White Paper on Global Energy Transition and Zero-carbon Development

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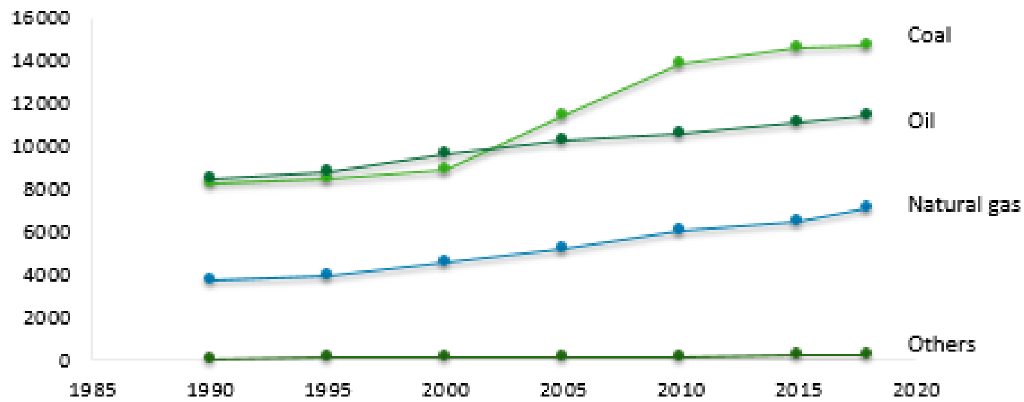
Section 1 Climate Change and Global Carbon-neutral Actions

From 1850 to 2019, about 2,400 gigatons (Gt) of CO_2 were emitted by human activities, causing the global temperature to rise by nearly 1.1°C [1] higher than that of pre-industrial era. The impact of climate change on the environment, society and economy is increasing with more frequent or intense extreme weather, accelerated sea level rise and the endangered extinction of millions of species. To fight climate change, nearly 200 countries around the world passed the Paris Agreement in 2015, which introduced the goal of global net zero greenhouse gas (GHG) emission around the mid-century and reached the consensus to limit the rise of global temperatures to 2℃ compared to pre-industrial level – or, if possible, to 1.5℃.

Country	Net-zero Goal	Nature of Commitment
United States	2050	Policy announcement
China	By 2060	Policy announcement
Japan	2050	Policy announcement
Germany	2045	Legislation
India	/	/
United Kingdom	2050	Legislation
France	2050	Legislation
Italy	2050	Policy announcement
Brazil	2050	Policy announcement
Canada	2050	Policy announcement

Table 1: Climate Commitments of Top 10 Largest Economies

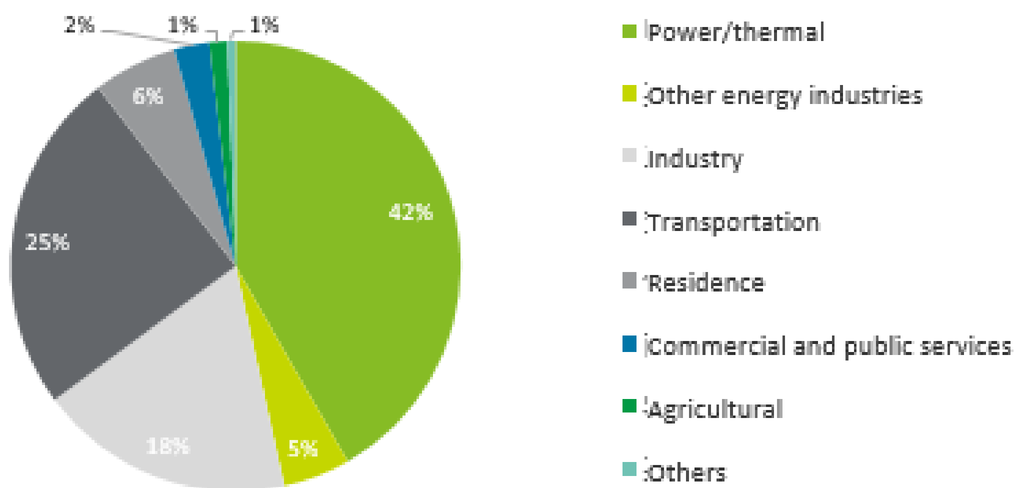
Achieving GHG net-zero emission around the middle of this century is the key to achieving Paris Agreement goals [2]. According to data from the Intergovernmental Panel on Climate Change (IPCC), under the scenario of limiting the temperature rise within 1.5°C in this century, starting in 2020 the remaining global carbon budget is a mere 500 Gt CO_2 equivalent [3]. On the other hand, the global emission in 2019 have already exceeded 50 Gt [4]. It would be difficult to achieve the net-zero goal in the middle of this century if current trends continue [5]. A rapid and radical transition towards zero carbon is urgently needed.



Source: International Energy Agency

Figure 1: Global Carbon Emission of Various Energy Sources (Unit: Mt)

Carbon emission from fossil fuel combustion have continued to grow in the past decade and it accounted for 65% of total GHG emission in 2019. Looking at the current climate actions of global economies, the large-scale deployment of renewable energy, the emission reduction and upgrading of industrial manufacturing, the green transition of transportation industry, the improvement of building energy efficiency and the development and utilization of carbon-negative technology have become the key areas of zero-carbon development.



Source: International Energy Agency

Figure 2: Percentage of Global Carbon Emission by Sector (2018)

1. Large-scale deployment of renewable energy

Since 2013, the global investment in renewable energy has averaged approximately USD 300 billion per year with solar energy and wind energy as the largest investment hotspots; in 2020, the offshore wind energy investment has jumped to around USD 50 billion, becoming the fastest growing sub-sector[6]. China, the United States and Europe are leading the world in terms of investment scale[7].

2. Emission reduction and technological upgrading in manufacturing

Chemical, steel and cement are the major industrial emitters, contributing 70% to the total carbon emission of the global manufacturing sector (2020) [8]. These industries are actively introducing new ways to reduce emission and exploring new technologies, such as integrating value chain, promoting waste conversion and utilization, using hydrogen in metallurgical processes to reduce direct emissions and applying carbon capture, utilization and storage (CCUS) to achieve net-zero emissions[9].

3. Green transition of transportation industry

The new energy transportation industry, which uses electricity and fuel cells to replace fossil fuels, has been booming since 2014. Global electric vehicles (EV) in use exceeded 10 million in 2020, representing an annual growth rate of 43%. The fuel cell vehicles (FCV) in use increased by 40% in the same period. Electrification of railways, utilization of hydrogen in freight transport and smart transportation systems are becoming global trends, paving the way for the green transition of transportation industry.

4. Improving energy efficiency in buildings

73 countries announced energy efficiency standards for buildings in 2019 and the number of sustainable/green building certifications worldwide continued to grow. Countries improve the energy efficiency of buildings in various ways, such as applying new wall materials, enhancing the thermal performance of building envelopes, improving the electrification of equipment, using energy-efficient equipment and improving the operating efficiency of building energy management-systems, etc.

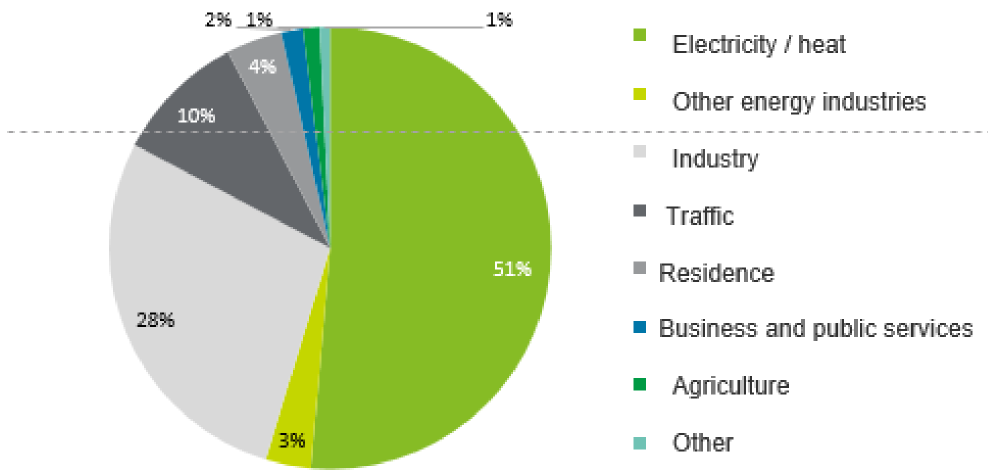
5. Development and utilization of carbon-negative technology

Globally, the carbon captured by CCUS has tripled between 2010 and 2020 and exceeded 40 million tons in 2020[10]. Increasing number of countries move to tackle climate change by developing carbon-negative technologies, such as CCUS, bioenergy with carbon capture and storage (BECCS), direct air capture (DAC) and ecological carbon-negative technologies such as afforestation and reforestation etc.

While advancing climate action, countries attach great importance to the application of digital technology to enable the zero-carbon transition of energy, manufacturing, transportation and construction industries. According to the analysis of the World Economic Forum, 5G, IoT, artificial intelligence, cloud and other digital technologies can help reduce global carbon emission by 15% by 2030[11].

Section 2 China's Carbon Neutrality Actions

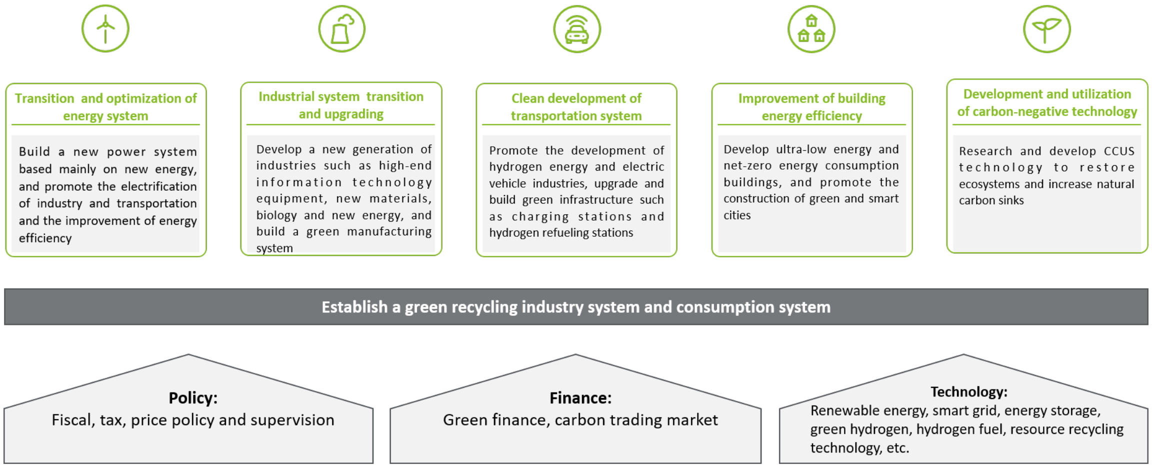
In 2020, China officially announced its "dual-carbon" climate pledge to reach a peak of CO2 emission by 2030 and striving to achieve carbon neutrality by 2060. Over the past four decades, China's rapid economic development has been accompanied by intensive consumption of resources, massive consumption of fossil fuels and rapid growth in pollutants and carbon emissions. China has issued a number of policies and adopted various measures to deal with climate change since 2010. The measures included industrial transformation and upgrading, adjustment of energy structure and technological innovation. At the end of 2019, China's carbon emission intensity dropped by 48% compared with 2005 [1 2], achieved the goal of reducing carbon emission intensity by 40%-45% proposed in 2015 ahead of schedule.



Source: International Energy Agency

Figure 3: Percentage of China's Carbon Emission by Sector (2018)

China's carbon emission is large and still on the rise. In 2020, China's GHG emission exceeded 10 Gt, accounting for about a quarter of the world's total [1 3] and ranked first in the world. Energy and industrial sectors contributed a large proportion of emissions. Facing the challenge of dual carbon targets under the premise of ensuring the steady development of the economy, supported by policies, finance and technology, China has carried out diverse actions to achieve carbon neutrality. A lot of efforts have been put into optimization of the energy sector, transformation and upgrading of industrial sector, clean development of the transportation sector, energy efficiency improvement of the building sector and development and utilization of carbon-negative technology.



Source: Deloitte Research, government documents and public information

Figure 4: China's Systematic Supports to Carbon Neutrality Initiatives

1. Optimization of the energy sector

In 2020, China's coal consumption accounted for 57% of primary energy consumption, the carbon intensity per unit of energy consumption was 30% higher than the world average level [14]. China's electric power and heating is highly dependent on coal and its carbon emission accounted for about one-half of the China's total in 2020. Chinas has set a new target for China's energy system development, which is to build a clean, safe and efficient energy system, in which power system will be mainly fueled by new energy. The new strategy promotes Reforms in energy supply, energy consumption, technology innovation and system and market reforms; it also aims to strengthen international cooperation in all aspects.

2. Transformation and upgrading of the industrial sector

China's energy consumption per unit of GDP is nearly 1.5 times the world average level [15]. The proportion of high energy-consuming industrial manufacturing is relatively high and the carbon emission of industrial manufacturing are second only to the power/heating industry [16]. By focusing on carbon intensity control supplemented by total carbon emission control, China contains the expansion of the high energy-consuming industries such as steel, eliminates outdated production capacity, promotes the development of energy-saving and environmental protection industries, deepens the application of new technologies such as the industrial Internet and deepens the construction of a green manufacturing system, so as to promote the structural adjustment and upgrading of the industrial manufacturing.

3. Clean development of the transportation sector

New energy vehicles (NEV) sector has grown rapidly in China, with the number of vehicles in use leading the world. China's development goal for 2035 is to have pure electric vehicles as the mainstream for new vehicle sales. In addition to the development of the NEV industry, China plans to accelerate the electrification of railways and boost use of liquefied natural gas (LNG) as marine fuel, so as to optimize the transportation structure with railway and waterway as mainstream options for medium and long-distance freight transportation. Meanwhile, the deepening of the integration of transportation, energy and information and communication technology (ICT) will accelerate the decarbonization of transportation system.

4. Energy efficiency improvement in buildings

During the period from 2015 to 2019, China has built more than 19.8 billion square meters of energy-saving buildings, accounting for 56% of the existing urban building area [17] and its proportion is expected to increase to 70% by 2022. China's Green Bond Endorsed Projects Catalogue (2021 Edition) had green buildings and building energy efficiency into it. A lot of efforts also have been put into the improvement of energy efficiency in buildings by switching to solar PV roofs and biomass and shifting toward relying on electricity for heating, cooking, etc..

5. Development and utilization of carbon-negative technologies

China's CCUS technology is currently at the stage of industrial demonstration as a whole and CCUS pilot projects have been launched in coal, electric power and chemical industries, etc. With the decline in technology costs and the expansion of application scale, it may basically be able to meet the needs of 0.6-2.1 GT captured carbon under the goal of carbon neutrality in the future [18]. At the same time, China has actively promoted the construction of ecological carbon sinks. The area of forests has maintained growth for 30 years and the role of wetlands and oceans in carbon sequestration has received increasing attention.

6. Policy, finance and technology support

Since 2016, the construction of China's green financial system has been steadily advancing, with the green bonds issuance and the green loan balance leading the world. Since the announcement of the "dual-carbon goal", the exploration of carbon financing such as carbon collateral and carbon repurchase has been accelerated. China's carbon market was officially launched in 2021, covering approximately 4.5 GT CO_2 emissions and is the world's largest carbon market. And the power industry has become the first industry that was included in the national carbon market. The coverage of the carbon market will be gradually expanded to other key industries. Pricing carbon emission will encourage enterprises to act on energy conservation and emission reduction. In the second half of 2021, the National Development and Reform Commission and the National Energy Administration jointly established a carbon emission statistical accounting working group to accelerate the establishment of a unified carbon emission statistical accounting system, improve the consistency of carbon emission information standards in various regions and industries and provide a basis for the formulation of emission reduction policies and for the adoption of emission reduction actions by various entities. In addition, China has escalated the digital transformation to a national strategy. The integration of digital technology and the real economy are deepening and the development of smart grids, smart manufacturing, smart buildings, smart transportation, smart cities, etc. is helping to build a green economy.

Section 3 Global Energy Transition

I. Interpretation of the energy transition

Energy transition is a key factor for achieving carbon neutrality. More than half of the world's GHG emission come from the energy industry. Therefore, the energy industry is the most important emission reduction area that all countries have always paid attention to and it faces the arduous task of reducing emissions. The Energy Technology Outlook 2020 released by the International Energy Agency (IEA) shows that, to achieve sustainable development of global economy and climate change resilience, it is required to achieve net-zero emission around the middle of this century and profoundly change the global energy production and consumption models[19].

Energy transition includes two aspects. The first is to shift from fossil-based system of energy production, transmission, conversion and storage to renewable energy; the second is to accelerate the electric energy substitution and electrification transformation, promote the integrated multi-energy system and the cascade utilization of energy, endorse energy conservation and emission reduction in various industries and improve energy efficiency.

II. Factors affecting global energy transition

The future energy landscape will face five key influencing factors:

1. Society

Including the publicity and implementation of green development and consumption concepts, the public's understanding of and actions on energy transition, the extent of the shifting of consumer behavior to green consumption and the reserve of talents related to energy transition.

2. Economy

Including energy industry policies, energy investment and financing costs, energy asset portfolios, energy market systems, energy prices, carbon prices and carbon assets and carbon taxes.

3. Politics

Including energy security and related safeguards, geopolitical landscapes, global relations and the speed and extent of developing countries' development towards renewable energy.

4. Environment

Including the level of GHG emissions, the impact of climate change, the degree of ecological protection and responses of the public and decision makers to climate change.

5. Technology

Including new energy development and utilization technology, clean and efficient utilization technology for fossil fuels, energy saving and emission reduction technology, carbon-negative technologies and energy digital transformation technologies.

III. Overarching ideas of global energy transition

The ever-increasing global energy demand and the increasing impact of climate change have put tremendous pressure on the energy market, therefore, it is necessary to accelerate the implementation of energy transition-related actions around the world. Based on the analysis of the five key influencing factors of global energy transition, we summarize the overarching ideas of global energy transition as follows:

1. Develop clean energy

According to statistics from the International Renewable Energy Agency (IRENA), since 2012, the annual new installed capacity of clean energy has exceeded the total installed capacity of all types of fossil fuels in the world. In 2020, the global installed capacity of clean energy has been more than four times that of other sources [20]. However, the total installed capacity of clean energy still occupies less than that of fossil fuels. To realize energy transition on a global scale, we should continue to promote large-scale development and utilization of clean energy and continuously reduce the cost thereof.

2. Attach importance to energy security

To attach importance to energy security, including the security of national energy supply and the security of the energy system itself. All countries shall combine their own resource endowments to promote the transition from traditional fossil fuels towards renewable energy to create favorable conditions for energy self-sufficiency and energy security. The characteristics of intermittency, volatility and randomness of renewable energy put forward higher requirements for the operation, distribution and control of energy network, therefore, it is necessary to establish an integrated and coordinated energy system of source-network-load-storage to ensure safe and reliable energy supply. To change the role of the fossil fuels from main energy to auxiliary mediated energy. As a backup for energy security, the clean and efficient use of fossil fuels will effectively reduce energy system risks.

3. Promote technological innovation

IRENA analyzed in the World Energy Transitions Outlook that, to successfully achieve the 2050 climate goal, more than 90% of the solutions would involve the application of other solutions and new technologies such as renewable energy supply, electrification, energy efficiency improvement, green hydrogen, bioenergy and carbon capture and storage. Taking green hydrogen as an example, technological innovation will empower the application of green hydrogen in emission-intensive industries such as steel, chemical industry, long-distance transportation, shipping and aviation and help industries that are difficult to decarbonize to achieve low-carbon development. The global energy transition should strengthen the guiding effects of policies, increase R&D investment, accelerate the speed of innovation and reduce development and application costs.

4. Promote international cooperation

With the signing of the Paris Agreement, many countries have begun to formulate relevant energy transition and zero-carbon transition strategies. For example, in March 2020, the European Commission issued the European Climate Law to establish a legal framework to clarify the European vision of achieving climate neutrality by 2050 and to promote all countries to formulate a path to achieve climate neutrality in accordance with the law. Carrying out effective international mutually beneficial cooperation in various fields and deploying coordinated measures across national borders will be conducive to achieve the global energy transition and zero-carbon development goals.

IV. Regional analysis on global energy transition

Considering their own resource endowments, energy strategy, technological level and other differences, countries have embarked on their own different transition paths. Developed economies will be earlier than other economies in formulating relevant measures. For example, Europe has taken the lead in the energy transition by decarbonizing energy and transforming energy consumption patterns, introducing policies such as the Green New Deal to support the development of renewable energy and shaping global leadership. The US energy transition focuses on seeking a balance between economic development and carbon reduction. While retaining hydrocarbon industry, US has introduced in 2020 a series of policies and measures such as the development of offshore wind power and restrictions on the development of the oil and natural gas industry to promote the sustainable growth of renewable energy.

Country	*Europe*	*North America*	*Middle East*	*Japan and South Korea*	*Australia*
Develop clean energy	· Develop rapidly commercial renewable energy and hydrogen energy to reduce the dependence on external energy supplies	· Formulate renewable energy subsidies and incentive policies to promote technological innovation of the renewable energy industry	·Using high-efficient energy-saving technologies to reduce carbon emission	· Vigorously develop clean energy to improve energy independence ·Focus on the innovation and application of new technologies such as green hydrogen	·Improve the development and utilization of renewable energy and the clean production capacity of traditional hydrocarbons
Promote technological innovation	Make use of the first mover advantage to export technology and intellectual property rights to countries in urgent need of low-carbon transformation	· Achieve regional energy self-sufficiency by developing technologies such as distributed energy, micro-grid and blockchain · Design and develop leading smart, energy-saving and innovative	·Attract foreign direct investment and introduce green technologies to support economic growth ·Undertake emission-intensive industries (such as manufacturing, etc.)	· Take various measures to cultivate the hydrogen energy industry through scientific and technological research, government investment and financial subsidies	· Expand the hydrocarbon value chain

		transportation modes			
Attach importance to energy security	On the premise of ensuring energy security, vigorously promote energy decarbonization and coal and other hydrocarbons have not completely withdrawn from the market	· Ensure energy security through large-scale extraction of shale gas, making the United States become a net energy exporter · The status of the hydrocarbon industry is still important and strengthen international trade cooperation	· The energy demand continues to increase, the renewable energy accounts for a relatively low proportion and the dependence on hydrocarbons is increasing	· Ensure a stable energy supply through close cooperation with energy exporting countries and free international energy trade	· Vigorously promote the development and utilization of clean energy such as solar energy to achieve energy diversification
Promote international cooperation	· Lead green transformations, promote the formulation of coordinated climate change policies and play a key role in improving global carbon trading mechanism	· Domestic energy enterprises continue to penetrate into the energy markets of developing countries and competition with other global multinational companies has intensified ·Use LNG vigorously to reduce carbon emission intensity in the industry where emission reduction is difficult	· The pace of renewable energy transition lags behind that of developed countries due to the lack of advanced low-carbon energy technology · Rely on global technology sharing and cooperation to accelerate the deployment of clean energy	· Actively develop the hydrogen energy industry through international cooperation	· Increase the proportion in the international energy market through free international energy trade

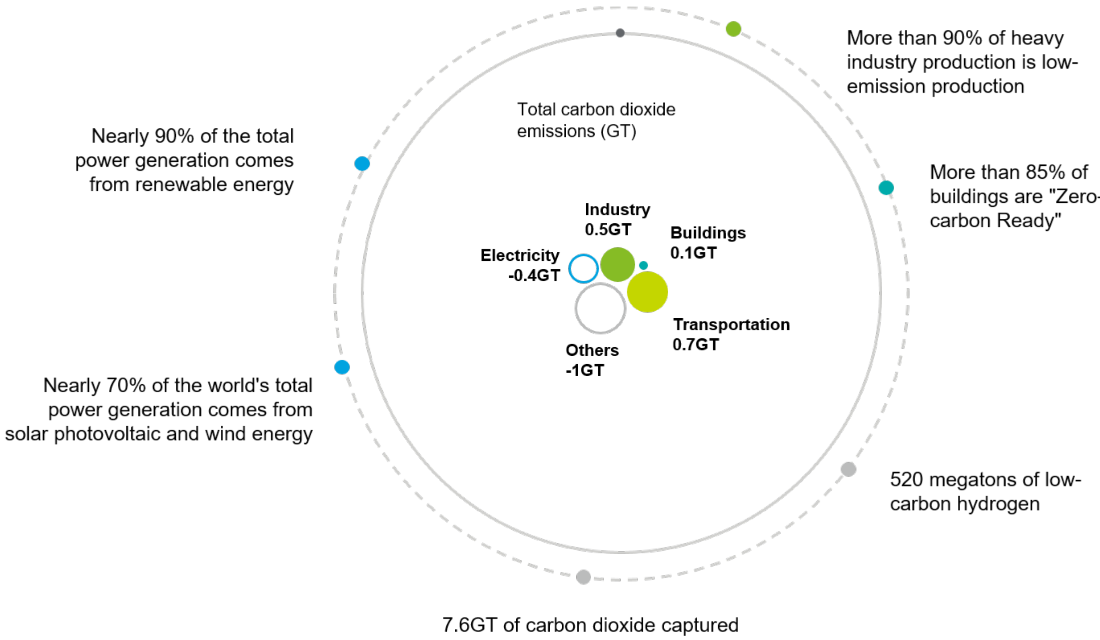
Source: Deloitte: *Deloitte Future Energy Outlook*

Table 2: Energy Transition Strategies and Characteristics of Selected Regions/Countries

V. 2050 global energy scenario forecast

Achieving net-zero emission on a global scale by 2050 is a key and arduous goal that requires concerted efforts and close collaboration of countries around the world.

According to the scenario forecast of the net-zero emission roadmap of IEA, the global energy will be dominated by renewable energy, with various low-carbon or zero-carbon technologies being mature and various industries will achieve low-carbon or zero-carbon emission by 2050.



Source: International Energy Agency

Figure 3: 2050 Global Energy Transition Scenario Forecast

Note 1: "zero-carbon-ready" buildings are energy-efficient buildings that directly use renewable energy or decarbonized energy

Note 2: low hydrocarbons include green hydrogen and blue hydrogen, mainly green hydrogen

Section 4 China's Energy Transition

As the international community continues to intensify actions against climate change, the global energy transition continues to accelerate. Guided by China's new energy security strategy featuring "four Reforms and one cooperation" and driven by the dual-carbon goal, China's energy transition has entered a new stage.

I. China's new energy security strategy

In 2014, China adopted a new energy security strategy featuring Four Reforms and One Cooperation, including the energy consumption reform, energy supply reform, energy technology reform, energy system reform and comprehensive strengthening of international cooperation. China's energy transition also applies this as a strategic guide to build a clean, low-carbon, safe and efficient energy system.

1. Energy consumption reform

Carry out the principle of prioritizing energy conservation, tighten the control of total energy consumption and energy use intensity and integrate energy conservation into all areas of social and economic development to promote clean and low-carbon energy consumption pattern.

2. Energy supply reform

Establish a diversified and clean energy supply system, prioritize the development of non-fossil energy, promote the clean and efficient use of fossil fuels and coordinate the development of energy transportation networks and storage facilities.

3. Energy technology reform

Oriented by green and low carbon principles, build a system that nurtures technological innovation, industrial innovation and business model innovation. Turn green energy technologies and its related industries into new growth drivers for industrial upgrading.

4. Energy system reform

Build an effectively competitive energy market, improve the energy price mechanism that is mainly determined by the market, streamline government administration and modernize law-based energy governance system.

5. Comprehensive international cooperation

Under the principle of equality and mutual benefit, China is opening its door wider to the world by actively participating in global energy governance, jointly maintaining energy market stability and strengthening international cooperation in response to climate change.

II. China's energy transition has entered a critical stage

China has become a major global energy production and energy consumption country and has formed a diversified energy production system consisting of coal, oil, natural gas, electricity, nuclear, new energy and renewable energy. Coal is the basic energy source to ensure energy supply. Crude oil production remains stable. Natural gas production has increased significantly. The installed capacity of nuclear power under construction is the largest in the world. The development and utilization of renewable energy is rapidly expanding. The cumulative installed capacity of hydropower, wind power and solar power generation ranks first in the world. The status quo of China's energy development presents the following features:

- China has become the world's largest energy producer and consumer, the world's largest coal producer and consumer, the second-largest oil consumer and the third-largest natural gas consumer.

- China has formed a high-carbon energy structure dominated by coal. Energy extraction, conversion and transportation infrastructures are usually large-scale and centralized. China's regional disparities also mean that the country has to transfer the energy generated from resources-rich regions in the west to populous regions in the east.

- Renewable energy technologies are developing rapidly and wind and solar PV have gained competitive advantages in the global market. Business models of energy storage, such as cold storage, thermal energy storage and chemical energy storage, are gradually mature.

- The oil & gas and power markets are opening up in an orderly manner. The reform of the energy price mechanism is progressing steadily and the energy market system is gradually improved.

China is committed to reaching carbon peak by 2030 and striving to achieve carbon neutrality by 2060. The energy transition is the key to the success of China's dual-carbon goal and the energy supply and consumption systems are in urgent need of reform. China plans to achieve the target with non-fossil energy accounting for about 25% of primary energy consumption and with the total installed capacity of wind and solar power exceeding 1.2 billion kilowatts by 2030. China's energy transition has entered a critical stage and is facing the following major challenges:

- **Balance between energy security and low-carbon initiatives:** China's energy resource endowment is often described as "Rich in coal, Poor in oil and gas". Considering this fact as well as frequent extreme events happening around the world, China's energy transition needs to take into account the security of energy supply and the low-carbon environmental goals and actively respond to the impact of extreme events.

- **Multi-energy coordination and complementation:** China needs to set a clear direction for the future development of coal, oil and gas and it also needs to realize multi-energy synergy and integrated cascade utilization of energy.

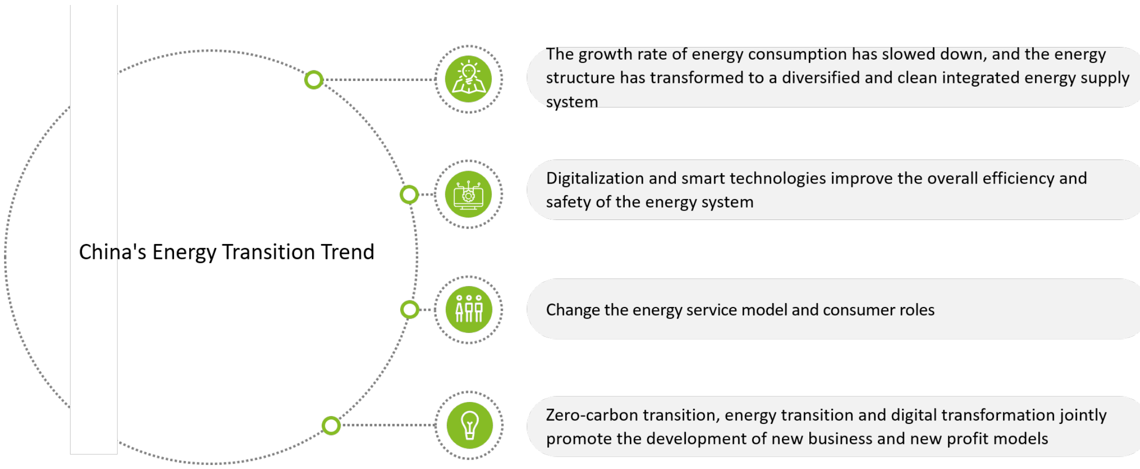
- **Optimization of energy consumption pattern:** improve energy efficiency by energy-saving technologies. Implement electricity substitution and radically transform energy infrastructure. ￿ .

- **Energy system and network adjustment:** a high proportion of renewable energy integration requires the establishment of new energy systems and networks, so as to achieve efficient absorption of renewable energy, safe operation of power grid and efficient and flexible market mechanisms.

- **Market-oriented reform:** China needs to push forward the market-oriented reforms in oil and gas industry and. build a power market system that connects mid-and long-term electricity markets, spot markets and ancillary service markets.

III. Trends of China's energy transition

The pathway of China's energy transition is also a process of overcoming the above challenges. China's energy transition presents four major trends.



Source: Deloitte Research

Figure 5: Trends of China's Energy Transition

1. The growth rate of energy consumption has slowed down and the energy supply will transform to a diversified, clean and integrated system

The growth rate of China's energy consumption has slowed year by year. China's total primary energy consumption was 4.98 billion tons of standard coal in 2020 [21]. The numbers are expected to be 5.6 billion and 6 billion tons of standard coal in 2025 and 2030 respectively [22]. The proportion and strategic position of fossil fuels and renewable energy will be switched. The energy supply will transform from high-carbon structure to a diversified, clean and integrated system, allowing the coordination of various energy types including electricity, heat, cooling energy, gas, water ,and hydrogen. At the same time, energy efficiency will be improved and the proportion of electricity in the energy consumption will increase. New energy consumption models such as integrated consumption and prosumers will emerge.

2. Digitalization and smart technologies improve the overall efficiency and safety of the energy system

Transiting to an integrated energy system will be accompanied by coordination among various energy sources, as well as the improvement of data utilization in energy production, transmission and consumption. Digitization and smart technologies will fully tap and utilize the data value of all kinds of energy throughout the life cycle: 5G provides energy systems with ultra-wideband and ultra-low latency; IoT enables online access and data collection of massive devices; and cloud computing and artificial intelligence improve the efficiency of calculation, processing and analysis of energy big data. Energy enterprises may optimize decision-making through data analysis, thereby improving the operational efficiency of energy production, transmission, trading and consumption and ultimately improving the overall efficiency and safety of the energy system. Take the power system as an example, it will inevitably become more efficient, interactive and intelligent driven by the large-scale integration of clean energy, combined with the utilization of interactive facilities such as distributed energy, energy storage, electric vehicles and smart electricity equipment, accompanied by the extensive application of information technologies such as big data, cloud computing, IoT and artificial intelligence.

3. Changes in energy service models and consumer roles

During the process of energy transition, the diversified and integrated development of energy services provides the consumers with various energy options. The relationship between energy consumers and suppliers has gradually changed from a one-way supply-demand relationship to a two-way interactive model. Energy consumers will also become energy producers, dealers and storage providers. Energy consumer's buying decision will not only depend on price, but also on factors such as energy quality, ease of use, environmental impact and technological change.

4. Zero-carbon transition, energy transition and digital transformation jointly promote the development of new business and new profit models

The deep integration of zero-carbon transition, energy transition and digital transformation is driving profound changes in energy supply-demand model and business ecosystem, giving birth to new business and new profit models. For example, energy enterprises may provide one-stop smart energy services by consolidating capabilities in energy consulting, green energy substitution, multi-energy complementation, integration of investment, construction and operation, energy efficiency management, carbon asset management and digital platform etc., resulting in the two-way interaction with users and the sharing of ecosystem data. Non-traditional energy enterprises such as digital technology and Internet companies have entered the market, forming a business ecosystem with the coexistence of traditional energy enterprises and emerging service providers.

Section 5 Cases Study

I. Enel - Promote decarbonization on energy supply, grid and user sides with a circular economy strategy

Enel implements the "circular economy strategy" to guide its energy transition: accelerate the decarbonization of the power supply side by investing in renewable energy while simultaneously divesting coal-fired power plants, increase renewable energy integration in power grids by developing and applying smart grid technology and support customers' electrification and decarbonization with digital solutions.

Enel (Enel S. p.A. / Enel Group) is the largest public utility company in Europe, the world’s largest private renewable energy operator and the largest private power distribution company. The Group's business covers 47 countries around the world, with a revenue of EUR 65 billion and a gross profit of nearly EUR 18 billion in 2020[23].

1. Background of transition

In response to climate change, major energy groups have initiated energy transition characterized by decarbonization, electricity substitution and digitalization. Enel Group is engaged in power generation, power distribution and power retailing, however these businesses belong to different business lines and it is difficult to effectively coordinate these business lines along the power value chain. Moreover, with the changing energy industry, managing the Group's business has become ever more complex. In order to adapt to the development trend of the energy industry and improve internal management, Enel urgently needs a transition.

2. Transition goals

Enel announced its 2050 zero-carbon goal in 2019 and plans to invest EUR 160 billion between 2021 and 2030 to promote the development of decarbonization, electricity substitution and digital platform:

- Becoming a "Renewable Supemajor", tripling the renewables capacity operated from 49GW in 2020 to 145GW in 2030, to reach a global market share of more than 4%;

- Becoming a world leader in power grid reliability, service quality and efficiency, making the power grid more resilient and increase the degree of digitalization to enable more effective and efficient management;

- Becoming the reference energy partner for all customers segments (industrial and commercial customers, transportation, households, cities, etc.), helping customers achieve decarbonization, emission reduction and electric energy substitution, enabling the creation of benefits in terms of emissions, costs and efficiency.

3. Transition measures

- **Guide the transition with the "circular economy strategy"**

Enel announced in 2016 that it will integrate sustainability into its business model and business operations and formulated a "circular economy strategy". Under the guidance of this strategy, Enel Group has substantially reduced GHG emission while achieving financial and business growth. During the period from 2015 to 2019, Enel Group's revenue increased by 6%, renewable energy generation increased by 20%. The number of electricity customers increased by 14% and GHG emission decreased by 41% [24].

- **Decarbonizing power generation by heavily investing in renewable energy and divesting coal-fired power plants**

Enel plans to invest EUR 7 billion per year by 2030 to triple the scale of its renewable energy assets (installed capacity of 145GW) and always adhere to the "circular economy strategy". For example, in the context of building solar power plants in a semi-desert area, Enel designed a series of technical measures based on its Creating Shared Value (CSV) model to alleviate the local water shortage problem. In addition, by shutting down coal-fired power plants to accelerate power supply-side decarbonization. Enel’s Futur-e project also uses the concept of circular economy, seeking new ways for old coal-fired power plants through cooperation with local governments and communities to turns them into industrial campus, museums, or leisure and cultural places.

- **Continue to develop and apply smart grid-related technologies to improve renewable energy integration in power grids**

Enel continuously improving renewable energy integration and enhancing the flexibility and stability of the power system by building smart grids, laying fiber optic networks, deploying grid-side energy storage systems and installing smart meters in large-scale. Enel also set up "Flexibility Lab" to cooperate with other energy supply enterprises and power distribution system operators to develop and test products and services designed to improve the flexibility of the power system. At the same time, Enel is adhering to its "circular economy strategy" to promote the grid-side decarbonization by recycling and reusing grid materials and equipment.

- **Support customers' energy conservation and emission reduction with digital solutions**

Enel X, an integrated energy service company established by Enel, provides digital products and various value-added services to industrial and commercial customers, transportation, urban and household users. Its services include energy efficiency improvement services, demand response services, EV charging services and urban energy-saving services, etc. Relying on its digital solution Enel X Connect, Enel X would combine with energy consulting services to provide the customers with customized energy use solutions. Enel X Connect consists four main digital tools: Utility Bill Management, Energy Exchange, Energy Management and , Comfort Management. It aims to improve user experience, helping customers manage energy consumption and optimize energy use during the process of energy purchase, consumption and optimization.

II. Singapore: synergies between a smart country and low-carbon energy transition

Singapore is vigorously promoting the simultaneous development of its Smart Nation initiative and energy transition through improving energy efficiency, developing renewable energy and empowering the smart energy and green development with digital technology, etc.

Singapore has achieved remarkable results in energy transition. According to the 2021 World Economic Forum report, Singapore’s "Energy Transition Index (ETI)" ranks first in Asia and 21st in the world. As is known to all, Singapore is severely deficient in energy resources. However, energy has not hindered its economic development, yet has become a starting point for its economic development.

1. Background

As a low-lying city, Singapore has at least 30% of land that is less than five meters above sea level. It lacks natural resources and is extremely vulnerable to climate change. Thus, the country has a strong sense of climate crisis.

Prior to its energy transition, about 95% of Singapore's electricity was supplied by natural gas, while its natural gas is mainly imported from Malaysia and Indonesia. Singapore's energy source was over concentrated and its storage capacity was low. As Singapore's energy demand continues to grow, diversified energy supply became the key to ensuring energy security.

2. Transition goals

In order to achieve carbon peak by 2030 (65 mt of carbon emissions), Singapore has set two goals for energy transition. The first is to strengthen energy resilience to ensure that it does not rely on any single energy supply channel. Due to its favorable conditions for utilizing solar power, Singapore vigorously develops solar energy and has set a long-term goal of obtaining 20% (at present: about 2%) of its electricity from solar energy by 2050. The second is to strengthen energy conservation and emission reduction and improve energy efficiency. By 2030, HDBs will reduce energy consumption by 15% through the deployment of smart LED lights and solar energy. 80% of the newly developed building projects will be ultra-low energy consumption buildings. All newly added vehicles and taxis will use clean energy.

3. Transition measures

- **Promote energy transition along developing smart nation**

Singapore launched the "Smart Nation 2025" strategy in 2015. It is a the government builds a "Smart Nation Platform" and by building infrastructure and operation system across the island, it allows the government to collect, connect and analyze data and provide better public service.

By coordinating smart city construction and energy planning, Singapore has created integrated solutions including urban management, transportation, energy, environment, etc., to achieve smart energy management and green development. For example, a smart energy town provides residents with a variety of smart energy services such as central cooling, fast and overnight charging of EVs and user digital display screens. The various energy services are displayed on the OneTengah digital platform, which is convenient for facility managers to monitor the status of the system, detect problems and take actions timely. Residents may use the MyTengah App to view household water and electricity consumption and control the usage of central cooling systems, etc., so as to live a green lifestyle.

- **Promote the utilization of renewable energy and improve energy efficiency through technology and design innovation**

Through SolarNova Programme, Singapore intends to install rooftop solar PV on HDBs to expand the utilization of solar energy. Singapore tackles with land restrictions through the integration of offshore floating solar PV systems and rooftop solar. It increases the proportion of renewable energy and strengthen energy resilience by investing in urban microgrids, distributed energy,

energy storage systems and other technologies. It improves the comprehensive energy utilization efficiency by promoting energy conservation and emission reduction on the energy consumption side, such as low-rise buildings with negative energy consumption and mid-rise and high-rise buildings with zero energy consumption, etc.

- **Empower smart energy with digital transformation**

Typical examples are virtual power plants, smart grids in business campus and P2P green energy trading platforms.

  - The Energy Market Authority of Singapore, together with Sembcorp and Nanyang Technological University, developed a virtual power plant to integrate real-time information of various distributed energy sources and optimize the power output of renewable energy across the island.

  - The Punggol Digital District (PDD) business campus smart grid project under construction aims to achieve energy data sharing between buildings and improve energy efficiency and reduce carbon emission through integration with the open digital platform in this region. It is estimated that this smart grid project could reduce carbon emission by 1,700 tons per year;

  - Electrify's SolarShare project uses blockchain technology to build a P2P green energy trading platform, allowing users to trade renewable energy with other uses nearby.

Section 6 Summary

Climate change brings huge risks to global community. All countries should take immediate actions to reduce GHG emissions and work together to build a zero-carbon future or achieve zero-carbon development. Critical actions include large-scale deployment of clean energy, upgrading of industrial manufacturing technology, green transformation of the transportation industry, improvement of building energy efficiency and development and utilization of carbon-negative technologies.

Energy transition is the most critical factor in achieving carbon neutrality. By developing clean energy, improving technological innovation, focusing on energy security and promoting international cooperation, we can effectively realize the energy and consumption mode transition and promote the development of human society towards a sustainable future.

Digital transformation plays an increasingly important role in energy transition and enables the transformation toward a comprehensive and integrated energy system. The establishment of a zero-carbon smart energy system is the key driver to achieve global climate goals, while maintaining world energy security and promoting economic growth.

Chapter II The Future of Energy

Section 1 Framework of the Zero-carbon Intelligent Energy System

The Zero-carbon Intelligent Energy System (ZCIESZCSES) is the choice for future energy development and the driver to achieve global climate goals and maintain global energy security and economic growth. The planning of future energy is introduced in this chapter to elaborate the goals, blueprint, characteristics, core capabilities and pathways of the system.

In general, it is proposed in the framework that the energy system should be able to achieve three goals, i.e., being "safe and reliable, highly efficient and economical, carbonless and intelligent". A blueprint of the system should be drawn under eight typical energy scenarios, namely, "centralized clean energy supply, clean utilization of fossil fuel, highly efficient application of biomass and hydrogen energy, zero-carbon intelligent energy network, zero-carbon intelligent industrial campus, distributed zero-carbon communities, zero-carbon intelligent Internet of vehicle, zero-carbon intelligent air transportation and shipping". It should be made clear in the framework that the energy system should have five outstanding characteristics: "zero-carbon energy supply, multi-energy complementation and coordination, comprehensive optimal energy efficiency, full digital empowerment, cross-border model innovation". Core competence of three transitions, i.e., "zero-carbon transition, energy transition, digital transformation" should be upgraded. The zero-carbon intelligent energy system building pathway should be promoted by the integration of four flows, i.e., "energy flow, carbon flow, information flow and value flow".

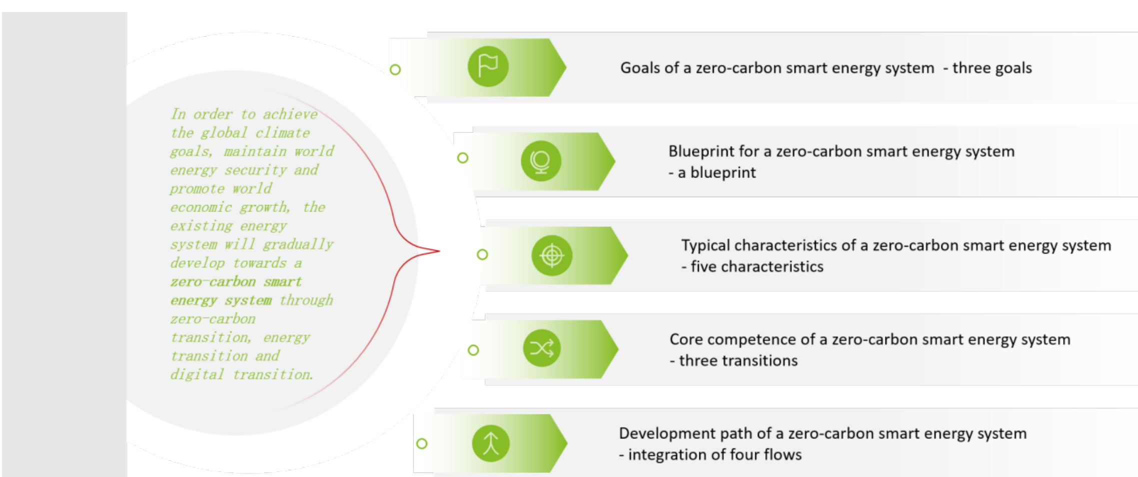


Figure 7: Framework of Zero-carbon Intelligent Energy System

Section 2 Goals of Zero-carbon Intelligent Energy System

Achieve three goals of being "safe and reliable, highly efficient and economical, carbonless and intelligent".

- **Safe and reliable**

Resource endowments of different countries and regions should be taken into account in effort to: optimize energy structure, increase renewable energy proportion, improve energy self-reliance and maintain strategic security.

Clean energy supply should be diversified to: achieve multi-energy interchange and multi-energy complementation, improve the transmission, conversion, dispatch and storage capacity of energy networks, strengthen energy system resilience its capacity to respond to extreme situation for safe and reliable supply of energy.

- **Highly Efficient and economical**

Competitive and orderly energy market system should be established, market entities guided to adjust industrial structure, reduce energy consumption and emission, optimizing cost of emission reduction for the zero-carbon goal.

The proportion of green electricity should be increased in final energy, optimizing comprehensive utilization efficiency of energy in the whole society.

New energy technology should be developed remarkably to reduce new energy development and utilization cost, creating competitive market prices and sustaining economic growth.

- **Carbonless and intelligent**

Renewable energy cored new energy systems should be formulated, carbon reduction and carbon-negative technologies applied to promote the complete decarbonization of energy systems, achieving green and sustainable development of energy systems.

The energy technology and digital technology integration should be accelerated so that self-adaptation, regulation and optimization is enhanced in energy system, thus upgrading technological and re-structuring industries, innovating business and commercial models.

Section 3 Blueprint of Zero-carbon Intelligent Energy System

The system blueprints include eight typical energy scenarios, i.e., centralized clean energy supply, clean utilization of fossil energy, highly efficient application of biomass and hydrogen, zero-carbon intelligent energy network, zero-carbon intelligent industrial campus, distributed zero-carbon communities, zero-carbon intelligent Internet of vehicles, zero-carbon intelligent air transportation and shipping. They cover the major targeted decarbonization industries or sectors including energy, industry, construction and transportation.

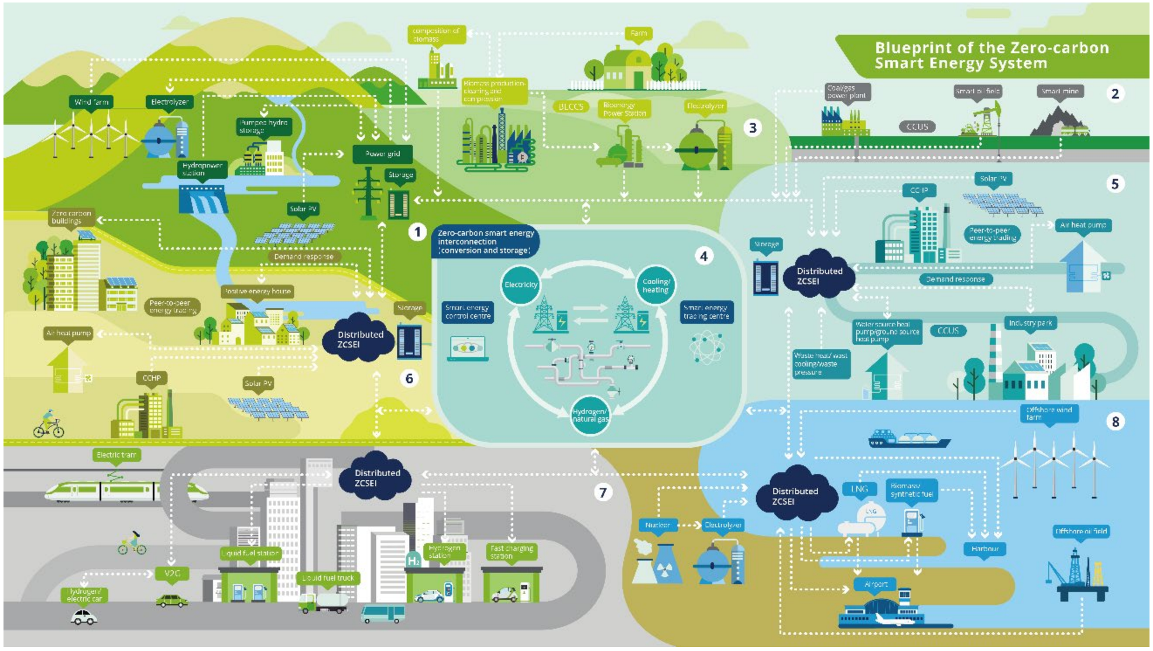


Figure 8: Blueprint of Zero-carbon Intelligent Energy System

The blueprint of the energy system is backboned with zero-carbon intelligent energy network. Typical energy scenarios are interconnected through interaction and coordination of trunk network and distributed networks, in which, new energy is main system, centralized networks and distributed networks are combined, source-network-load-storage is coordinated and interacted, multi-energy conversion, multi-energy complementation, multi-network integration and complete digital empowerment is possible in the zero-carbon intelligent energy system. The energy system is able to be in safe, reliable, highly efficient and economic operation by optimally allocating resource allocation on a larger scale from intelligent energy trading centers and control centers.

1. Centralized clean energy supply

Wind power, solar energy, hydropower, nuclear, stored energy and hydrogen cored centralized clean energy bases will be constructed in different regions with their resource empowerment. These clean energies will then be dispatched and distributed in best way in entire system through zero-carbon intelligent energy interconnection.

2. Clean utilization of fossil fuel

It is advisable green intelligent mines, green intelligent oil fields and zero-carbon intelligent power plants be constructed for clean and efficient development and utilization of coal, oil and gas, fully safeguarding energy security. Carbon-negative technologies like carbon capture, utilization and storage (CCUS) should be applied to minimize carbon emission from mining and the use of fossil fuel.

3. Efficient application of biomass and hydrogen

Modern agriculture is combined in developing cycled usage of biomass power, combined heat and power generation (CHP) and biomass fuel production. Technologies like BECCS are applied negative emission in entire process of biomass development and utilization. The nature of hydrogen as fuel, raw material and energy storage medium is used, electrolysis hydrogen production technology applied to produce green hydrogen, hydrogen transmission, distribution, storage and sales network established for highly efficient conversion between hydrogen and electricity, natural gas, synthetic fuel, etc.

4. Zero-carbon intelligent energy interconnection

Being a backbone network, the energy system supports the flexible, convenient access of multiple entities, the efficient, flexible conversion and storage of multiple energy sources. It is interconnected with distributed energy networks, so it has strong resource allocation capacities and service support capabilities. When the intelligent energy management system is in place, intelligent prediction and dispatch is possible on energy supply and demand sides, which will help stabilize the volatility of new energy on supply sides, adjust randomness of demand-side consumption and achieve continuous optimization and unmanned operation of the energy management system.

5. Zero-carbon intelligent industrial campus

Integrated energy service providers offer one-stop zero-carbon utility services. They coordinate and interact in managing demand-side and with the help of zero-carbon intelligent energy networks. They are able to increase energy self-sufficiency and comprehensive energy utilization efficiency by adopting technologies such as rooftop solar PV, heat pumps and waste heat/cooling/pressure re-use. Energy consumption intensity and carbon emission intensity in industrial campus is reduced through technological transformation, energy-saving renovation and CCUS technologies.

6. Distributed zero-carbon communities

Rooftop solar PV, solar PV curtain walls, energy-saving and environment-friendly materials, heat pumps, energy storage technology, intelligent HVAC systems, intelligent, smart lighting systems and intelligent building control systems are installed or applied in zero-carbon and carbon-negative buildings to increase energy self-sufficiency in communities. Integrated energy service providers offer one-stop zero-carbon utility services and they utilize industrial waste heat/cooling energy in steps to reduce energy consumption magnitude and carbon emission intensity in these communities.

7. Zero-carbon intelligent Internet of vehicles (IoV)

A road transportation system with electric vehicles, fuel cell vehicles, biomass fuel/synthetic fuel trucks as the main road users is expected in future. Such a system will provide a one-stop service of charging, hydrogenation and refueling through the zero-carbon intelligent **IoV**. V2G technology can be applied for controllable charging and discharging and for reliable and stable energy network, which will promote integration of the energy network with electric vehicles charging and discharging networks.

8. Zero-carbon intelligent air transportation and shipping

Biomass fuel/synthetic fuel will replace traditional fossil fuels in future aviation industry in regions with available resources. Synthetic fuel is mainly green hydrogen and CO2 based. The cost-effectiveness of biomass fuel and synthetic fuel will be continuously upgraded in future and they will sustain the aviation development. Integrated use of electricity, hydrogen energy, biomass fuel, synthetic fuel and other energy sources will be possible and decarbonization achieved in future shipping industry.

Section 4 Characteristics of Zero-carbon Intelligent Energy System

Five major characteristics: "zero-carbon energy supply, multi-energy complementation and coordination, comprehensive optimal energy efficiency, full digital empowerment, cross-border model innovation".

1. Zero-carbon energy supply

- Large-scale development and utilization of new energy with apparent cost advantages, renewable energy becoming the main energy;
- Local production and absorption of green electricity, plug-and-play of various energy facilities;
- Coordinated operation of centralized and distributed energy systems, safer, reliable and flexible hierarchical and level-to-level energy supply;
- Highly efficient exploitation and utilization of fossil fuel, applying clean, efficient and CCUS technologies for lifecycle near-zero emission;
- Applying technologies such as hydrogen and energy storage for efficient, flexible, safe and economical transmission, conversion and storage.

2. Multi-energy complementation and coordination

- Create green electricity cored energy consumption pattern, constantly upgrade full society electrification level ;
- Extensively apply energy conversion technology so that different energy like electricity, cold, heat, gas are efficiently and flexibly converted and mutually supplemented;

- New energy infrastructures are accessible in huge scale, users/producers and consumers are combined deeply in the chain. Energy is consumed flexibly and at users' own choice.

3. Comprehensive optimal energy efficiency

- Zero-carbon campus, zero-carbon factories and zero-carbon buildings cored new energy units promote integrated energy utilization efficiency and completely decouple the economic growth from carbon emission;

- Build energy-saving, efficient integrated transportation system, advocate clean energy use in transportation and improve the energy efficiency of vehicles;

- Intelligent and clean transformation of traditional industries, large-scale application of energy-saving technology, energy-saving equipment and decarbonization technology. Raise people's awareness of energy conservation and the overall energy efficiency in sustainable way.

4. Full digital empowerment

- Ubiquitous Internet of Things, holographic perception and panoramic monitoring and digital scenario of energy is available everywhere;

- Physical world and digital world are in interaction and coordination, energy system decision-making control is on real-time basis, efficient and intelligent;

- Resources are distributed and dispatched in optimized manner and digital empowerment of energy business is possible;

- Digital technologies are applied to drive the integration of four flows, namely, energy flow, carbon flow, information flow and value flow.

5. Cross-border model innovation

- Establish energy market system that integrates energy spot markets, futures markets, auxiliary service markets, carbon trading markets and green finance, where energy transaction and consumption is highly flexible and democratic and market activities are significantly increased;

- Diversified market players such as traditional energy service providers, energy equipment vendors, Internet enterprises and energy users jointly build an energy ecological value chain through cross-border operations in which customer-centered business models, such as energy-as-a-service, contract energy management, energy custody and BOT, are innovated sustainably.

- Energy big data is extensively applied in scenarios such as load forecasting, energy efficiency management, carbon asset management and demand-side response. The value creation ability of energy data is greatly improved in this way.

Section 5 Core Capabilities of Zero-carbon Intelligent Energy System

The three core capabilities, i.e., "zero-carbon transition, energy transition, digital transformation" shall be strengthened for the purpose of building the energy system. Carbon asset management and decarbonization will be promoted in various industries on the basis of their own characteristics by upgrading zero-carbon transition capacity. The transformation of energy production and consumption patterns to a green, energy-saving, efficient and economic trend is advocated by upgrading energy transition capacity so that comprehensive energy utilization efficiency is raised. Support is given to zero-carbon transition and energy transition by upgrading digital transformation that data cored production factor drives the shift of traditional energy system toward the energy system.

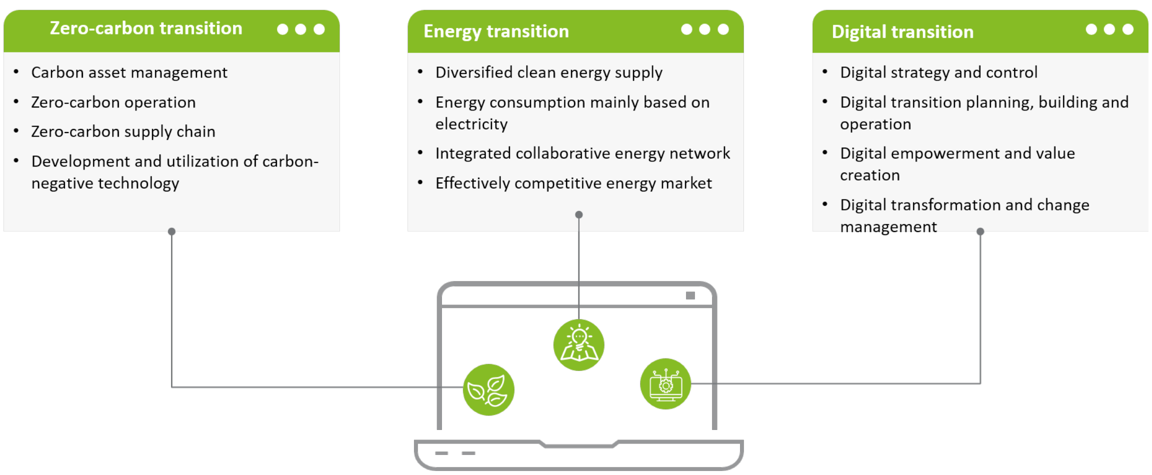


Figure 9: Three Core Capabilities of Zero-carbon Intelligent Energy System

1. Zero-carbon transition

- **Carbon asset management**

Upgrade the capacity of carbon neutrality planning, carbon emission prediction, monitoring, reporting, verification, contract performance and trading, apply green financial tools like green bonds and green credit for zero-carbon development.

- **Zero-carbon operation**

Push the construction of zero-carbon campus, zero-carbon factories, zero-carbon buildings and zero-carbon transportation, vigorously develop cycled economy and boost carbon emission reduction in the entire process of production and operation.

- **Zero-carbon supply chain**

Formulate zero-carbon supply chain standard system, ecosystem, monitoring system and evaluation system, track and evaluate the supply chain carbon footprint, promote the transition of the supply chain to green and zero-carbon direction.

- **Development and utilization of carbon-negative technology**

Strengthen the research and development and utilization of carbon capture, utilization and storage (CCUS), bioenergy and carbon capture and storage (BECCS), direct air capture (DAC) and other technologies, fortify building of ecological carbon sinks, assist those industries with difficult task of decarbonization to achieve low-carbon development.

2. Energy transition

- **Diversified clean energy supply**

Promote large-scale development and utilization of new energy, green development of hydropower, safe and orderly development of nuclear power, clean and efficient development and utilization of fossil fuel, for diversified clean energy supply.

- **Energy consumption mainly based on electricity**

Promote electrification and electric energy substitution of energy-consuming terminals, reduce energy magnitude and carbon emission intensity by promoting comprehensive cascaded utilization of energy, energy-saving and decarbonization transformation of production processes and equipment and demand-side response and virtual power plant construction.

- **Integrated collaborative energy network**

Build integrated electricity, cooling, heating and gas energy networks, hydrogen production, transportation, storage and sales networks, EV charging and discharging networks, centralized and distributed energy storage networks, integrating multi-energy conversion, multi-energy complementation and multi-networks.

- **Effectively competitive energy market**

Develop unified, open and effectively competitive power markets, distributed energy trading sectors, coal, oil and natural gas trading markets and carbon trading sectors, guiding market entities to improve energy efficiency and zero-carbon development.

3. Digital transformation

- **Digital strategy and control**

Develop digital strategies and visions, optimize organizational and control models and carry out data-driven business decision-making. Zero-carbon transition, energy transition and digital transformation strategies are mutually supportive and organically integrated, becoming important part of the enterprise-level transition strategy.

- **Digital transformation planning, building and operation**

Conduct top-level design of digital transformation and formulate digital transformation plans, build digital projects, optimize digital governance system, upgrade digital capabilities and continuously improve digital operations. Digital transformation should be done in view of business need for zero-carbon transition and energy transition, provide support in terms of platforms, data, algorithms and computing power.

- **Digital empowerment and value creation**

Build digital platforms for platform empowerment and data enablement, build energy ecosystem, promote the sharing of energy big data, explore the value of energy big data, innovate commercial models, business models, product services and ecosystem integration.

- **Digital transformation and change management**

Upgrade digital literacy among enterprises and employees, cultivate digital culture and change culture, build talent pools for digital transformation, cultivate cross-domain talents who grasp new technologies, business and have data management experience. This is important for the success of digital transformation.

Section 6 Development Path of Zero-carbon Intelligent Energy System

Energy flow, carbon flow, information flow and value flow are fused step by step by building three-element transition core capabilities. In this way, zero-carbon intelligent energy system with data cored production elements is born gradually, accelerating energy industry digitalization, upgrading network and intelligence level of the energy sector.

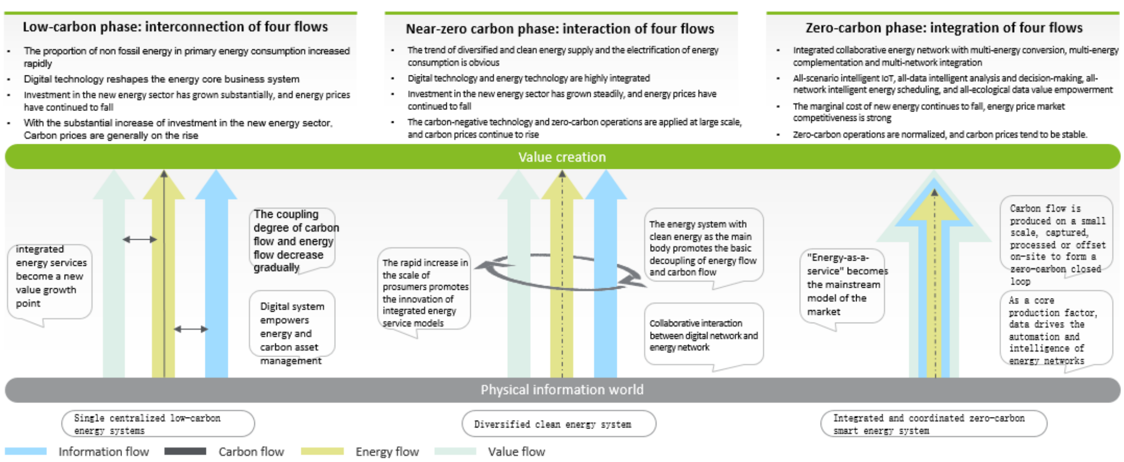


Figure 10: Development Path of Zero-carbon Intelligent Energy System

I. Low-carbon phase: interconnection of four flows

A single and centralized low-carbon energy system remains dominant and fossil fuels are still on the play though the coupling of carbon flow and energy flow declines gradually. Digital technology empowers energy and carbon asset management and provides support for integrated energy service to become a new value growth point.

- The proportion of non-fossil fuels in primary energy consumption is on rapid rise. The fast growth of proportion of new energy has led to drop of the coupling between energy flow and carbon flow.

- Digital technology reshapes the energy core business system and its integration with energy technology supports the extensive interconnection of various energy units.

- Investment in the new energy sector is on remarkable rise, decarbonization investment portfolios are being optimized. Mergers and acquisitions have become a booster for the transformation of energy industries. Energy prices continue to fall.

- Carbon-negative technology and zero-carbon operations are to be mature. The carbon price mechanism has expanded globally. Carbon prices are generally on the rise.

II. Near-zero carbon phase: interaction of four flows

The diversified and distributed clean energy system has become the mainstream. The energy system based mainly on clean energy is basically disengaging energy flow and carbon flow. Digital networks and energy networks interact with each other to support efficient, flexible conversion of different energy forms. Large-scale distributed energy and centralized energy is mutually interoperable. The rapid increase in the scale of prosumers significantly innovates integrated energy service models.

- Diversified and clean energy supply and electrification of energy consumption is the apparent trend. The conversion efficiency between different energy has greatly improved.

- Digital technology and energy technology are highly integrated. Energy big data is completely ecologically coordinated and shared, driving the deep exploration of customer value.

- The investment in new energy sector has grown steadily. A large number of high-carbon stranded assets are to be handled. Energy prices continue to fall.

- Carbon-negative technologies and zero-carbon operations are being applied at large scale. The carbon trading mechanism is breaking geographical and industrial boundaries. Carbon prices continue to rise.

III. Zero-carbon phase: integration of four flows

Once the energy system is built, data, being core production element, drives the automation and intellectualization of energy networks and promotes the integration of four flows (i.e., the energy flow, carbon flow, information flow and value flow). Digital technologies empower energy business model and commercial model innovation. Energy-as-a-service has become the mainstream model of the market and carbon flow is being produced on a small scale, which is captured, processed or offset on-site to form a zero-carbon closed loop.

- Integrated collaborative energy networks with multi-energy conversion, multi-energy complementation and multi-network integration.

- All-scenario IoT, all-data intelligent analysis and decision-making, all-network intelligent energy distribution and whole-ecosystem data value empowerment.

- The marginal cost of new energy continues to fall. Energy transactions are highly flexible and energy prices are highly competitive.

- The application system of negative-carbon technology is mature, zero-carbon operations are normalized, an open, transparent carbon price mechanism is formed and carbon prices tend to be stable.

Chapter III Energy Transition Paths

Section 1 Power Industry Transition Paths

Electricity, a clean and efficient secondary energy, plays a pivotal role in energy transition process. Accelerating the transition of power industry is the key to promoting energy transition.

I. Guidelines of power industry transition

Build a new power system based mainly on new energy, take wind power and solar PV power as main increment of installed power and coal power as auxiliary energy. Coordinated supply of multiple energy sources such as “electricity, heat, cold, gas and hydrogen” will be formed transversely, a comprehensive energy supply system developed in the way of multi-energy complementation and coordination, interaction within "source-grid-load-storage" interacted and optimized longitudinally, the characteristics of coordination and complementation, power grid-side efficient absorption, load-side flexible adjustment, and real-time balance of energy storage on source side fully put on play, satisfying individualized need of energy consumption. The key points of power industry transition will be analyzed from three dimensions of zero-carbon transition, energy transition and digital transformation.

II. Zero-carbon transition

1. **Power source: both structural transition of power generation and the management of carbon emission are taken into account**

Plan mid-to-long-term power generation structural transition, invest in assets and technologies that are highly economical and conducive to achieve the net-zero goals, develop a technical combination of "renewable energy power generation + energy storage" and "thermal power + CCUS", reasonably design a pragmatic phase-out path of coal power.

Push the integration of carbon trading sectors with electricity markets, incorporate carbon prices into power generation costs, encourage clean energy development by changing the priority of power sources, accelerate the transition and phase-out of high-emission fossil fuels.

With the improvement of monitoring systems and advancement of monitoring technologies, gradually introduce data quality rating systems and increase the penetration rate of CEMS (Continuous Emission Monitoring System), upgrading the accuracy of carbon accounting.

Set up special carbon asset management companies or departments in electricity enterprises to coordinate corporate carbon management, participate in carbon financial markets, hedge the risk of rising emission costs with financial means and effectively revitalize corporate carbon assets.

2. Grid: plan grid and power source construction as a whole

Optimize grid planning and layout, support the large-scale access to and absorption of renewable energy, focus on promoting the transformation and upgrading of the distribution network and build a microgrid that mainly absorbs distributed renewable energy. Develop and apply green and smart power transmission and distribution equipment to improve energy efficiency and decarbonize the grid.

3. Load: parallel development of technologies, application scenarios and markets

Accelerate research and promotion of electricity substitution technologies, establish an electricity-centered energy consumption system with complementary hydrogen and biomass and reduce carbon emission from various terminals.

Encourage decarbonization of industrial clusters. Deploy zero-carbon smart campus management platforms in industrial campus, business campus, export processing zones, coordinate electrification of energy-consuming terminals, build energy conservation, smart energy management, carbon asset management and circular economy systems, achieve green development of the campus.

Optimize renewable energy power trading mechanism and promote power user-side procurement of renewable energy.

4. Storage: use energy storage technologies to raise absorption capacity of renewable energy

Advocate the application of energy storage to stabilize renewable energy fluctuation, shift grid peak-load and manage demand-side, increase absorption capacity of renewable energy.

III. Energy transition

1. Power source: access to new energy at high proportion

Develop wind and solar power both in centralized and distributed ways to optimize the power source structure, improve the grid's capacity to integrate new energy through joint operation of wind power stations, PV power stations and energy storages, upgrade the efficiency and reliability of new energy through new wind and solar power technologies, digital smart operation and maintenance and new environmental protection materials; accelerate flexibility renovation of coal/gas-fired power plants, promote the transformation of the role of fossil fuels from primary energy sources to adjustable energy sources, strictly control newly-installed coal-fired capacities, phase out certain coal-fired power plants and use CCUS-equipped coal/gas-fired power plants for peak-shaving of renewable energy.

2. Grid: optimize resource allocation with highly resilient grid

Future power grid will be in operation in the form of AC/DC long-distance transmission, regional grid interconnection and interaction between the main grid and the microgrid. AC/DC long-distance transmission technologies will be adopted for whole network distribution and balance of centralized clean power supply. Interconnecting and interactional technologies between the main grid and the microgrid will be applied for local integration and absorption of distributed energy. Energy storage and demand-side response technologies are used to maintain the integration of new energy and safe and stable operation of the system.

3. Load: upgrade electrification, interaction and controllability level at load side

Improve the electrification level of the industrial, construction and transportation sectors, apply automation and smart technology to enhance the integrated efficiency of energy. Coordinate with power sources, power grid, load and energy storage through demand-side response and the construction of virtual power plants, increase the proportion of green power, suppress the fluctuation of the load curve, develop energy use model to interactional and controllable trend.

4. Storage: multi-scenario application of energy storage

Promote the application of energy storages in different segments of the power industry, improve the operational reliability of power system or enhance the ability to receive new energy. For instance, wind/solar power stations + energy storage, energy storage + thermal power units jointly take part in frequency modulation auxiliary service market, stored energy, being independent resource, takes part in frequency modulation auxiliary service market, the connected stored energy is used to upgrade grid capacity, stored energy at user's side helps peak-load shifting and load balancing, V2G technologies are applied to achieve controllable EV charging and discharging.

IV. Digital transformation

1. Empower integration of 'source-grid-load-storage' through digitalization

Rely on technologies including the Cloud, big data, IoT, mobile Internet, artificial intelligence, blockchain, break data barriers of all segments of the power industry chains, foster the multi-directional interaction of "source-grid-load-storage" and drive smart regulation and structural transition of power supply with massive data.

Use digital technologies to connect power sources of different types at source side, strengthen the monitoring and prediction of new energy output, integrate wind, hydro, thermal power stations and energy storages. Strengthen the flexible adjustment at power source, build digital twin power grids that cover whole processes and all links of production at grid side, empower smart decision-making and distribution control of the grid. Automatically adjust load with digital technologies at load side. Combine load-side resources such as distributed power sources, charging stations and energy storage to form a virtual power plant and to facilitate supply-demand interaction. Monitor power source, power grid, load, battery at energy storage side and apply its flexible adjustment performance to safeguard the reliable and economic operation of the power system.

2. Build a power big data model to deeply explore data value

Manage and operate data resources as core assets, empower science-based planning, smart operation and business model innovation in power industry. For instance, use the data model to plan science-based investment and select optimal plans for renewable energy investment. Develop multi-scenario power grid planning based on data analysis and select power grid planning schemes keeping safety, reliability and cost-effectiveness in mind. Build equipment energy efficiency models, conduct real-time load analysis and forecasting and optimize the energy consumption, energy efficiency and energy use management. Optimize charging and discharging decision-making model, automatically adjust charging and discharging parameters and improve the utilization rate and economic efficiency of energy storage facilities. By integrating the big data with the external data such as those from governments, enterprises, or consumption, environment and weather, build power big data analysis models and application scenarios such as power economic index, supply chain finance and enterprise multi-dimensional portraits.

3. Comprehensive digital energy service

Build an integrated energy service platform on the basis of cyber-physical system coupling technology, intensively access to and perceive on real-time basis its operating status. Apply digital technologies to scenarios such as multi-energy complementation and coordination control, synergetic distribution of power source, power grid, load and energy storage, energy optimization management, hybrid energy storage utilization, energy efficiency management and control and smart operation and maintenance, achieve multi-energy coordinated supply and integrated cascaded utilization of energy, upgrade the efficiency of energy system and reduce the energy production and consumption costs.

Section 2 Transition Path of Oil & Gas Industry

I. Guideline for oil and gas sector transition

With the world's major economies announcing net-zero goals, the global oil and gas market has undergone tremendous changes, but the special role of oil remains irreplaceable. With the gradual decline in direct consumption of oil and gas, the oil and gas industry will present two trends: **(1) transit to international integrated energy companies and build low-carbon asset portfolios; (2) innovate and develop the industry based on traditional oil and gas business + carbon-negative technologies.** Regardless of the trend, oil and gas enterprises need to strengthen cooperation with organizations involved in new materials, new technologies, new equipment and professional services, expand their ecosystem, improve operation and innovation capacities, study different business models and formulate rigorous capital expenditure methods for their energy transition.

II. Transition to international integrated energy companies and build low-carbon asset portfolios

1. Zero-carbon transition

- Comply with international standards and relevant national laws and policies

Oil and gas enterprises, in course of expanding their business to other energy fields, need to comprehensively consider and follow the zero-carbon transition-related policies, regulations and industry standards. For instance, German carbon neutrality-related legal system (including the Renewable Energy Law and the National Hydrogen Strategy) guides domestic companies to transit into integrated energy companies. The French government has implemented the Energy Transition for Green Growth Act and the Mid- and Long-term Energy Plan to provide paths and safeguard for green energy transition of national enterprises.

- Strengthen the carbon asset management mechanism

Build a carbon asset management mechanism, count and analyze direct and indirect carbon emission from different sectors in production and operation, conduct inspection, verification and trend forecast, optimize low-carbon asset portfolios, promote green transition of product structure, support the mechanism with carbon offset measures such as purchasing carbon credits and afforestation for low-carbon development.

2. Energy transition

- Step into renewable energy sector

Develop renewable energy technologies of different types for diversified transition, foster the competitiveness in renewable energy sector. For instances, to acquire renewable energy enterprises and take the advantages of ocean operation to develop offshore wind power plants. To boost downstream business innovation by deploying charging stations.

- Develop hydrogen industry chains

Oil and gas enterprises can use their industrial advantages: realize integrated development of both hydrogen and oil & gas sectors through upstream hydrogen production, midstream storage and transportation and downstream utilization, actively develop green hydrogen manufacturing technologies, increase the proportion of hydrogen business and build the entire industrial chain of hydrogen industry.

3. Digital transformation

- Integrate systems among different sectors

Build an integrated energy management platform, offer directory and automated services, promote the integration of diversified energy services and various business sectors, achieve information sharing, interconnection and coordination among sectors, promote the coordination of the upstream, midstream and downstream industrial chains and optimize global ecosystem supply chain.

III. Innovation and development based on traditional oil & gas business + carbon-negative technologies

1. Zero-carbon transition

- Strengthen carbon asset management

Develop an overall strategy for carbon asset management, establish a carbon asset management mechanism and implement plans for carbon emission statistical analysis, inspection and verification and trend prediction in the production and operation. Foster recruitment and training of talents in carbon accounting, carbon trading and carbon consulting, upgrade the capacities in managing carbon asset portfolios, credits, trading and performance.

- Develop carbon-negative technologies

Traditional oil and gas enterprises are required to intensify the development of various carbon-negative technologies for systematic utilization. CCUS, methane capture technology, CO2 reuse technology are applied to extend the clean carbon sequestration industry chain and promote low-carbon transition of the fossil fuels industry. Companies such as British Petroleum, Shell and Total have jointly established the Northern Endurance Partnership (NEP) to develop offshore CO2 transportation and storage infrastructure in the North Sea of the United Kingdom and to realize the industrial application of carbon-negative technologies.

2. Energy transition

- Conduct energy conservation and consumption reduction, improve resource utilization

Adopt unconventional oil exploitation technologies for benign production increase or stable production, improve the energy utilization efficiency in production by replacing production equipment. Deploy the latest technologies to control carbon emission in production. Reduce waste and enhance the flexibility of the supply chain through three-phase separation, apply exhaust fume recycling technologies and additive manufacturing methods.

- Increase the use of renewable energy

Expand clean energy substitution in production, transform electrification in production and operation, adopt renewable energy technologies such as solar PV and geothermal power to increase the self-sufficiency rate of electricity.

- Coordinate transportation proactively and optimize production decision-making patterns

The decline in oil and gas consumption and the long-term drop in oil prices have prompted the oil and gas industry to improve overall efficiency and reduce operating costs. Oil and gas enterprises reduce fuel consumption and carbon emission by optimizing the logistics links. For instances, coordinate logistics equipment such as land transportation and ships, optimize logistics models and realize the sharing of transportation capacity; Oil and gas refineries are driven by market demand to optimize their production decision-making patterns and improve their production efficiency.

3. Digital transformation

- Improve production and operation

Apply IoT technology to acquire, transfer, analyze and process data at perception layer, transfer layer and application layer, use digital tools such as digital twins and virtual reality to simulate scenarios, monitor operations, track energy usage, optimize the production process of oil and gas industry and improve quality and reduce consumption. Adopt artificial intelligence technology in precise modeling of oil and gas reservoirs, optimizing of drilling operations, dynamic diagnosis of oil and gas equipment and preventive maintenance. Upgrade production management and analysis and decision-making capacities. Explore application scenarios of AI, blockchain and 5G technologies in oil and gas sectors and gradually use new technologies to empower business.

- Provide analytical support for management decisions

Improve the data governance system, strengthen big data analysis and data insights capabilities and enhance the complete life-cycle management capabilities of data assets to fully explore the value of data assets. Use OSDU data platform for multi-disciplinary collaborative operations and build an integrated collaborative system of exploration and development through data standardization, scientific research results sharing and digital transfer, optimize the precise decision-making in oil and gas exploration, development and production segments.

Section 3 Transition Paths of Coal Industry

I. Guideline for coal industry transition

Given the proportion of coal in energy consumption gradually declines, coal enterprises should actively proceed to transition and upgrading. Since coal sector's carbon emission mainly comes from coal consumption, the key to energy transition and zero-carbon development for these enterprises is how to optimize the industrial layout and industrial structure and how to promote the coal consumption-side energy conservation and emission reduction. Coal companies should adhere to the direction of "coordinated coal reduction and decarbonization" and gradually realize energy transition.

II. Zero-carbon transition

1. Develop carbon-negative technologies

Coal enterprises should increase research and investment in various carbon-negative technologies, provide technical support to achieve near-zero emission of the industry. The captured carbon can be re-used as chemical raw materials to improve the economic efficiency. For instance, the China Energy's CCS model project is currently China's largest coal-fired power plant model project which covers the whole process to capture CO2 from combustion and displace oil and reserve carbon. It has successfully captured large-scale CO2 in the flue gas of coal-fired power plants, a milestone of achieving double-carbon goal.

III. Energy transition

1. Coal production side - focus on cleanness and efficiency

Foster the research and development and application of high-efficiency mining technologies, accelerate intelligent mine construction, promote clean production, build ecological green coal mines and develop quality production capacity through mergers, reorganizations and international cooperation. Optimize simultaneously logistics processes and coordinate logistics equipment to reduce fuel consumption during transportation.

2. Coal consumption end - strengthen technological innovation

Transform coal from fuels to both raw materials and fuels, realize "using coal without carbon emission" through coal low-carbonization technology innovation and coal industry low-carbonization. Develop new modern coal chemical industries such as coal-to-liquid, coal-to-gas, coal-to-methanol and fine chemical products. Promote clean and efficient utilization of coal, advocate coordinated development of upstream and downstream coal industries and build the future coal industries (low-carbon transition + high-tech upgrade + demand-oriented scale).

Optimize blast furnace process, reduce energy consumption, apply technologies such as waste heat recovery, dry quenching and jet alkaline oxygen converters for energy conservation and emission reduction in consumption segments. Implement precise tailor-made supply and cooperate closely with the enterprises in supply chains (such as steel, electric power, etc.) to achieve exact production and launching, creating an industrial chain of reduced carbon emission.

IV. Digital transformation

1. Digital application of coal industry chains

Upgrade low-carbon and clean coal production capacities and apply digital technology in all segments of coal industry chain (coal development, mining (stripping), transportation, ventilation, washing, procurement, sales, security assurance, operation management), including upgrading the intelligent level of mining equipment (such as large unmanned compound mining equipment), realizing high-efficiency data transfer (such as underground 5G technology). Reduce losses during execution while improving coal production efficiency, work quality and safety.

2. Digital application of coal value chain

Integrate and optimize the integrated systems and related technologies in the coal value chain. Rely on digital technologies to conduct high-level analysis, improve system decision-making and to achieve coordination in the upstream and downstream industries. Build an integrated smart management system for coal industry and optimize the layout of the new coal chemical industries for high-efficiency operation.

Section 4 Summary of Energy Transition Paths

Digital transformation is important support for energy transition and zero-carbon development. Upon path analysis on energy sector transition, it can be concluded that the development and application of carbon asset management, zero-carbon operation, zero-carbon supply chain and carbon-negative technologies may promote zero-carbon transition of energy sectors. The transition of energy supply, consumption, network, market and other sectors will build the energy supply structure based mainly on clean energy. This will improve energy efficiency of various industries. The integration of four flows (i.e., energy flow, carbon flow, information flow and value flow) will empower energy service model innovation, accelerate digital and intelligent processes of energy production, transmission, storage and consumption and build a multi-network integrated zero-carbon smart energy system.

Chapter IV Supporting System of Energy Digitalization

Section 1 Definition of Energy Digital Transformation

Future intensive integration of digital economy and real economy will bring new opportunities and challenges to the energy sector. It is necessary to lay a digital path for energy transition and zero-carbon development through digitalization. Huawei will work with its partners to assist the global energy industry build the energy system and create green and low-carbon new value together with energy enterprises.

I. Definition and connotation of digital transformation

With the passage of time, the connotation of digital transformation has always been evolving. We believe that, in the current era, digitization is a data-centered ideological and theoretical system, methodology and technical architecture system and its essence is to demand productivity from data. As far as digital transformation is concerned, digitalization is the direction and trend and transition is the path and means. The essence is a change driven by software and services, accompanied by the reconstruction of production relations. We must hold the anchor of value creation, change our habits and pay for the data and knowledge. We need to make the value of software and services explicit, allowing the transformation clear and clean and proceed with it continuously. This is precisely the aspect that non-digital native companies tend to ignore. The "data-centered" is the core feature that distinguishes digitization from informatization and it is also the basis of intelligence.

II. Digital transformation has become a global development consensus

The EU has made it clear in its 2020 work plan that it will focus on promoting the transformation of EU's economy and society to green and digitalization from 2020 to 2025. Japan has set up a special work organization for digitalization to promote the overall development of digitalization. China has put forward the work direction of promoting digital industrialization and industrial digitization and guiding the deep integration of digital economy and real economy.

III. Digital transformation is an important support for energy transition and zero-carbon development

1. Digital transformation is a booster for energy transition and zero-carbon development

Energy transition and zero-carbon development is complex and systematic, involving the adjustment of energy strategy, the transformation of energy structure, the optimization of energy system and the evolution of energy business. Digital transformation will build a zero-carbon smart energy digital infrastructure, develop a zero-carbon smart energy technology system and form a zero-carbon smart energy digital industry cluster, which can support large-scale development and utilization of new energy, energy consumption dominated by green power, multi-energy conversion, multi-energy complementation, multi-network integration and complete lifecycle management of carbon asset. It will help optimize resource allocation on a larger scale and improve energy consumption efficiency and level.

2. Digital transformation lays a solid foundation for zero-carbon smart energy system

Apply cloud computing, big data, IoT, mobile Internet, artificial intelligence, blockchain technologies to build the digital base of energy enterprises and create a digital neural network, cover the data collection, transmission, processing, storage and control of all aspects of energy development and utilization and carbon asset management where digital technology is embedded in the whole process of production, distribution, operation, marketing and customer service of energy enterprises. Empower the energy system through platforms, data, algorithms, computing power and adopt digital technology as a means to improve the resource allocation, security assurance and intelligent interaction capabilities of the zero-carbon smart energy network and thus to promote the integration of four flows (i.e., energy flow, carbon flow, information flow and value flow).

3. Empower commercial model innovation and value creation through digital transformation

The essence of digital transformation is to demand productivity from data. Data Lake and energy big data center will help integrate the energy ecological chain data resources with the concept of sharing and openness. Social perception data and environmental data is introduced so that data assets are continuously accumulated and optimized. Discover high-value digital application scenarios, fully explore the value of data assets, capitalize data, allow asset in service, to empower energy companies' commercial model innovation and value creation.

Huawei Energy Tower Ring is a mature methodology for energy digital transformation

Digital transformation involves the reshaping of production relations and requires corresponding methodological support. On September 23, 2020, Huawei officially released the energy industry digital transformation methodology-Energy Tower Ring, hoping to inspire energy enterprises and help them improve their performance.

The "Energy Tower Ring" methodology contains five major elements. First, adhering to one vision of change. Transition is a head project requiring a clear vision of enterprise change. Second, building two core drivers, the two-wheel driver of business element and technical element. Third, implementing three key processes, integration planning, construction and operation. One blueprint is drawn throughout and key breakthroughs are made, focusing on "solving problems and creating value" in continuous building and iterative operations. Fourth, creating two guarantee conditions. Digitalized culture, atmosphere, knowledge and skills should be built, breakthroughs are made with talents and consolidated by team and platform, creating capacities. Fifth, building a digital base to realize on-demand interconnection of everything, platform empowerment, data enablement and intelligent leading.

On the basis of "Energy Tower Ring" methodology, future energy system planning is considered in this paper to clarify the energy digital transformation capability framework. The energy digital transformation methodology addresses how energy enterprises proceed with digital transformation and the energy digital transformation capability framework focuses on what energy companies should do in digital transformation. Huawei's energy digital transformation methodology and capability framework have established a theoretical system and action plan for the digital transformation of the energy sector.

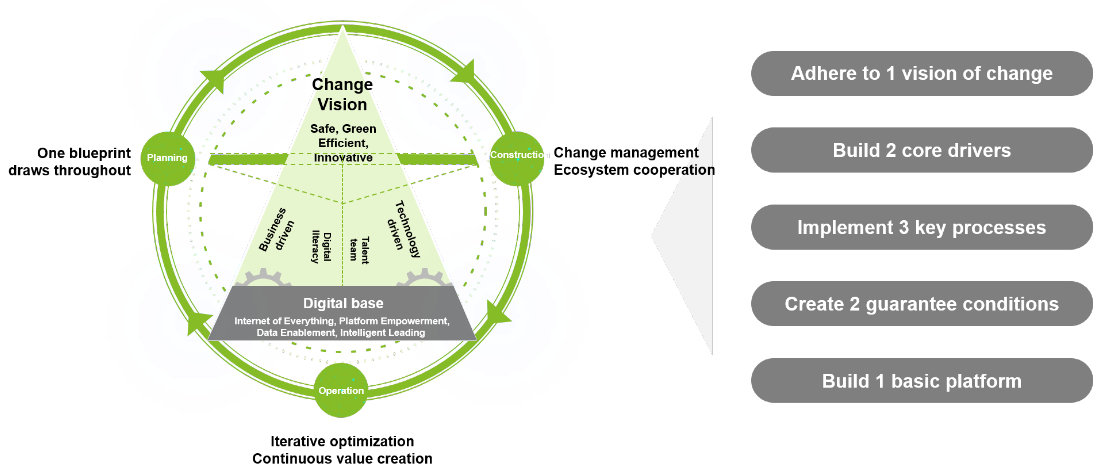


Figure 11: Huawei Energy Tower Ring – Energy Sector Digitalization Transition Methodology

Section 2 Capability Framework of Energy Digital Transformation

Digital transformation is not merely limited to the implementation and operation of new technologies. True digital transformation usually has a profound impact on an enterprise's strategy, talents, commercial model and organizational methods. Digital transformation capabilities include digital strategic capabilities, digital management and operation capabilities, digital scenarios and service capabilities, digital organization and talent capabilities and digital technology, data and security capabilities.

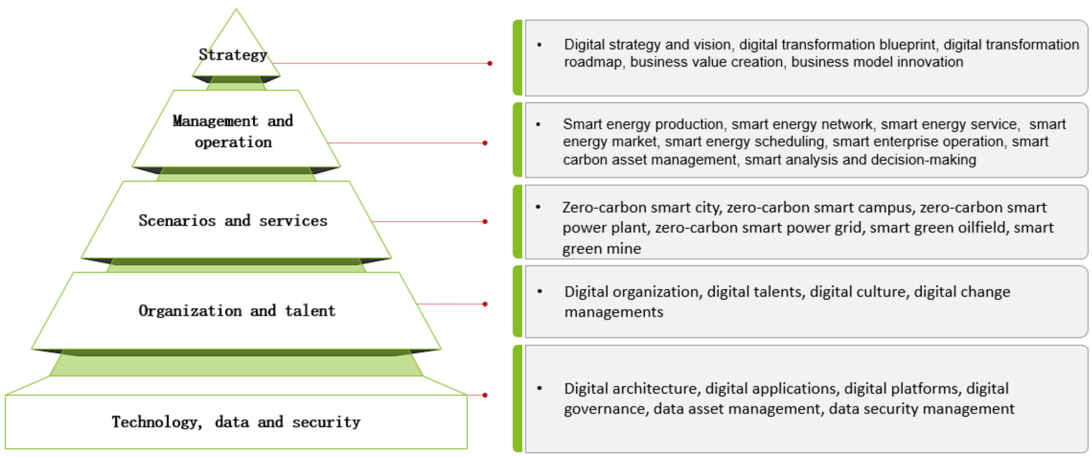


Figure 12: Energy Digital Transformation Capability Framework

I. Digital strategic capabilities

Energy enterprises take "digital transformation" as an enterprise-level transition strategy and an important part of their overall strategy of the company. Guided by the strategy, they proceed with digital transformation at a high level and make directional and overall changes.

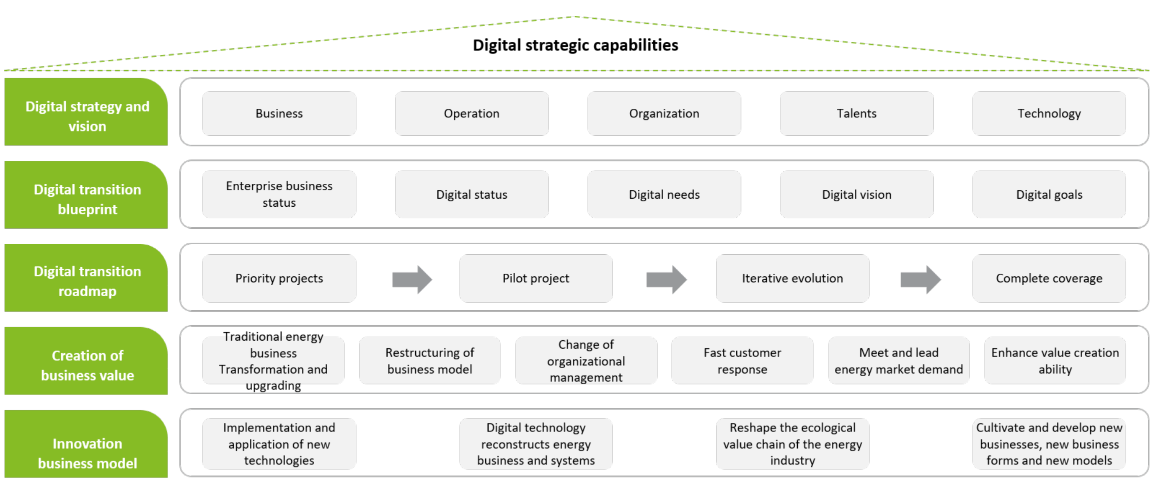


Figure 13: Digital Strategic Capabilities

1. Digital strategy and vision

Digital transformation requires combination with enterprises' development strategies. Clear vision and goals should be available. All businesses such as business, operation, organization, talent and technology should be comprehensively considered. The transition should empower business transformation and support energy transition and zero-carbon development.

2. Digital transformation blueprint

Digital transformation requires planning and designing the blueprint for digital transformation based on such factors as current business situation of the enterprise, their current digital situation and requirements and the digital vision and goals. The blueprint will be treated the guiding framework for the digital transformation of company. In the design of the blueprint of the digital transformation for energy enterprises, the requirements of large-scale development and utilization of new energy, carbon asset management and energy big data should be comprehensively taken into account.

3. Digital transformation roadmap

Digital transformation requires the formulation of a forward-looking, holistic and operable roadmap, which may be implemented step by step with prioritized items clarified when resources are limited. Implement pilot projects based on the developed roadmap and goals to quickly win digital change and establish confidence in digital transformation. Promote digital transformation with agility and through continuous iterations, form the normal operation and evolution capabilities of digital organizations, achieve comprehensive digital transformation and coverage. In the roadmap of digital transformation, priority may be given to high-value application scenarios such as smart power plants, smart mines and smart oil fields.

4. Creation of business value

Digital transformation requires a digitally empowered business innovation system. Accelerate the data-driven process of the integration of four flows, promote the transformation and upgrading of traditional energy business, business model reorganization, organization and management reform, quickly respond to, meet and lead the energy market demand and improve the value creation ability.

5. Innovation of commercial models

Digital transformation requires active application of digital technology to re-build energy business and systems, reshape the ecological value chain of the energy industry, innovate commercial models from the perspective of light assets, servicing, convenient payment, monetization of carbon assets, foster the development of digital integrated energy services, energy big data services, smart Internet of Vehicles services and other new businesses, new business forms and new models.

II. Digital management and operation capabilities

Energy digital transformation should be driven by the "two-wheel driver" of business and technology. Apply digital technology into the management and operation process of enterprises, promote business and management changes, upgrade management and operation efficiency, optimize the cost structure, promote the optimization and integration of the energy industry value chain.

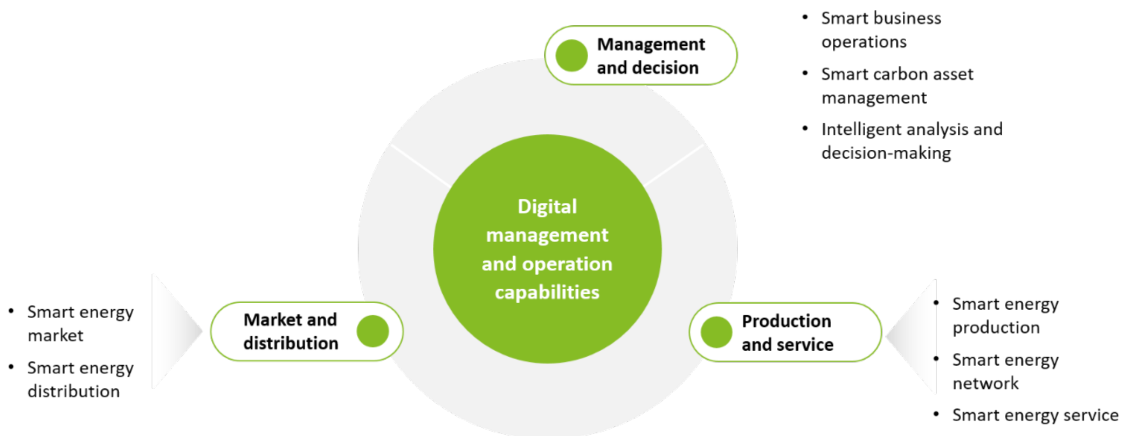


Figure 14: Digital Management and Operation Capabilities

1. Smart energy production

On the basis of industrial Internet platform, integrate the technologies such as smart sensing and execution, smart control and optimization, smart management and decision-making, form a smart energy operation control management model with self-learning, self-adaptation, self-optimization, self-recovery and self-organization, achieve a safer, more efficient, cleaner and flexible energy production method.

2. Smart energy network

Utilizing the digital energy network technology to support the friendly interconnection of centralized energy systems, distributed energy systems, various energy storage facilities and various users. Different energy systems are inter-connected. Satisfy large-scale development and utilization of new energy and "plug and play" of various energy facilities, achieve coordinated interaction of "power supply, power grid, load and energy storage" and meet the distributed, interactive and integrated energy development requirements.

3. Smart energy service

Apply artificial intelligence, knowledge graphs, mobile applications and other digital technologies to break sector boundaries, re-build energy customer experience, respond quickly to customer needs and actively lead the new trend of energy consumption, offer customers with one-stop integrated energy service and create a customer-centric energy ecological value network.

4. Smart energy market

Adopt digital technologies like energy blockchain technology to eliminate the pain points of each transaction link in energy value chain, provide smart infrastructure for payment, sales, transaction and value distribution, support the decentralization of energy production and consumption, realize the disintermediation of the point-to-point transactions and distributed energy systems, enable the electricity purchase and sale transactions and demand-side response to be completed automatically. Utilize online-offline system, IoT, cloud computing and big data technologies to effectively accumulate massive small and medium-sized load resources and participate in energy market transactions and demand-side response and execute load distribution plans.

5. Smart energy distribution

Based on the energy big data platform, strengthen the access and management capabilities of diversified and distributed energy entities, realize the smart economic distribution of renewable energy and the multi-energy complementation and multi-energy conversion, optimize the energy balance and configuration on a larger scale, improve the security and reliability of the energy network to support the efficient operation of energy trading market.

6. Smart business operations

Reshape the core business system, support coordination and integration among various businesses of energy enterprises, integrate internal and external resources to achieve efficient corporate operations, drive corporate process optimization and lean management with data, optimize the allocation of human, financial, material and other resource to achieve corporate cost reduction and efficiency and management improvement of enterprise.

7. Smart carbon asset management

Build a digital carbon asset management platform to realize real-time monitoring of carbon emissions, support scientific carbon targets setting, multi-scenario simulation analysis of carbon emission reduction, carbon cost calculation, carbon verification, performance and trading, reduce cost, increase benefit and upgrade management capacity.

8. Intelligent analysis and decision-making

Apply cloud computing, big data, artificial intelligence and other technologies to establish intelligent analysis and decision-making models, conduct real-time monitoring and trend analysis, support multi-scenario simulation and upgrade the real-time, continuity and scientific nature of decision-making.

III. Digital scenarios and service capabilities

Digital energy transformation must be performed in specific business scenarios for the integration of digital technology, energy technology and automatic control technology. The transformation should promote energy transition and zero-carbon transition and solve business problems and create business value.

Figure 15: Digital Scenarios and Service Capabilities

1. Zero-carbon intelligent city

Build city's life body perception capabilities. This is possible on the basis of cloud computing. Combining AI and big data technology, the city brain analyzes the city in all respects and on real-time basis. It connects cross-domain, deep-level and multi-dimensional data for cross-domain integration of all elements of cities and intelligent coordination of systems, allowing resources to search people in intelligent way, which optimizes human-oriented experience without stop; Digital technology is applied to support intelligence, energy-saving and zero-carbonization of the city's functional systems, developing zero-carbon buildings, zero-carbon transportation and green energy. Build a zero-carbon intelligent city characterized by "full-scenario perception interaction, all-link intelligent decision-making, all-factor coordinated promotion, all-contact experience operation, all-environmental green and zero-carbon".

2. Zero-carbon intelligent campus

Apply new energy technology, carbon management technology, carbon energy trading technology and digital technology to achieve multi-energy complementation, energy conservation and efficiency and build a "green, efficient, all-domain integration, intelligent and agile" intelligent zero-carbon campus.

3. Zero-carbon intelligent power plant

Adopt digital technology, automatic control technology, CCUS technologies to build the core capabilities of intelligent zero-carbon power plants such as intelligent perception, intelligent operation, intelligent control, intelligent maintenance, intelligent emission reduction, intelligent safety, intelligent management, construct a zero-carbon intelligent power plant characterized by "near-zero/zero carbon emission, no-one or few on duty, optimal performance operation".

4. Zero-carbon intelligent grid

Integrate digital technology, intelligent energy technology and automatic control technology, promote the interconnection of various energy sources, the coordinated interaction of the "power supply, power grid, load and energy storage", support large-scale integration of new energy power generation, diversified energy storage and new loads, build a "green and zero-carbon, safe and reliable, intelligent and efficient" zero-carbon intelligent grid.

5. Green intelligent oil fields

Use digital tools such as IoT sensors, digital twins and virtual reality to simulate scenarios, monitor operations, track emission and energy usage, realize predictive maintenance of equipment, optimize production and reservoir management. Data is analyzed to optimize capacity utilization, expand clean replacement of production energy. Accelerate decarbonization with active cooperation between ecosystem partners to build oil fields characterized by "intelligent, safe, reliable, green and efficient".

6. Green intelligent mines

Realize the real-time perception of coal mine full space-time and multi-source information, maintain substantial safety in closed-loop risk management and control. The entire process of human-machine-environment-management is digitally interconnected for efficient and coordinated operation and fully automated operations at production site. Develop coal mining carbon emission control technology and energy-saving technology and build green intelligent mines characterized by "intelligent production decision control + robot operation".

IV. Digital organization and talent capabilities

Major challenges are on the way to energy digital transformation in terms of lack of digital skills and human resources, corporate cultural transition. Adjusting and fostering corresponding digital organizations, cultivating the digital literacy of employees and cultivating digital culture and change culture are important guarantees for the success of digital transformation.

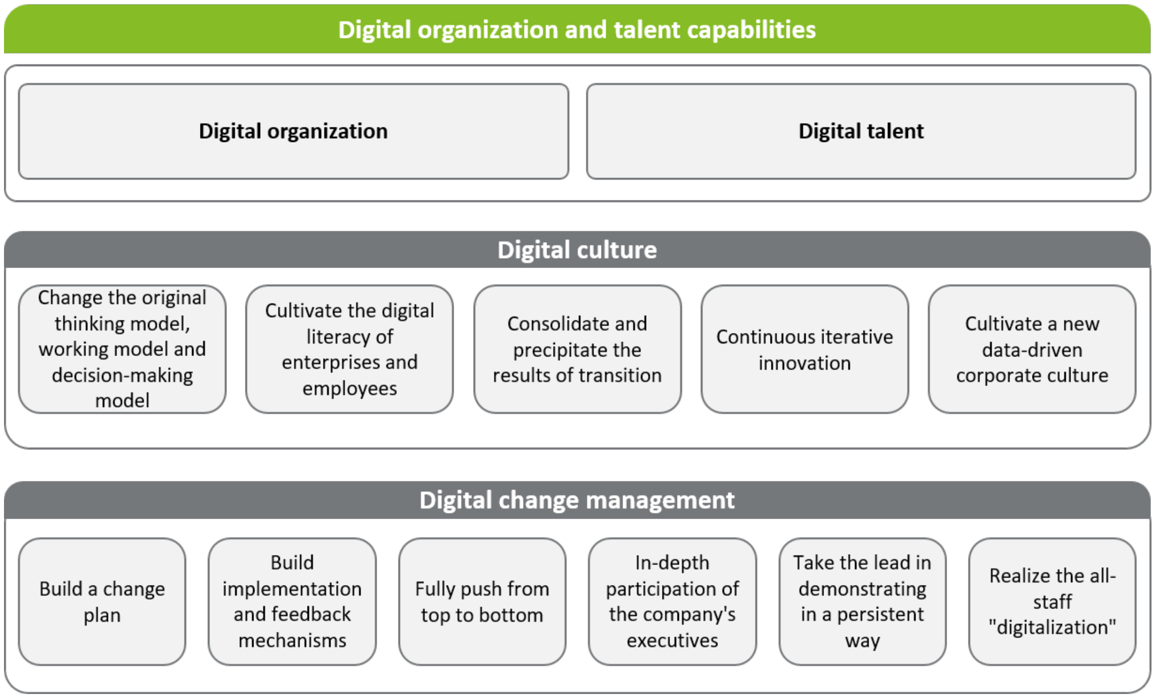


Figure 16: Digital Organization and Talent Capabilities

1. Digital organization

Establish an agile and versatile digital transformation management office to enhance cross-functional integrated business demand analysis capabilities and cross-system efficient collaboration and resource integration capabilities. Manage the top-level design and requirements in a unified manner to form a digital organization cored and digital operation purposed agile delivery model with continuous iterative method. Fully realize planning and control and ensure the effective implementation of digital top-level design.

2. Digital talents

Digital transformation requires the increase of the awareness among employees, especially middle and senior management personnel, of digital transformation. They should master the concepts, knowledge, tools and methods of digital transformation. Recruit, train and maintain digital talents to build a talent team for digital transformation. Cultivate compound talents who have new energy technology, digital technology, energy business management and energy big data analysis capacity to support and implement digital transformation.

3. Digital culture

Digital transformation is a long-term process that requires the change of the original thinking model, work model and decision-making model to cultivate the digital literacy of employees. Consolidate and accumulate the results of transition, maintain iterative innovation and fully realize that data is the core asset and core production factor of an enterprise. It is necessary to foster a new data-driven corporate culture.

4. Management of digital transformation

Cultivate the "digitalization" awareness of all employees from the top to the bottom of the enterprise, develop a planning, execution and feedback mechanism, make every effort to promote it from top to bottom. Digital transformation requires deep participation, demonstration and perseverance of the company's senior management in leading the company to move forward steadily to the road of digital transformation. Traditional energy enterprises should introduce Internet thinking, actively embrace change and promote business and commercial model innovation through "Internet + Energy".

V. Digital technology, data and security capabilities

Digital transformation requires the application and integration of multiple technologies to develop and innovate new business. It should also solve the problems of data security and privacy protection at the same time.

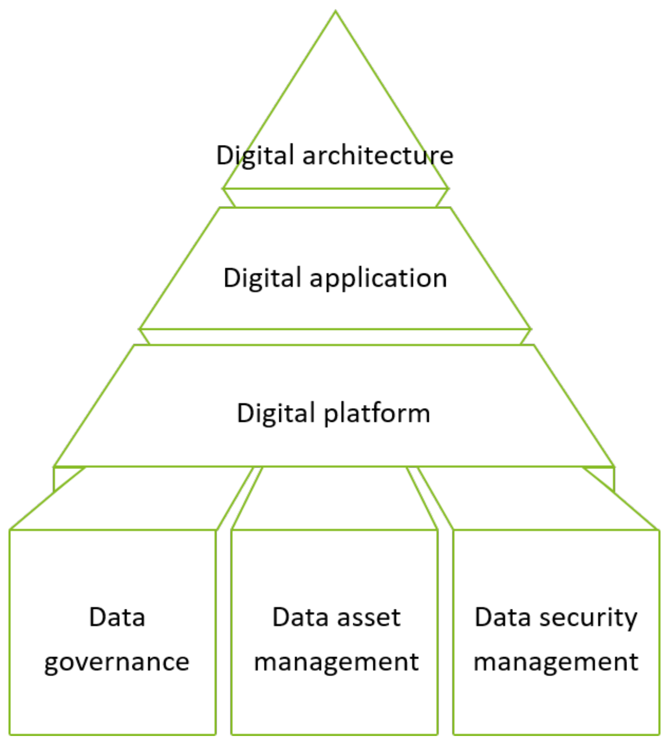


Figure 17: Digital Technology, Data and Security Capabilities

1. Digital architecture

Digital technology drives changes of commercial model and operation of enterprises. Companies are required to introduce cloud structure and platform-based ideas. Establish a digital ecosystem, innovate ecological integration, drive and lead the green development and innovation of business. Adopt enterprise structure methods and apply a business technology integration model, actively develop agile development models and cultivate agile delivery capabilities.

2. Digital application

New generation digital technologies such as cloud computing, big data, IoT, mobile Internet, artificial intelligence and blockchain are core driving force. They are applied to build various digital application capabilities, support the business to invoke digital applications on demand, build big data analysis and AI capabilities that support data insights, intelligent decision-making and automatic execution, quickly respond to changes in market demand, thereby accelerating the innovation and change of business, gaining sustainable competitive advantages. For instance, power grid enterprises can fully explore the commercial value of massive amounts of intelligent meter data by establishing artificial intelligence and big data analysis technologies.

3. Digital platform

Build a digital base for energy enterprises on the basis of cloud network platforms, IoT platforms, big data platforms, realize the functions such as supervision, data analysis and interconnection covering the energy ecosystem. Assist companies to organize, connect and manage applications and data through the unified coordination of the cloud, network, applications, edges and devices. For instance, oil and gas enterprises can use the Open Subsurface Data Universe (OSDU) to visualize seismic, oil reservoir and oil well data, promote the industrialization of data management and shorten the development cycle of new solutions.

4. Data governance

Develop data standards and data models, conduct data governance, continuously improve data quality. Build a data governance system that matches the building, operation and optimization of digital capabilities. For instance, power generation enterprises may be able to standardize data management and share data by developing a unified data model for thermal power, solar PV and wind power equipment.

5. Data asset management

Integrating data resources of the energy ecological chain with the concept of sharing and openness to introduce social perception data and environmental data and continue to optimize and accumulate data assets. Taking data as the core production factor and fully exploring the value of data assets to realize data capitalization and asset servicing and to comprehensively support the continuous enrichment of new demand for energy business innovation and scenarios.

6. Data security management

Apply and integrate a variety of technologies to meet the requirements of new business development and innovation, establish a data security protection mechanism and protect data security and privacy. Apply a variety of protective measures intensively and intensify data identification, classification and protection measures. Optimize network and terminal data leakage prevention systems and foster application of data disaster recovery backup facilities, realize the "visual, manageable and controllable" process of data security management.

A "campus" refers to a complex of buildings with complete supporting facilities and a reasonable layout. They mainly include enterprise campus, industrial campus, manufacturing campus, business centers, government public buildings, residential campus, etc. Campus is a basic unit of a city and the main carrier of living and industrial agglomeration. It is also an economic platform constructed by multiple systems such as energy, industry, transportation and buildings.

Huawei has put forward the zero-carbon intelligent campus concept of being "**green and efficient, all-domain integrated, intelligent and agile**". The campus is taken as a microcosm to provide a reference for more zero-carbon intelligent scenarios.

I. Value proposition of zero-carbon intelligent campus

Aiming at "intelligent lean management, efficient energy complementation, low-carbon and green operations and online carbon energy trading", the zero-carbon intelligent campus applies digital technology to collect energy, transportation, carbon emission and other elements' data through edge intelligent gateway. The campus, on the basis of unified digital platform, intelligent energy management, zero-carbon management, carbon energy trading and integrated management application modules, achieves the interaction, integration, coordination and optimization of the campus's carbon emission flow, energy flow, information flow and value flow and promote the zero-carbon transition, energy transition and digital transformation of the campus.

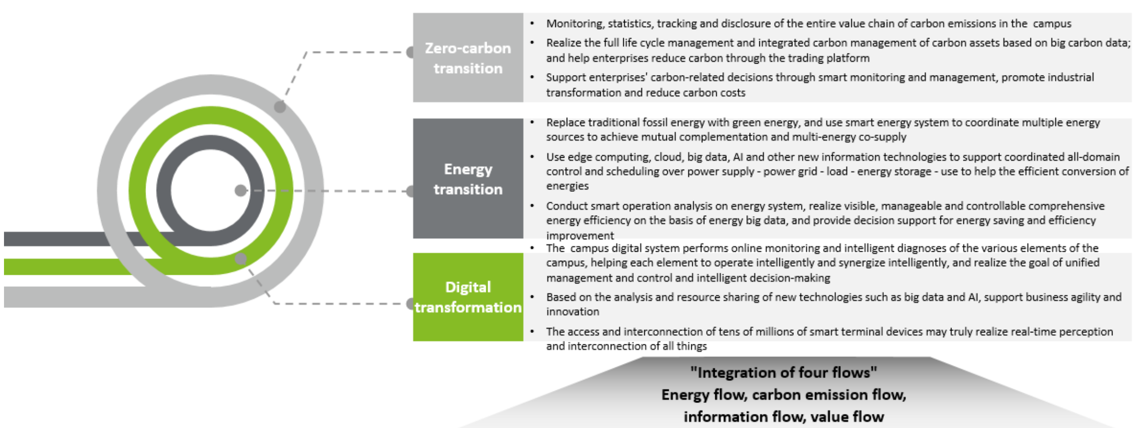


Figure 18: Value Proposition of Huawei Zero-carbon Intelligent Campus

II. Business blueprint of zero-carbon intelligent campus

Building, transportation and energy systems constitute the main infrastructure of the campus. It has five major subsystems: energy, building automation, low current, office and recycling. The emission of Scope 1 of the campus mainly comes from the direct use of fossil energy in building heating and transportation. The emission of Scope 2 mainly comes from purchased non-renewable energy power used by buildings, transportation and public facilities.

Therefore, the green buildings, electrification of transportation, clean energy and intelligent energy facilities are the main trend of achieving net-zero emission in the campus. Develop green buildings by combining the use of energy-saving and low-carbon building materials, distributed green energy and intelligent building management systems. Promote the intelligentization of energy facilities and the electrification of transportation by using safe, cost-effective and efficient power distribution network and by combining the use of energy-consuming terminals such as intelligent sensing devices represented by intelligent meters and the electric vehicle charging stations. Use solar energy, wind energy to supply main energy for the campus, promoting the use of clean energy. Eventually realize the green and intelligent operation of energy systems, transportation systems and building systems and minimize the emission shown in Scope 1 and Scope 2, assist the campus achieve net-zero emission with the introduction of carbon reduction, carbon-negative technology and carbon trading.

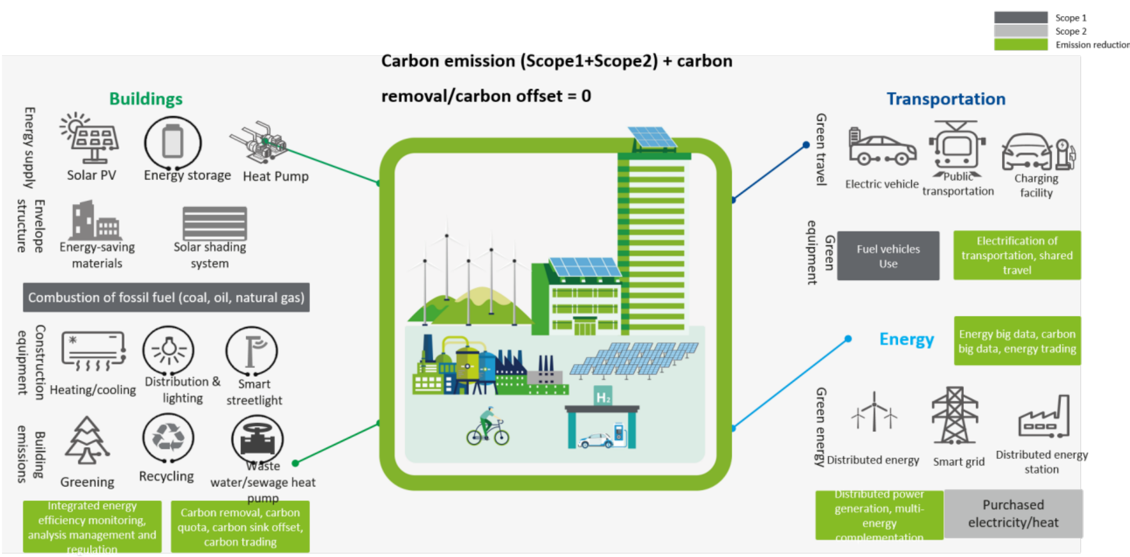


Figure 19: Business Blueprint for Huawei Zero-carbon Intelligent Campus

III. Building path of zero-carbon intelligent campus

The building of a zero-carbon intelligent campus is progressed dynamically in three phases: low-carbon, near-zero carbon and net-zero carbon. Apply three-dimensional model NSI (Net-zero Carbon-Intelligent Campus-Integrated Energy) to evaluate the development phases of the campus from three aspects: "zero carbon", "intelligence" and "integration of energy" to determine the development phase of the campus and to support the campus to develop building goals and action plans. Gradually develop it into a zero-carbon intelligent campus through continuous optimization and iteration of the integration of planning, construction and operation.

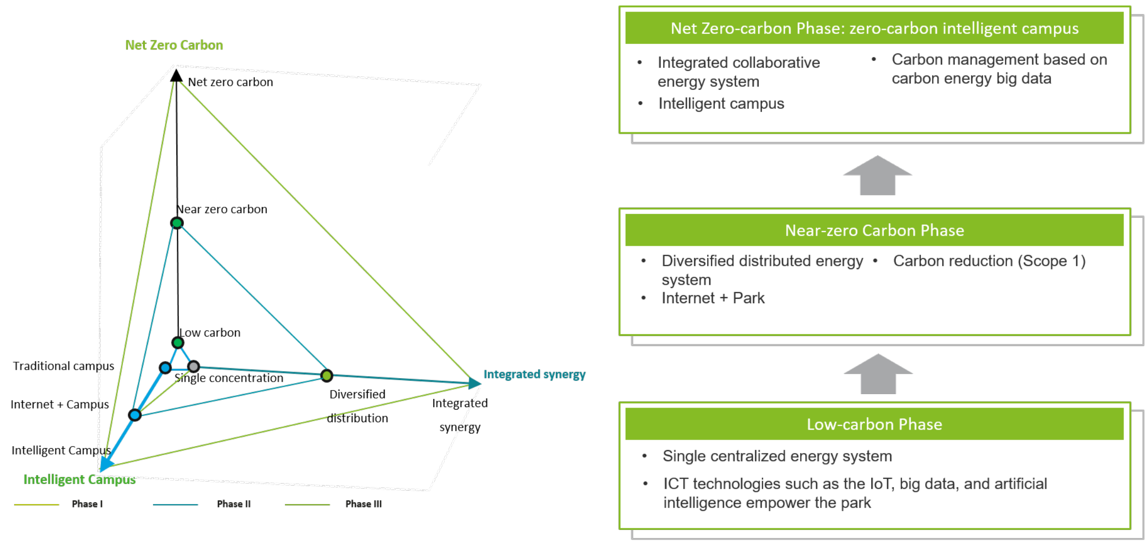


Figure 20: Building Path of Huawei Zero-carbon Intelligent Campus

1. Low-carbon phase

Apply ICT technologies such as the IoT, big data and artificial intelligence to empower the campus for comprehensive, real-time and accurate perception of the campus's energy status and carbon emission status, reduce the campus's CO2 emission, thus increasing the campus's social and economic value.

2. Near-zero carbon phase

On the basis of low-carbon phase, apply distributed energy and new energy to change the means of single centralized energy supply, diversify energy supply and reduce direct CO2 emission from burning fossil energy in the campus (Scope 1). Reduce the campus’s direct and indirect CO2 emission (Scope 1 and Scope 2) by improving energy efficiency and carbon emission reduction measures, decrease the campus’s CO2 emission drastically and to zero gradually.

3. Net-zero carbon phase: zero-carbon intelligent campus

On the basis of the near-zero carbon, develop a comprehensive intelligent energy system to realize multi-energy complementation and comprehensive coordination and optimization, promote energy conservation and emission reduction through intelligent management system and further reduce the campus’s direct and indirect CO2 emission (Scope 1 and Scope 2). Offset the remaining CO2 emission through carbon capture, carbon absorption, carbon trading, achieve net-zero CO2 emission in the campus. Conduct real-time monitoring of carbon energy by building carbon energy big data platform, realize the "visualization, manageability and controllability" through the campus's intelligent operation center (IOC).

IV. Solution structure of zero-carbon intelligent campus

Huawei's zero-carbon intelligent campus solution connects energy, building, offices and cycling subsystems through edge intelligent devices. It connects data to the digital platform, supports energy management, carbon management, carbon trading and integrated management. It analyzes carbon energy big data to assist intelligent operation management and control to achieve the goals of being "green and efficient, all-domain integrated, intelligent and agile" of the campus.

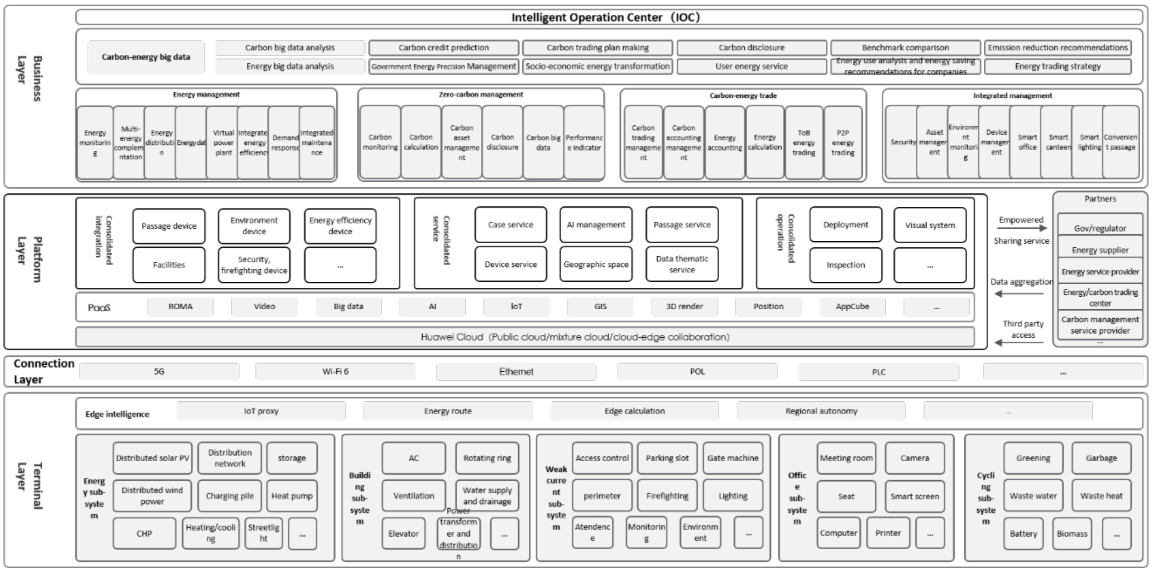


Figure 21: Solution Structure of Huawei Zero-carbon Intelligent Campus

1. Edge intelligence and terminal layer

The edge intelligent gateway is an open platform based on the integration of control, management, computing and communication. It combines multiple capabilities such as IoT agents, high-speed communications, edge computing and security reinforcement to achieve the complete connection, complete collection and complete management of the various terminals such as energy, buildings, low current, offices and recycling subsystems. It achieves real-time perception and interconnection of all things.

2. Platform layer

Digital platform is the core of the solution for the zero-carbon intelligent campus. Relying on cloud platform, big data, video cloud, IoT, GIS and AI technologies, the platform, with three capabilities of "consolidated integration", "consolidated service" and "consolidated operation", accesses to and integrates the energy, buildings, offices, low current and cycling subsystems. It supports full analysis and display, integrates synergies and consolidates service. On the one hand, it provides data support for campus business operations and campus operations. On the other, it drives the integration of and access to third-party partners' data for intelligent operation of the campus with data as a production factor.

3. Business layer

- Energy management system

The energy management system enables data collection, access and monitoring management of various energy supply and consumption systems in the campus. The management of the system covers distributed solar power generation systems, distributed wind power generation systems, energy storage systems, ground source/water source/air source heat pump system, charging pile/charging station system, combined cooling, heating and power system, heating/cooling system, intelligent streetlamp and DC microgrid system. It achieves multi-energy complementation and coordination and the refined operation of the campus's energy system.

- Zero-carbon management system

The zero-carbon management system is the foundation of the campus's zero-carbon management. The system assists operators to be informed of carbon emission from daily operation, meeting the national and industry regulatory requirements and reducing the risk of corporate carbon emission reduction compliance. The zero-carbon management system also helps campus and the enterprises in the campus to establish and improve their capabilities in carbon asset management, carbon footprint management, carbon emission reduction project management, carbon market prediction in order to maximize the benefits of carbon trading. The system supports enterprises to flexibly participate in carbon trading.

The system includes three modules: carbon emission monitoring, basic carbon emission database and carbon emission management. The monitoring module monitors and records data of various energy supply and energy-consuming facilities in the campus and inputs data to the basic carbon emission database. The database builds a framework in accordance with national and industry regulatory requirements to manage various carbon emission calculation factors. The management module relies on the basic carbon emission database and the carbon emission monitoring module to realize four major functions: carbon emission measurement and accounting, carbon quota management, carbon credit management and carbon asset trading. These modules enable closed-loop carbon management of the campus and empower the campus to reduce the overall emission.

- Carbon-energy trading system

The carbon-energy trading system includes carbon trading, energy trading and carbon-energy trading interaction. Carbon trading and energy trading cover internal and external trading: internal trading is designed to build a distributed energy trading market in the campus to support members in the campus to carry out market transactions and P2P transactions between members. External trading is to build a platform by the campus for member enterprises to support them to participate in external carbon market and energy market transactions. Carbon energy trading interaction focuses on analyzing the dynamic relationship and interaction between carbon prices and energy prices, providing companies with market insights and further promoting the use of clean energy, energy conservation and emission reduction.

- Integrated management system

The integrated management system is oriented to the daily operation and management of the campus. With the campus's digital platform, the originally isolated subsystems such as perimeter, access control, fire protection, vehicles, buildings, group control, facilities, assets, environment and office are uniformly connected, aggregated and modeled. Applications such as safety management, personnel management, vehicle management, facility management, asset management, environmental space management and office management are established in the system, supporting comprehensive analysis, integrated linkage and unified services. The system enables complete connection of the campus management objects and complete integration of data and helps a safe, comfortable, efficient and low-cost operation.

- Carbon energy big data

Carbon energy big data analyzes carbon emission and energy big data, forecasts future energy supply and consumption of the campus, as well as the campus's carbon peaking and carbon neutrality progress, compares transversely with international and domestic benchmarks and longitudinally with historical data so as to provide support for making decisions on the campus's energy conservation and emission reduction. At the same time, upon carbon trading and energy trading data analysis, it provides trading plans and strategic suggestions for the campus and its member enterprises to participate in internal and external carbon trading and energy trading, maximizing the benefits of the campus and enterprises.

- Intelligent operation center (IOC)

IOC, being the reporting center, command center and integrated entrance of the zero-carbon intelligent campus system, visualizes the campus energy, carbon and integrated management operation status, analyzes business and supports early warning, auxiliary decision-making and execution. It enables visualization, manageability and controllability of the campus's energy, carbon and integrated management operation status and the digital operation goal of the campus.

Conclusion

A total of about 2.4 Gt CO2 were emitted from human being activities since the industrial revolution. The Earth's surface temperature is rising at an unprecedented rate. Extreme weather events occur frequently. Coping with climate change has become the consensus of the global community. Nearly 200 countries around the world adopted the Paris Agreement in 2015. However, a big gap remains between emission reduction commitments and practical actions of all nations. It has become urgent that Zero-carbon transformation be accelerated.

More than half of the global greenhouse gas emission comes from the energy sector. Green and sustainable socio-economic development requires profound change of energy production and consumption models. The energy structure should be transformed from fossil fuel to renewable energy. Energy efficiency should be fully upgraded through multi-energy complementation. The industries should substitute fossil fuel with electricity, proceed with electrification transformation, promote multi-energy coordination and integrated cascade utilization of energy at consumption terminals, conserve energy, reduce emission and improve energy efficiency. Given the goal of carbon neutrality, future energy system is confronted with various challenges, e.g. large proportion of new energy installation, highly flexible energy distribution, integrated energy demand, diversified energy trading. The task of energy transition is supposed hard and challenging.

Energy transition and zero-carbon development is complex as it should balance socio-economic development, energy supply security and the realization of carbon neutrality. It involves energy strategy adjustment, energy structure transformation, energy system optimization, energy business reform and energy conservation and emission reduction actions. They require full implementation of digitization. In energy digitalization methodologies should be put at the frontier and then capacity built systematically, digital technologies and energy technologies deeply integrated, forming "digital path" for zero-carbon transformation and energy transition.

Current situation and trends of energy transition and zero-carbon development are analyzed in the paper while the direction of future energy development is pointed out, that is, building a zero carbon intelligent energy system including "three goals, one blueprint, five characteristics, three transitions and four flows integration". It also advises energy transition paths for power, oil and gas and coal industries. With energy digitalization methodologies, capabilities frameworks and support systems, a scenario-based solution for zero-carbon intelligent campus is presented, which provides valuable reference and recommendations for green and sustainable development practices.

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