FPV) is a new direction for solar PV.

FPV plants can be installed in near-shore marine areas, ponds, small- and medium-sized lakes, reservoirs, river basins, or flooded mining pits. There are three types of FPV installations: thin-film, floating arrays, and submerged. Thin-film PV modules use micrometer-thick solar cells made of non-silicon materials such as cadmium sulfide and gallium arsenide. Thin film is light-weight and does not require the support of a rigid pontoon structure. Submerged PV modules can be supported with or without a pontoon structure. Floating arrays must be supported by rigid pontoons.

Compared with land-based PV (LBPV) systems, installation of FPV systems on water saves land for agricultural use. The lack of obstacles on the surface of the water means less shading loss and less dust. In addition, the natural cooling potential of the body of water may enhance PV performance, due to higher wind speeds offshore, along with the presence of water.

In 2020, a research team from Utrecht University in the Netherlands simulated an FPV system on the North Sea. They found that the apparent temperature at sea was much lower than on land, due to higher relative humidity and higher wind speeds. The average ambient temperature difference between the two locations was 5.05°C, but the apparent temperature difference was nearly twice that, at 9.36°C[33]. This study found that an FPV system performs 12.96%[34] better on average on an annual basis than an LBPV system.

As the technologies mature, rapid growth is anticipated in FPV. On July 14, 2021, Singapore's Sembcorp Industries unveiled a floating solar farm deployed on the Tengeh Reservoir. With 122,000 solar panels spanning across 45 hectares (equivalent to about 45 football fields), the 60 megawatt-peak (MWp) solar farm is one of the world's largest inland floating PV systems[35]. According to Rethink Energy, the global FPV market capacity will exceed 60 GW by 2030[36]. Globally, the estimated potential capacity is 400 GW, meaning that FPV could double the current global installed capacity of solar PV[37].

The floating solar market is set to accelerate as the technologies mature, opening up new opportunities for scaling up global renewables.

Direction for exploration: Intelligent generation-grid-load-storage-consumption through the Energy Internet

The conventional electric power industry is built around large power plants which generate electricity centrally, and a large transmission and distribution network which delivers electricity to consumers. A balance is maintained between generation and demand, and pay-as-you-use is the main charging model.

The only flexible variable in traditional power systems is on the production side. To ensure the stability of the power grid, power plants adjust how much power they are generating based on changes in the consumption load. Today, the cost of renewable installation capacity and the Levelized Costs of Energy (LCOE) for renewables is coming down, and renewable energy has become an important power source. Moving forward, distributed power systems will become more widespread, gradually replacing the old, centralized generation model. Electricity plus digital, or "diglectrification," will drive a paradigm shift. As most renewable energy sources are intermittent, future power systems will need to be more flexible in the way they balance supply and demand, and this will require the help of advanced ICT technologies.

Snapshot from the future: Virtual power plants, a paradigm shift for the power value chain

The emergence of virtual power plants (VPPs) is redrawing the boundaries between power producers and power consumers. VPPs are set to reshape the power generation value chain. IRENA defines a VPP as "a system that relies on software and a smart grid to remotely and automatically dispatch and optimize distributed energy resources. In orchestrating distributed generation, solar PV, storage systems, controllable and flexible loads, and other distributed energy resources, VPPs can provide fast-ramping ancillary services, replacing fossil fuel-based reserves."[38]

VPPs aggregate distributed heterogeneous energy sources. Distributed energy sources include innovative renewable energy generation systems, such as rooftop PV plants and small-scale wind power plants. They also include industrial and household energy systems, such as heating, ventilation and air conditioning (HVAC) systems, electric heating pumps, and battery-based hydrogen production systems. To offset the variability of renewable energy generation, VPPs may also be connected to conventional energy sources such as small gas-fired power plants, small hydroelectric plants, and diesel generators. As electric vehicles and household energy storage develop, they will also be incorporated into the heterogeneous energy equipment connected to VPPs.

Commercially, VPPs will leverage economies of scale to realize the commercial model that distributed energy producers cannot achieve alone. In order to participate in the future energy market and generate profits, distributed energy producers should be able to sense market prices in real time. Distributed new energy devices will need to respond to market changes and power grid fluctuations in real time. This requires ICT

infrastructure such as interconnected networks and edge gateways or edge computing. Producers will incur the kinds of transaction costs that come with being part of the market, such as insurance and compliance costs. These additional costs represent a barrier to market entry for distributed energy producers, but by aggregating the large number of distributed energy sources, VPPs reduce costs and generate profits through economies of scale.

VPPs may operate in either grid-oriented or user-oriented models. In the grid-oriented business scenario, VPPs provide services for power grid operators, aggregating power from distributed heterogeneous resources. Typical services include providing frequency response for power grids through aggregated power generation systems, energy storage equipment, and thermal storage facilities. In this case, VPPs treat aggregated distributed resources as a whole and are rewarded for enabling demand-side flexibility in the power grid. In the user-oriented business scenario, VPPs track energy market prices and provide users with paid services such as peak load shifting, reducing their users' power bills. In short, VPPs provide flexibility to power grids by aggregating distributed energy assets, automatically scheduling and managing distributed energy resources remotely, and tracking energy markets in real time. VPPs enable small producers of distributed energy to save costs through less power consumption and profit by delivering generated electricity to the grid. At the same time, they give greater flexibility to innovative power systems based on renewables.

The VPP model requires the collaboration of different players who bring different skills to the table. They include software, new energy, fossil fuel, and electric power companies. A case study saw technology companies partnering with the government of South Australia to install rooftop PV systems and home batteries in more than 1000 low-income homes, and connecting them to form a VPP[39]. The Australian energy market operator, AEMO, released its first review of the VPP model in 2021, arguing that the VPP model provides frequency response following critical grid problems through timely battery charging and discharging, and helps maintain grid stability[40]. In addition to helping stabilize power grids, homeowners who have installed rooftop PV systems and residential batteries have seen their electricity bills fall by as much as 20%[41]. Although there are currently a number of technical and commercial problems standing in the way of the ultimate success of the VPP model, it is expected that VPPs will have a place in the power systems of the future.

Snapshot from the future: Energy cloud as the operating system for the Energy Internet

Conventional energy networks are typically built with centralized architecture. The operator builds up equipment capacity, operates higher voltages, and expands the network to profit from economies of scale. Energy production, transmission, and consumption are separated, and there is no way to implement end-to-end management and scheduling of electricity production, transmission, and consumption. Different energy networks such as electricity, gas, heat, and cooling supplies are separated from each other, which hinders comprehensive energy efficiency. As distributed energy is increasingly deployed, energy consumers that also have production capacity will simultaneously act as producers and consumers, or prosumers, blurring the once clear boundary between energy production and consumption. Demand-side responsiveness is becoming increasingly important. The interconnection of multiple types of energy can also improve comprehensive energy efficiency and contribute to the consumption of renewable energy. There is an urgent need for integrated platforms that address these issues, and energy cloud may be a solution.

Energy cloud is a new multidisciplinary concept which is very much still evolving and crystallizing. It can be understood as the operating system of the energy Internet, and is typically characterized by convergence, openness, and intelligence.

Generation, grids, storage, and consumption of power need to be converged in an end-to-end manner. Generators now include a large number of distributed new energy sources, such as solar energy, wind energy, and biomass, as well as fossil fuel sources such as gas. The most important entity in the grids is the energy router that

can direct energy flows free of constraints. Consumers include various industrial, commercial, and household facilities, such as HVAC systems and electric heating pumps. Storage entities include various fixed energy storage devices at the generation, grid, and consumption sides, plus mobile energy storage devices such as electric vehicles. The energy cloud will also break down the boundaries between electricity, gas, heat, and cooling. By connecting multiple systems of energy sources, such as heat, gas, and cooling, the energy cloud offers a comprehensive converged system that can optimize total energy use through synergy of multiple types of energy.

With the energy cloud, the energy Internet of the future will be a democratic and open system. Energy cloud users will include consumers (e.g. electric vehicle owners and residential power equipment), businesses (e.g. zero-carbon campuses and VPPs), and governments (e.g. zero-carbon cities). The number of users will far exceed that of traditional energy users. In addition, the energy cloud needs to interconnect with third-party systems, such as carbon trading systems. Therefore, the energy cloud should be an open ecosystem. It will offer a variety of open energy data and programing interfaces to developers, enabling them to implement apps for different scenarios. In addition, an energy app store will be built on the cloud to distribute apps to users so that developers can benefit commercially from their work. Open decoupled programing will enable interconnection with third-party ecosystems, such as energy and carbon trading ecosystems, creating the potential for the emergence of new business models for the energy industry.

To enable convergence and openness, the energy cloud must be an intelligent platform. AI algorithms will make energy assets smarter. For example, AI technologies can be used to control the angle of solar panels to increase energy yield. But intelligence will also be built into the fabric of the energy cloud itself. The energy cloud will build data assets based on massive data of distributed energy sources and end-to-end information on energy generation, grids, load, storage, and consumption. It will have a user- and developer-oriented data platform based on data assets and big data modeling capabilities. Algorithms can be used to forecast distributed generation of energy and energy demand based on historical data, to dynamically respond to demand, and to analyze energy market prices in real time. With the support of efficient, intelligent technologies such as AI and big data, the energy cloud aims to enable a frictionless flow of energy from producers to consumers as they demand it. Ultimately, it will create a green, low-carbon, safe, stable, and diverse energy system.

In July 2020, the EU launched a EUR1.8 trillion economic recovery plan. The plan focuses on supporting the EU's green and digital transformation[42]. Green and digital technologies both drive economic transformation. Energy is the foundation of the digital world, and digital technologies will help the energy industry become smarter. Building an energy Internet operating system and promoting the modernization of the energy industry through digital technologies will help reduce emissions across the industry.

Direction for exploration: Efficient power use for ICT: Saving energy and cutting more emissions

According to Shaping Europe's Digital Future, the EU's digital strategy, digital solutions can increase energy efficiency and cut the use of fossil fuels[43] by tracking when and where electric power is most needed. However, the ICT industry itself also needs to undergo a green transformation. It is estimated that the ICT industry accounts for 5–9% of the world's total electricity consumption and more than 2% of total emissions[44]. Data centers and telecom networks need to improve their energy efficiency, reuse waste energy, and increase the share of renewables. The EU requires that all data centers be climate neutral, energy efficient, and sustainable by 2030, and that telecom operators adopt more transparent measures to track their environmental footprint[45].

Snapshot from the future: Low-carbon data centers and sites

According to the IEA, since 2010, the number of Internet users has doubled, global Internet traffic has increased by 12 times, and the electricity consumed by data centers and transmission networks has increased significantly. In 2019, the global electricity demand from data centers was about 200 terawatt-hours (TWh), accounting for about 0.8% of global electricity demand[46]. Data networks consumed approximately 250 TWh in 2019, accounting for approximately 1% of global electricity consumption, with mobile networks making up two-thirds of this figure[47]. Data center power consumption in China alone is expected to exceed 400 billion kWh in 2030, accounting for 3.7%[48] of the country's total power consumption. If data center power usage effectiveness (PUE) improves by 0.1, the result will be 25 billion kWh of power saved and 10 million fewer tons of carbon emissions. If all data centers use green power, carbon emissions will be reduced by 320 million tons each year[49]. Green power and PUE optimization are key measures for low-carbon data centers.

Large ICT companies have been the biggest purchasers of green power, as they strive to reduce carbon emissions in data centers and telecoms networks. Google, Facebook, Amazon, and Microsoft were the world's top four buyers of green power in 2019[50]. Amazon was the world's largest buyer of new energy in 2020, purchasing more than 5 GW, while TSMC and Verizon rose to the third and fourth places[51]. Google has announced plans for "24/7 zero-carbon" global operations by 2030. If successful, this means that the company will not achieve zero carbon by averaging emissions and offsets over a year, but by actually emitting no carbon on an hour-by-hour basis[52]. Facebook plans to achieve net zero emissions across the supply chain by 2030[53]. Microsoft declared that it will achieve negative carbon emissions by 2030 and eliminate all historical carbon emissions by 2050[54].

According to Uptime, the average PUE in data centers around the world in 2020 was 1.59[55]. This means that about 38% of the power drawn by data centers was used for cooling and other auxiliary functions. As an increasing number of high-temperature-proof servers are put into use, cooling using natural air instead of traditional chillers and air conditioners will become possible.

This will reduce the energy consumption of cooling systems, thereby decreasing the PUE. There have been a number of practices in the industry. The cooling system in a data center is powered entirely by seawater[56]. Another data center uses cold outdoor air to ensure its equipment stays at optimal temperatures. A submarine data center keeps its PUE as low as 1.07[57].

In addition to applying renewable energy and free cooling, AI is another effective way to make data centers more efficient and save energy. Sensors in data centers collect data such as temperature, power levels, pump speed, power consumption rate, and settings, which are analyzed using AI. Then, the data center operations and control thresholds are adjusted accordingly, reducing costs and increasing efficiency. AI is used in data center cooling to reduce the energy used for cooling by 40%[58].

China Unicom (Henan) uses Huawei's iCooling@AI solution, which leverages big data and AI technologies to automatically optimize energy efficiency in data centers. It can improve data center PUE by about 8–15%[59]. According to Datacenter Dynamics, the Boden Type Data Center (BTDC), an experimental data center built in Sweden with funding from the EU's Horizon 2020 programme, has achieved a PUE level of 1.01[60] by using AI algorithms to achieve synergy between the cooling system and computing loads, server fans, and temperatures, in addition to environmental cooling. As AI becomes more widespread, heterogeneous computing is on the rise and data center power density is increasing. Large data centers need holistic systems. Balancing power supply, servers, and workloads based on AI algorithms may be the next technological step required to reduce data center system PUE while continuing to support density increase.

In terms of communications networks, in February 2020, the ITU, GeSI, GSMA and SBTi published a science-based roadmap, consistent with the Paris Agreement, to reduce the greenhouse gas emissions of the ICT industry by 45% before 2030[61]. In addition to using green power in data centers, we can also use solar-grid hybrid solutions and a simplified network architecture to build greener telecoms networks with lower carbon emissions.

Telecoms and computing equipment share the same fundamental technologies. Today, Moore's Law is breaking down. Optoelectronic integration is the next step for the industry's structural reform towards higher energy efficiency. The use of optoelectronic hybrid technologies in networks, devices, and chips can continuously improve the energy efficiency of communications devices. The green telecoms networks of the future will be built to support more than 100 times today's capacity, but their total energy consumption will be no higher than that of today's networks. Conventional telecoms networks are defined by their specialist functions, which makes for fragmented operation and maintenance (O&M) and means they cannot keep pace with the latest network automation and intelligence. Networks need to be reconstructed to deliver essential services through a simplified architecture that consists of three layers: basic telecoms network, cloud network, and algorithms. This simplified network architecture will greatly reduce the complexity of the algorithms in autonomous driving networks, reducing the demand for computing, and cut O&M costs, contributing to greener, low-carbon networks.

Using green power, innovative architecture, AI algorithms, and other effective approaches, data centers and communications networks will be more energy-efficient, and will allow us to finally achieve zero carbon.

Conclusion:

ICT makes green energy smarter and the economy sustainable

The world needs to halve its emissions by 2030. On the production side, new energy sources, such as wind and PV, are being deployed at an accelerated pace, providing clean energy alternatives. On the consumption side, electricity's share is increasing, gradually phasing out fossil fuels. The ICT industry is reducing its own energy consumption and emissions, and at the same time, ICT solutions are enabling other industries to cut their carbon emissions. Huawei predicts that by 2030, renewables will account for 50% of all energy generation globally, 3,000 GW of PV plants will be in place, LCOE of PV plants will reduce to US$0.01 per kWh of electricity, and renewable energy will power 80% of digital infrastructure.

In 2030, ICT will make green energy smarter and enable a wide variety of industries to further reduce emissions. ICT will support green, low-carbon transformation and sustainable development for the global economy.

Huawei predicts that by 2030,

Renewables will account for **50%** of all electricity generation globally.

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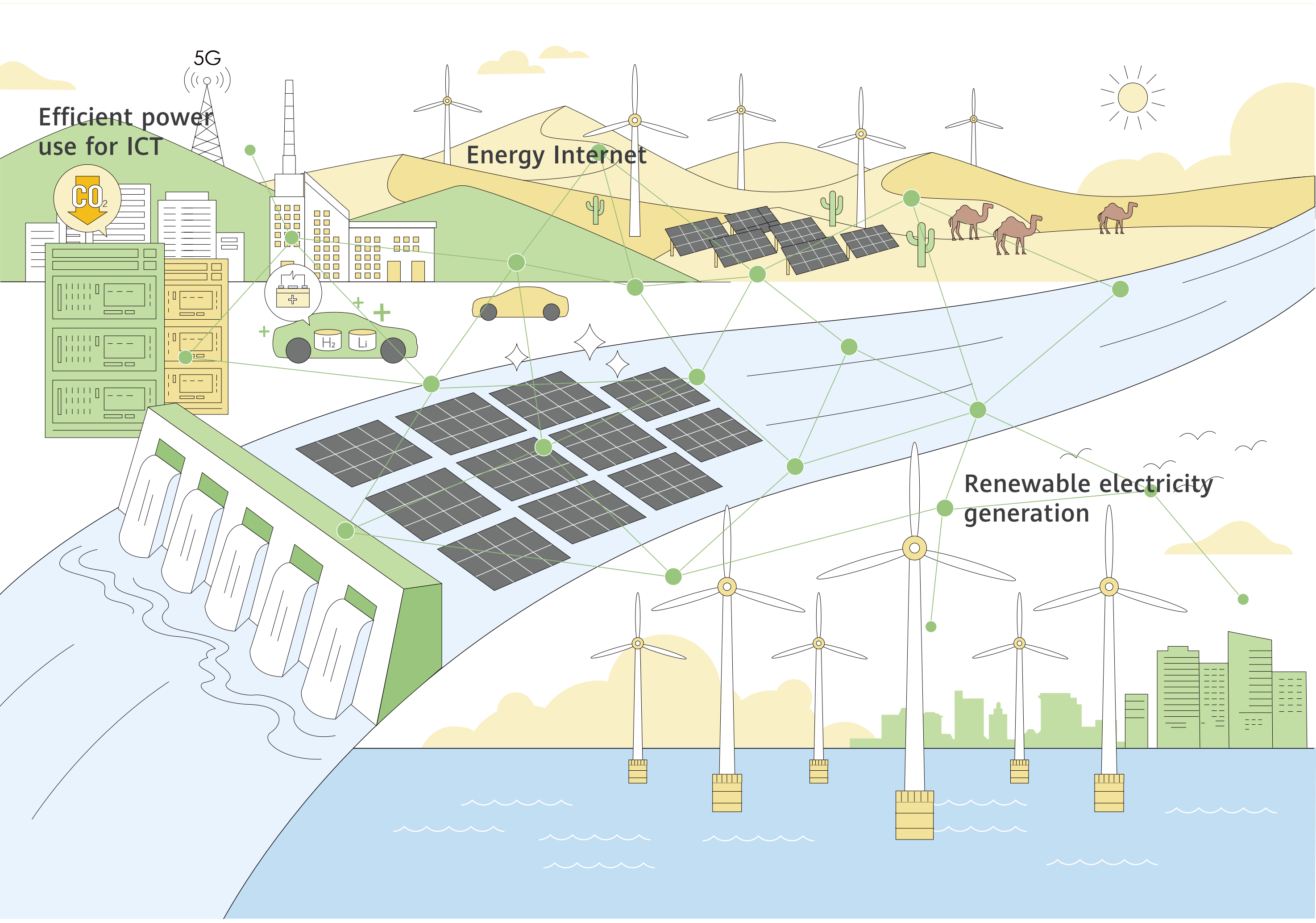
5G
Efficient power use for ICT
CO2
Energy Internet
H2
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Renewable electricity generation

Digital Trust

Technologies and Regulations Shape a Trusted Digital Future

Collaboration drives progress, and the basis for collaboration is trust. In the business world, all interactions are ultimately based on trust, from market research to customer engagement, enterprise operations and management, and the supply chain. Now, digital technology is reshaping these interactions and new concepts such as the metaverse are emerging. Building digital trust has become one of the most important strategic goals for companies and other organizations. Interactions between organizations, between organizations and customers, and within organizations, are migrating to the digital world ever more quickly. Valuable digital assets are generated during these processes. However, the basis of these interactions, i.e., the trust, will be lost if information security is compromised or private information is leaked. As a result, business operations, business value (e.g., brand and market value), reputation, and public credibility will all be at risk.

Digital trust is a complex system that covers a range of areas, including privacy, security, identity, transparency, data integrity and governance, and compliance[1]. Therefore, the realization of digital trust must involve different dimensions and use a variety of tools, such as blockchain, privacy-enhancing technology, and artificial intelligence (AI). New technologies and new rules will help shape a trusted digital future.

Direction for exploration: ICT enables digital trust

For both organizations and individuals, digital assets are enabling unprecedented efficiency and convenience. However, digital assets also create high risks of information theft. Their security and integrity rely on technologies such as risk prediction, digital ledgers, encryption, and digital authentication. Research into ICT technologies for digital trust will help support data sharing and data transactions that are traceable and verifiable, with well-defined data ownership. This will help organizations and individuals fully realize the value of their data, effectively manage digital assets, and better protect core data.

Snapshot from the future: Smart contracts on the blockchain

Many companies are looking for olutionsthat enable contracts to be drafted and executed efficiently, and provide automated performance and neutral supervision. In 2020, the average value of a dispute in the construction sector was US$54.26 million, and the average length of a dispute was 13.4 months[2]. Not only do these disputes cause financial loss, they also disrupt the operations of the companies involved.

Smart contacts, executed on a blockchain, have been one of the most exciting areas of development in recent years.

Smart contracts were first defined by Nick Szabo in 1994 as a set of promises, specified in digital form, including protocols within which the parties perform on these promises. Thus, a smart contract is a special type of agreement that creates, verifies, and enforces performance of obligations. However, smart contracts were only a theoretical concept until the introduction of blockchain, because the technology to create them did not exist.

Blockchain-based smart contracts contain terms expressed in a digital form on a blockchain, and the recording and processing of these terms are completed on the blockchain. The code of the contract contains the obligations of the parties and all information relating to the transactions. The obligations are performed automatically when the set conditions are met, and no third parties are required. Blockchain technology allows information to be recorded and distributed, which ensures that the entire process, from contract storage and access to performance, is transparent, traceable, and non-tamperable. In addition, the decentralized technology that underpins smart contracts can help companies reduce operational costs, improve contract performance efficiency, and prevent third-party interference, which would make transactions more accurate and reliable. However, these same features of blockchain also create challenges to the widespread adoption of smart contracts. For example, if there are errors in the code of a smart contract, the errors cannot be corrected.

The decentralized nature of smart contracts means that they are often not legally enforceable, leaving them governed only by their own code.

Smart contracts have huge market potential in logistics, e-commerce, finance, insurance, and other sectors. According to Capgemini Consulting[3], smart contracts may help US consumers save US$480 to US$960 per mortgage loan, and enable banks to cut costs in the range of US$3 billion to US$11 billion annually by lowering operational costs in the US and European markets. Consumers in the US and EU could save US$45 to US$90 per year on their motor insurance premiums, and insurers would reduce the cost of settling claims by US$21 billion a year globally.

Snapshot from the future: Using AI to identify fraud and maintain organizational reputation and credibility

AI-based behaviors are increasingly human-like. Therefore, some people may use AI for deception. For example, AI-based audio and video can be used for fraud. As reported in the Wall Street Journal[4], the executive of a UK-based energy firm thought he had received a call from the CEO of the firm's parent company and sent US$243,000 to a Hungarian supplier as directed. However, after investigation, the company's insurance firm found that this was a fraudulent request that used AI to mimic the CEO's voice, and the money had been moved to Mexico and other locations. The loss was ultimately borne by the insurance firm.

In 2020, the UK's Channel 4 used deepfake technology to create a "deepfake" queen for an alternative Christmas message on Twitter[5]. This

video was criticized by some media commentators and members of the public as "disrespectful". A report from the Brookings Institute suggests that deepfake technology will erode trust in public institutions[6].

These stories suggest that it is difficult for humans and traditional technologies to distinguish fake video and audio created using digital technologies from legitimate audio and video. However, the solution to this malicious use of AI may come from AI itself.

Neural networks for deep learning can be used to analyze natural language and images, and even to understand video and audio. This can allow us to distinguish between authentic and deepfake videos. AI can be used to detect differences between videos, or even slight differences in audio waves. It can thus identify whether a video or audio was composed using AI. Machine learning and API technology can be used to automate defense. In particular, discriminator algorithms and causal inference models can be used to automatically detect, assess, and remove fake information on the Internet, and trace it back to the data source to provide evidence for the prosecution of digital crimes.

Snapshot from the future: Privacy-enhancing computation

In the era of big data, data is the new oil. Butunlike oil, data will not be depleted. The value of data will be realized again and again in different scenarios and regions by all kinds of enterprises and organizations. However, data sharing presents new challenges to security and privacy. Data mining and analytics driven by machine learning is becoming increasingly prevalent. Sectors such as finance, healthcare, and retail in particular need to guarantee data privacy as they seek to mine data, obtain its value, and share it for collaboration. As data analytics and data warehouse environments become increasingly complex, traditional data desensitization technologies are no longer sufficient. Therefore, privacy-enhancing computation (PEC) technologies are being explored as an alternative.

PEC technologies are data security technologies used to protect and enhance privacy and security during the collection, storage, search, and analysis of private information. PEC supports efficient, high-quality services by protecting

personal data from abuse, while allowing effective use of the data, and realizing its business, scientific, and social value. PEC technologies are being explored in the following areas:

Differential privacy: Random noise is injected into the database to be mixed with personal data, while statistical estimation can still be performed using the data. This method guarantees personal privacy even when the data is shared, because the original data has been scrambled.

Homomorphic encryption: This technique allows users to perform computations on encrypted data without decrypting it. When data is homomorphically encrypted, the computations on the data are also in an encrypted form. When decrypted, the output is identical to the answers that would have been obtained if the computations had been performed on the unencrypted data.

Federated learning: This method allows data to stay in companies' local servers for machine learning. Separate learning models are built after encrypted samples have been aligned, and a virtual joint model is developed based on these models. The performance of this joint model is almost identical to a model trained on data directly gathered in the conventional way.

In addition to the above-mentioned technologies, PEC technologies include a trusted execution environment (TEE), zero-knowledge proofs, k-anonymity, and l-diversity.
In the future, PEC will be supported by more algorithms and widely used in more applications, helping us to find the right balance between privacy and data value.

Direction for exploration: Rules redefine digital trust

Technical measures cannot completely eliminate the risk of information leaks, cyber fraud, or other behaviors that compromise digital trust. Rules and regulations are needed for a trusted intelligent world. Personal data security is not only about individual rights; it is also an essential part of national digital strategies. Large platforms with data traffic advantages may grow into digital giants and abuse their position to collect, use, and distribute consumers' personal information. This trend will deepen the distrust between companies and their customers, and will intensify unfair competition, which will be detrimental to communities as a whole.

Snapshot from the future: New mechanisms for collecting personal information online

More and more laws and regulations concerning the over-collection of data have been passed in recent years. In the context of big data, a fair digital strategy would contain optimized mechanisms that balance the privacy of individuals and the interests of data users creating value with consumer data. The level of control data subjects have over their own personal information will be further enhanced while preserving the conventional approach of obtaining informed consent. In 2021, China promulgated its first Personal Information Protection Law. This law emphasizes multiple basic principles for protecting personal information, including openness, transparency, knowledge of purpose, and minimization. In the future, regulatory frameworks will be further refined so that users will have more knowledge and control over the ways in which their data is collected and used, and the associated risks.

Snapshot from the future: Data protection rules in international markets

The General Data Protection Regulation (GDPR) is currently the most stringent privacy and data security law in the world. It was drafted by the EU and took effect on May 25, 2018. There have been more than 281,000 data breach notifications since it went into effect[7]. Statistics show that by September 2, 2021, there had been 841 fines worth more than EUR 1.287 billion, and the largest fine was EUR746 million[8].

Other countries have also passed laws and regulations on data protection. In 2020, the US published its Federal Data Strategy 2020 Action Plan, which includes the goals of protecting data integrity, conveying data authenticity, and ensuring data storage security. The UAE passed a Data Protection Law for specific sectors, and the Privacy Act 2020 is in effect in New Zealand. On August 20, 2021, China passed the Personal Information Protection Law, which will take effect on November 11, 2021.

Snapshot from the future: The global rise of antitrust action in the data domain

In 2019, the US Department of Justice launched sweeping investigations into the biggest tech giants, suggesting that they had monopolized the market, suppressed competition, and violated user privacy. On May 27, 2020, Japan passed the Act on Improving Transparency and Fairness of Digital Platforms, which was designed to regulate specific digital platforms and enforce obligations to the public on those platforms. On January 19, 2021, the 10th amendment to the German Act Against Restraints of Competition entered into force. The amendment expands the scope of competition law to prevent companies from abusing their positional advantages. In 2021, the Anti-Monopoly Committee of the State Council of China published the Guidelines for Anti-monopoly in the Platform Economy. These regulations represent a global trend towards antitrust action in the data domain.

As antitrust laws are further modernized and adopted, data users and third-party companies will be granted more data rights against industry giants. This will help develop a healthy digital trust ecosystem, and prevent large platforms from committing digital security violations or engaging in other behaviors that compromise fair competition, such as illegally obtaining, abusing, and trading personal data.

Conclusion:

Building an intelligent world with digital trust together

Looking forward to 2030, we will be using technologies such as blockchain and AI to better protect user privacy and data assets; to fight against digital fakes and fake news more effectively; and to reduce the risk of fraud and data theft. PEC and other technologies will enable data sharing with secure encryption, maintaining the value generated by data flows while protecting privacy. Huawei predicts that by 2030, PEC will account for over 50% of all computations, and 85% of companies will have adopted blockchain technology.

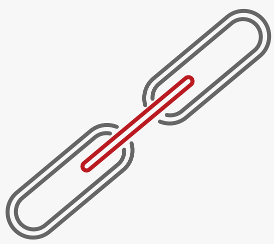
At the same time, digital security laws and regulations, such as the GDPR, and the rising tide of antitrust action in the data domain will be seen in more countries. This will help build trust between individuals and organizations, and help organizations maintain legal compliance in terms of digital trust.

A robust digital trust ecosystem needs the cooperation of multiple parties. Companies will need to maintain their own legal compliance and manage the compliance of their partners, and they may also need to work with regulators to fight against information security violations and data monopolies, as well as to protect user data security. Companies should also proactively support public education and training to help build digital skills and awareness of data and privacy issues in the community. Working together, we can build an intelligent world with digital trust.

giv global industry vision

Huawei predicts that by 2030,

Privacy-enhanced computing technologies will be used in more than **50%** of computing scenarios.



85% of enterprises will adopt blockchain technology.

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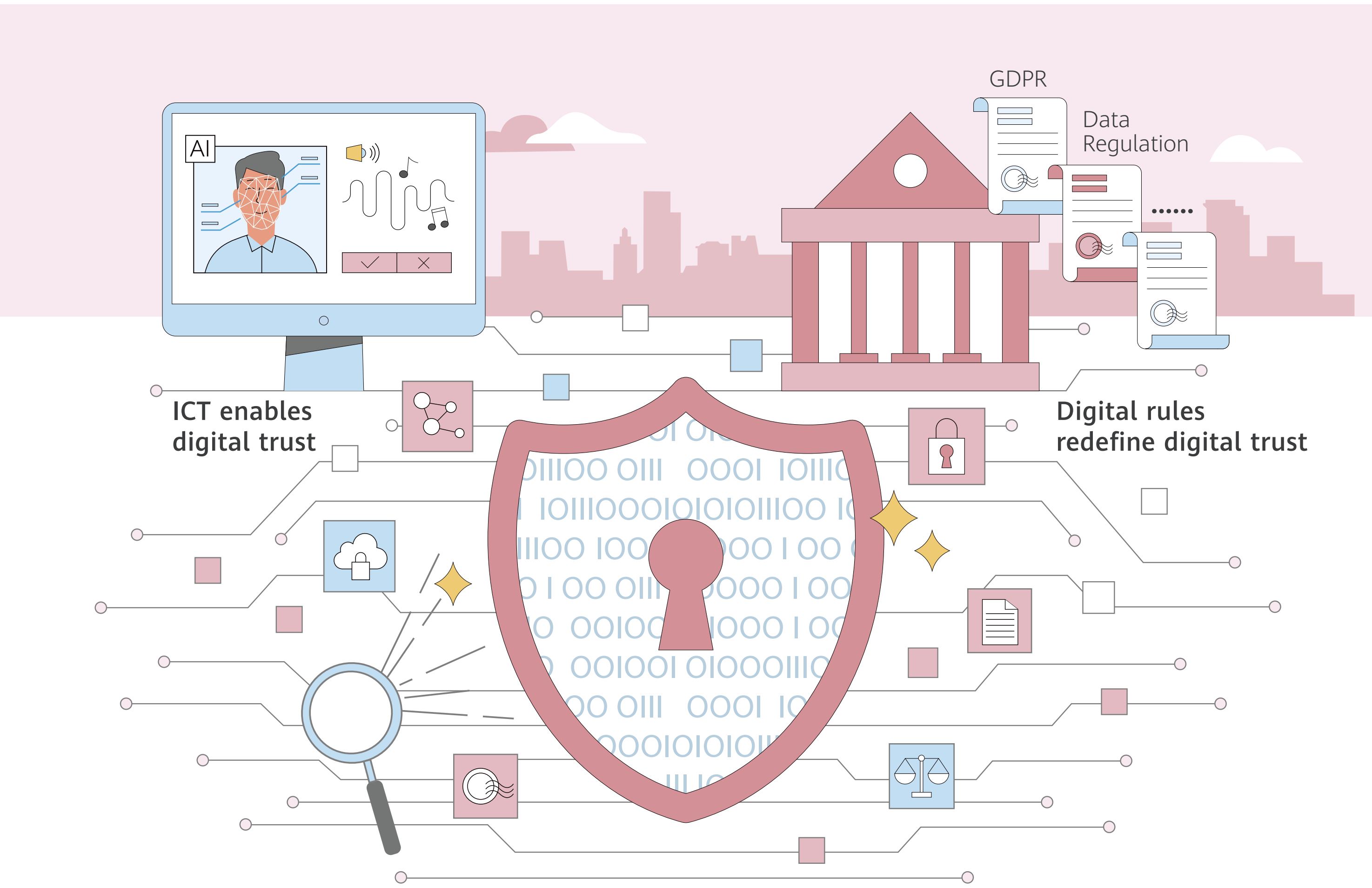
AI
GDPR
Data Regulation
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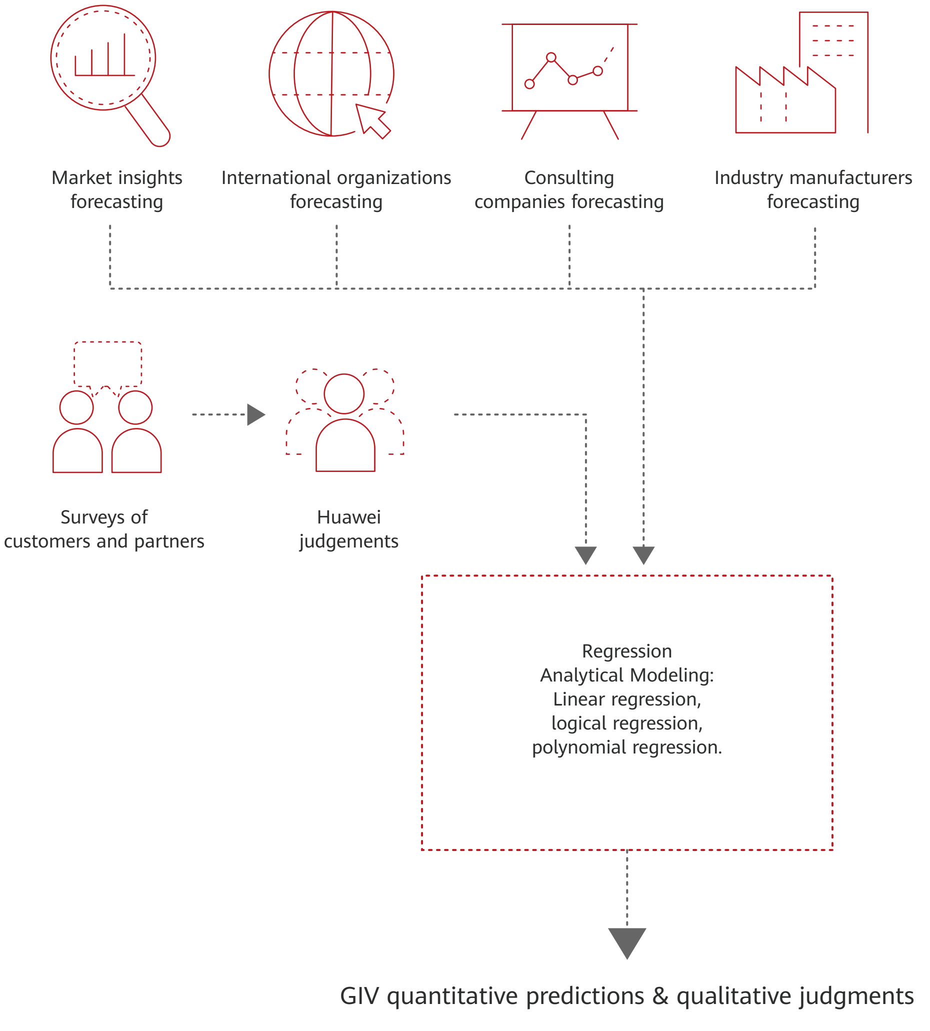
ICT enables digital trust
Digital rules redefine digital trust

Methodology

Humankind has always been driven to explore, and bring certainty to this uncertain world.

We believe that collaboration is essential for future exploration. Over the past three years, in addition to our own Huawei experts who have been building their own insights and plans for the future, our GIV@2030 research team has also been communicating extensively with industry scholars, customers, and partners. We have studied data, methodologies, and insight reports from prominent players around the world, including the United Nations, GSMA, and other third-party consulting firms.

The GIV@2030 research team used trend extrapolation and time series forecasting to arrive at their findings about the future.



Definitions of the Metrics

Category	No.	Indicator	Definition	Prediction for 2030
Connectivity	1	Global connections	Total number of connected people and things worldwide	200 billion connections
	2	Wireless (cellular) connections	Total number of people and things connected through wireless (cellular) technology worldwide	32.5 billion cellular connections 80 billion passive cellular connections
	3	Gigabit/10 gigabit fiber broadband household penetration	Households using gigabit or higher fiber broadband as a proportion of total households worldwide Households using 10 gigabit fiber broadband as a proportion of total households worldwide	Gigabit or higher fiber broadband household penetration: 55% 10 gigabit fiber broadband household penetration: 23%
	4	4K/8K TV household penetration	Households with 4K/8K TVs as a proportion of total households worldwide	4K TV household penetration: 58% 8K TV household penetration: 17%
	5	IPv6 adoption	Connected devices and applications using IPv6 worldwide	90%
	6	VR/AR users	Number of VR/AR users worldwide	1 billion
	7	Robots per 10,000 workers Household robots	Number of robots per 10,000 workers Households with home robots as a proportion of total households worldwide	390 robots per 10,000 workers Households with home robots: 18%
	8	Intelligent connected vehicle penetration	C-V2X vehicles as a proportion of total vehicles	60%
	9	Average monthly data use on wireless cellular networks per person	Average monthly data (GB) used on wireless cellular networks per person (all owned devices)	600 GB (40-fold increase)
	10	Average monthly fixed network data usage per household	Average fixed network data usage per household, per month	1.3 TB (8-fold increase)
	11	5G private networks	Number of 5G private networks (including virtual private networks) Proportion of medium or large enterprises using 5G private networks	Number of 5G private networks: 1 million 5G private networks penetration in medium/large enterprises: 35%
	12	Gigabit/10 gigabit Wi-Fi network penetration in enterprises	Proportion of enterprises using gigabit Wi-Fi networks and 10 gigabit Wi-Fi networks	Gigabit Wi-Fi network penetration in enterprises: 50% 10 gigabit Wi-Fi network penetration in enterprises: 40%
	13	FTTR/FTTD penetration	Fiber-to-the-room households as a proportion of total households worldwide/Fiber-to-the-desk enterprises as a proportion of total enterprises worldwide	Fiber-to-the-room household penetration: 31% Fiber-to-the-desk enterprise penetration: 41%

Category	No.	Indicator	Definition	Prediction for 2030
Computing	14	General computing power & AI computing power	Total general computing power of global data centers and edge servers Total AI computing power of global data centers and edge servers	General computing power (FP32): 3.3 ZFLOPS (10-fold increase) AI computing power (FP16): 105 ZFLOPS (500-fold increase)
	15	Computing as a proportion of total enterprise IT investment	Investment in general computing and AI computing servers as a proportion of total annual IT hardware investment of an enterprise (The IT hardware investment include investment into data centers, edge, and device hardware)	32%
	16	Cloud services as a proportion of total enterprise application expenditure	Proportion of enterprise application expenditure on cloud services	87%
	17	Global data volume generated annually	Total volume of data generated by all digital devices and digital instruments worldwide each year, including devices, edge, and data centers, as well as newly generated, replicated, or cloned data, back-up data, process data, and cached data.	1 YB (23-fold increase)
	18	Penetration of privacy enhancing computing technology	Proportion of scenarios where the built-in privacy computing capability of the computing system is enabled	50%
	19	Blockchain technology penetration	Proportion of enterprises deploying blockchain technology	85%
Vehicle	20	Electric vehicles as a proportion of new vehicles sold	Electric vehicles as a proportion of new vehicles sold annually	50%
	21	Autonomous vehicles as a proportion of new vehicles sold	Autonomous vehicles as a proportion of new vehicles sold annually	Global: 10% China: 20%
Energy	22	Proportion of renewables in global electricity generation	Proportion of electricity from renewables in the total electricity generated worldwide	50%

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HUAWEI TECHNOLOGIES CO., LTD.
Huawei Industrial Base
Bantian Longgang
Shenzhen 518129, P. R. China
Tel: +86-755-28780808
www.huawei.com