2019 Climate Investment and Finance Case Studies

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Research Report

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Center for Environmental Education and Communications of Ministry of Ecology and Environment

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Content

Chapter 1 Background

Climate change is a major global challenge that humans face in the 21st century. China attaches great importance to the work of tackling climate change and follows the path of sustainable development unswervingly. Carrying out the climate investment and finance, opening up funding channels and improving the efficiency of the use of capital use are important guarantees for achieving China's 2030 climate change goals and the medium and long-term goals after 2030. The climate investment and finance related projects includes two categories, including mitigation and adaptation (as shown in graph Figure 1-1). The pathways of mitigation mainly includes end-use fuel and power efficiency, renewable energy, carbon capture and storage, the replacement of end-use fuel switch, nuclear energy, power generation efficiency and fuel substitution; The pathways of adaptation includes more efficient use of scarce water resources, use of building standards that are resistant to extreme climatic conditions, construction and upgrading of flood protection projects, development of crops that can adapt to arid environments, selection of forest species and management models that can withstand storms and fires, and establishment of land corridors which can assist in the migration of species.

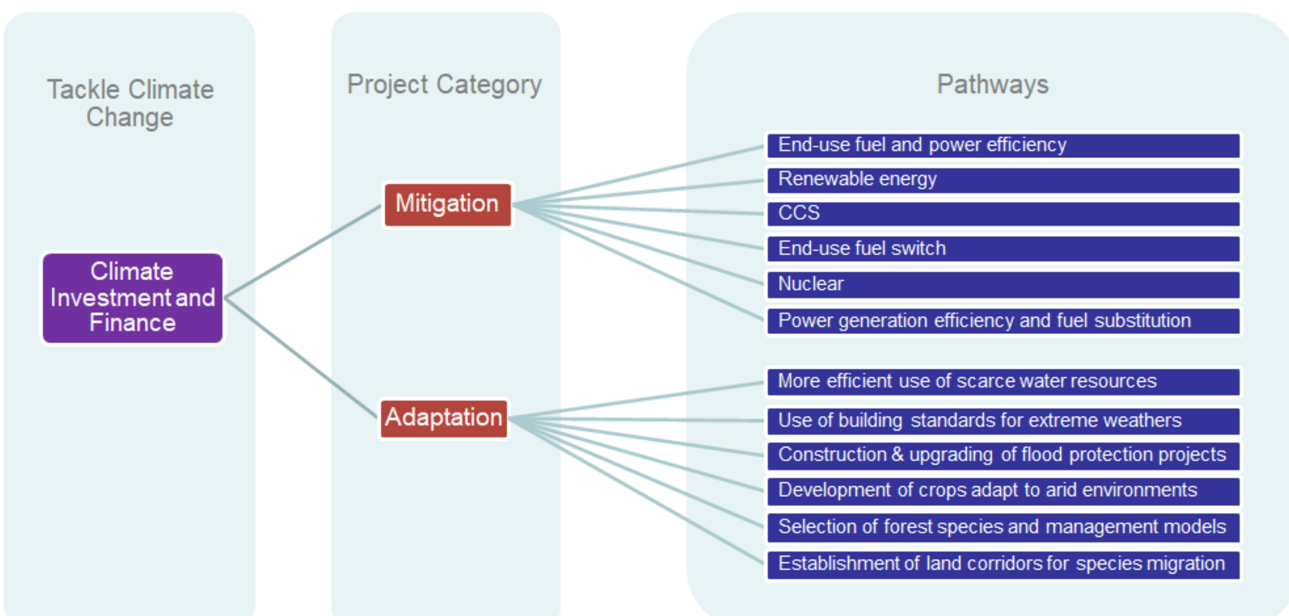


Figure 1-1 Classification and technical path of climate investment and finance projects

Existing researches shows that the funding gap of climate investment and finance is big. According to China Climate Finance Report 2015 and Climate Adaptation Finance Report 2015 of the Chinese Academy of Sciences and the Central University of Finance and Economics, China's climate investment and finance faces a funding gap of more than 2 trillion yuan per year. It is necessary for China to use economic means such as finance, investment and, taxation effectively to improve the positive incentives for resource allocation, and establish a climate investment and finance framework to ensure the climate change related goals could be achieved. They framework will enable a financial system that is actively promoting friendly projects.

However, the development of climate funding channels and the accumulation of adequate funds is a long-term process, and it is difficult to fully cover the funding gap in the short term. In order to allocate limited fund more efficiently and to respond to the call for high-quality development policy in China, with support by the Department of Climate Change of the Ministry of Ecology and Environment (MEE), the Center for Environmental Education and Communications of Ministry of Ecology and Environment, has organized relevant experts to take an exploratory step to identify excellent industry practices, complete the researches on the screening method of representative climate finance and investment cases and contribute to the development a climate investment and finance project database.

> ***"Climate Investment and Finance Case Studies Selection' aims to establish and promote sectoral benchmark, guide sectoral progresses in climate change mitigation and adaptation."***

The 'Climate Investment and Finance Representative Case Studies Selection' project promotes the investment and finance of climate change mitigation and adaptation projects by setting industry benchmarks to guide various industries to cope with the development and transition related to climate change. The project aims to build on the development status of domestic and international climate change technologies and business models, and combine existing research on green finance (Annex) and climate investment and finance standards system to establish a screening indicator system for selecting representative case projects of climate investment and finance, and to put them into practice. Through the collection and research of representative cases, it is recommended that future climate investment and finance standards focus on supporting leading projects in different industries. This approach would allow more efficient use of limited resources, encourage pioneering demonstration projects, and assist governments in allocating climate funds.

Due to the time limit, the industries considered for this project only include 10 areas: onshore wind power, solar photovoltaic, offshore wind power, energy storage projects, low carbon buildings, urban low carbon transportation, sponge city climate adaptation projects, energy saving projects for steel enterprises, methane recovery from waste, and carbon capture, utilization and storage. Future research can be extended to more areas based on the experience and lessons learnt from this project.

Under the direction of the Climate Department of the Ministry of Ecology and Environment, the Center for Environmental Education and Communications ('the Center') has publicly called for representative cases of climate investment and finance. Representative cases considered with four criteria during the screening process include: climate change effect, investment and finance model, technological innovation and demonstration role, and social benefit. As of October 11, 2019, the Center had received 26 applications for typical case projects in 9 fields, including 14 projects that meet the threshold requirements and 3 regional projects submitted by multilateral agencies. The purpose of this report is to present and share climate investment and finance cases in five areas. The report will also share our analysis on existing standard and guidance of green finance and climate investment and finance in China and internationally.

> ***"Climate Effect, Technology Innovation, Investment and Finance Model, and Social Benefit are key selection criteria for Climate Investment and Finance Case Studies."***

Chapter 2 Offshore Wind Power Case

2.1 Industry overview

Offshore wind power is a rapidly developing low-carbon energy technology, and its related industries are developing rapidly in Europe and in China. Offshore wind power produces electricity from wind turbines fixed to the seabed or floating in coastal waters. Compared with onshore wind power, offshore wind power has four advantages:
(1) Abundant resources, high wind speed and few environmental constraints;
(2) Generally little occupation of land and low interference with human activities;
(3) Offshore wind turbine is relatively low, because the surface friction of seawater is low, and the wind speed changes little with the height;
(4) Offshore wind turbine has a longer life, because the wind breeze turbulence intensity is low and the turbine fatigue load is reduced.

The wind energy reserve per unit area is an important indicator of offshore wind power development. The wind energy reserves per unit area in most of the world's sea areas are over 2000 kWh/m^2, which means they have the capacity to develop offshore wind power. The wind energy reserve per unit area of the North Pacific westerlies (including the coastal areas of China) is 4,000 to 7,000 kWh/m^2, and the wind energy reserve per unit area of the north Atlantic westerlies (including the northwest Europe region, the UK, the Netherlands, Germany, Norway and other countries) is more than 5,000 kWh/m^2.

> ***"Offshore wind energy resources in China are about 750 GW, accounting for 75% of the country's wind energy resources"***

According to the global maritime wind data set of the national oceanic and atmospheric administration (NOAA), the annual average wind speed distribution in the global sea area is shown in Figure 2-1 below. The coastline of China is very long – 18,000 kilometers

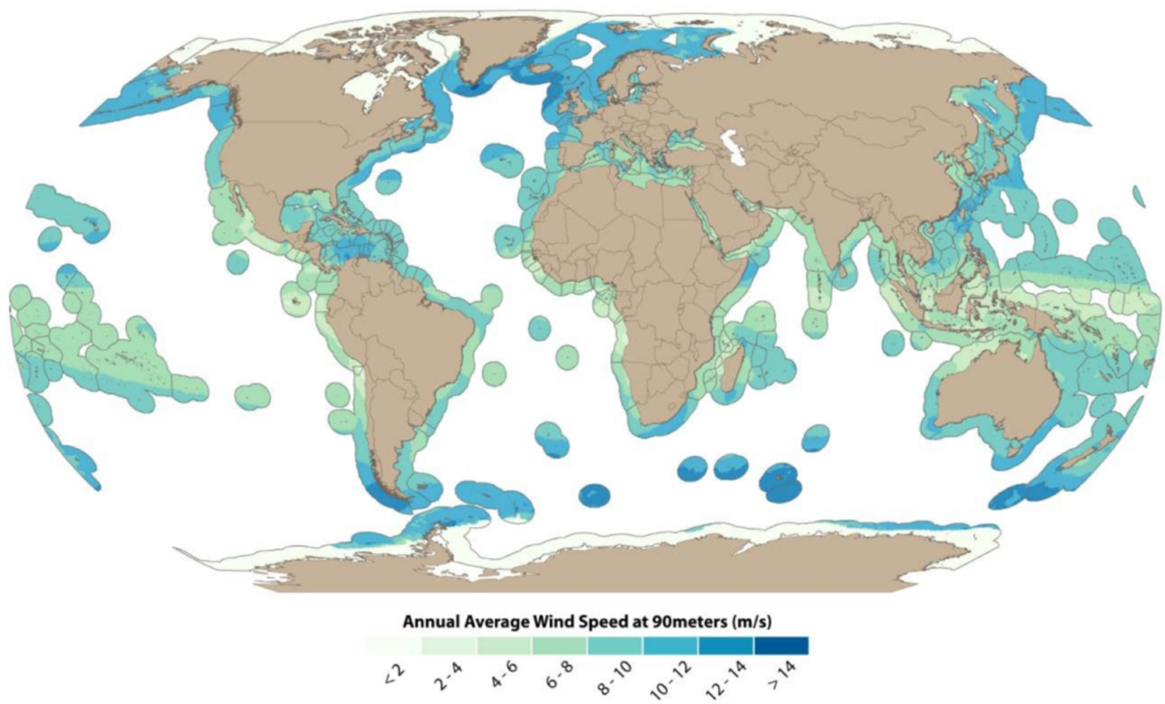


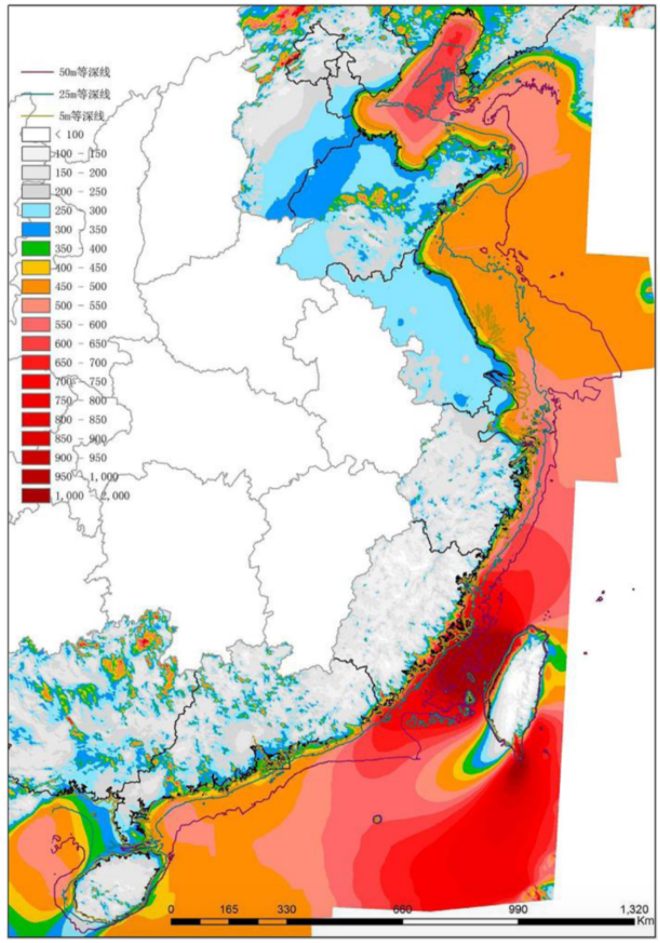
Figure 2-1 Distribution of wind energy at a height of 90 meters in the global sea area

with the Bohai, the Yellow sea, the East China Sea and the South China Sea, which are four territorial seas. The offshore wind energy resources are rich in China. The Wind Energy and Solar Energy Resource Evaluation Center of the China Meteorological Administration conducted a preliminary numerical simulation of the offshore wind resources in China (as shown in Figure 2-2). The results show that the Taiwan Strait has abundant wind energy resources, followed by eastern Guangdong, Zhejiang and offshore Bohai bay in north-central. The regional distribution of offshore wind power resource is relatively less in the coastal waters of Beibu gulf, northwest of Hainan Island.

Offshore wind power projects generally include intertidal and subtidal beach wind farms, near sea wind farms and far-reaching sea wind farms. At present, the substantial development of offshore wind power in China is still mainly concentrated in the intertidal zone and offshore wind power areas. Since 2009, the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) have

Figure 2-2 distribution diagram of the average annual wind power density of 100 meters above sea depth of 5-2

0 meters off the coast of China



guided the orderly development of China's offshore wind power by organizing offshore wind power development planning in coastal areas, conducting offshore wind power project demonstration, and issuing offshore wind power policies. Since the issuance of "The Notice on the Development and Construction Scheme of Offshore Wind Power" by the NEA in 2014, China's offshore wind power has accelerated its development, the growth of installed capacity has accelerated, the level of offshore wind power manufacturing, construction and operation and maintenance technology has been continuously improved, and the cost of power generation has gradually declined year by year, showing the trend of accelerating the development of scale.

In terms of the development layout of offshore wind power, China has focused on promoting offshore wind power construction in Jiangsu, Zhejiang, Fujian, Guangdong

Table 2-1 Development status and planning of offshore wind power in relevant provinces of China

	Key policy document	Development status in 2020	Development goal by 2030
Jiangsu	18 projects in Jiangsu in *The National Offshore Wind Power Development and Construction Program (2014-2016)*	By 2020, it plans to have 3.5 GW of offshore wind power connected to the grid, keeping the national leading level	Jiangsu will also strengthen wind measurement and layout optimisation design of wind turbines, promote the application of wind power equipment and operation and maintenance technology adapted to low and medium wind speed resources; promote the coordinated development of coastal onshore wind power and inland low-wind wind power; organise the application demonstration of distributed wind energy and promote the construction of distributed wind power connected to low-voltage distribution network; carry out pilot demonstrations for hydrogen production from wind power and seawater desalination from wind power.
Fujian	*Fujian 13th Five-Year Energy Development Special Plan* and *Fujian Offshore Wind Farm Project Planning Report*	By 2020, Fujian will have built more than 2 GW of offshore wind power	By the end of 2030, the capacity of offshore wind power is expected to reach more than 3 GW. At the same time, a mature offshore engineering equipment and construction technology adapted to the situation of Fujian will be formed to lay a solid foundation for further development of offshore wind power resources. It will focus on promoting the development of offshore wind power projects in Putian Pinghai Bay, Fuzhou Xinghua Bay, Pingtan Island and other areas with good resources, and build 17 wind power plants in Fuzhou, Zhangzhou, Putian, Ningde and Pingtan, with a total capacity of 13.3 GW.
Guangdong	*Guangdong Offshore Wind Power Development Plan (2017-2030) (Revised)* by Guangdong DRC	By the end of 2020, it will start construction of more than 12 GW of installed offshore wind power capacity, of which more than 2 GW will be put into operation	By the end of 2030, the installed capacity of offshore wind power will be about 30 GW. The province plans to build 23 offshore wind power sites with a total installed capacity of 66.85 GW, including 15 offshore wind power sites with an installed capacity of 9.85 GW, including 4.15 GW in the east of Guangdong, 1.5 GW in the Pearl River Delta and 4.2 GW in the west of Guangdong. There are 8 planned offshore wind power sites in the offshore deep water area (35-50 meters deep), distributed in the east and west of Guangdong, with an installed capacity of 57 GW.

and other coastal provinces during “the 13th five-year plan” period, and each province has published its offshore wind power development plan during this period (as shown in Table 2-1). Jiangsu province is the region with the fastest offshore wind power construction speed in China, and it is also the dense region with offshore wind power construction connected to the grid during “the 13th five-year plan” period. The coastal areas of Fujian and Guangdong are the important areas to carry out the preliminary work of offshore wind power in national wide. Based on better wind energy resources and policy support, they will become the important construction layout of offshore wind power during “the 13th five-year plan” period.

Offshore wind power research and development, and the equipment manufacturing industry will also usher in new development opportunities. According to “The 13th Five-Year Plan for Wind Power Development” and The 13th Five-Year Plan for National Marine Economic Development” and other documents, the key development directions at this stage mainly include strengthening the development of high-capacity offshore wind power equipment, formulate novel offshore substations design and develop technologies for operation under the seabed. Key technologies are cable transmission, extending energy storage equipment, smart grid and other offshore wind power supporting industries, encouraging the construction of offshore wind farms in the deep sea, adjusting wind power grid integration policies, and improving the offshore wind power industry technical standards system and sea use standards.

2.1.1 Climate Benefit of Offshore Wind Project

By replacing fossil fuels to generate electricity, wind energy can reduce (and already reduce) greenhouse gas emissions and bring about synergy of reducing other air pollutants. Similar to onshore wind energy, the main climate (environment) benefit of offshore wind energy is generated by substitution, as the increase in offshore wind energy generation could replace electricity generated from existing coastal fossil fuel power plants.

As an offshore wind power project is a renewable energy project, it will not use fossil fuels in the operation process. According to the methodology of voluntary emission reduction project CM-001-V01, the carbon emission of the project is close to zero.

Therefore, offshore wind power's carbon dioxide emission reduction is close to its baseline carbon dioxide emission. According to the latest marginal emission factors of the regional power grid issued by the National Development and Reform Commission and the methodology of voluntary emission reduction project CM-001-V01, the regional unit power generation (MWh) carbon dioxide emission reduction baseline by the domestic regional power grid can be calculated, as shown in Table 2-2 below:

In addition, the manufacture, transportation, installation, operation and de-commissioning of wind turbines will have some indirect negative effects, and changes in wind power generation will also affect the operation and emissions of fossil fuel power plants. When calculating the net greenhouse gas emission reductions for offshore wind power, consideration should be given to reducing greenhouse gas emissions from the project life cycle. The United Nations Intergovernmental Panel on Climate Change's (IPCC) "Special Report on Renewable Energy and Mitigation of Climate Change", uses a life cycle assessment (LCA) program based on ISO 14040 and ISO 14044 to analyze these effects and the results show that most of the life cycle estimates of greenhouse gas emissions are mainly between approximately 8-20g of CO_2e/kWh.

Table 2-2 Emission Factors of China's Regional Grid Baseline and corresponding Potential CO_2 Emission Reduction

China regional power grid baseline emission factor (tCO_2/MWh)			Unit generating capacity (MWh)	Carbon dioxide emission reduction (kgCO_2e)
2017	$EF_{grid,OM,y}$	$EF_{grid,BM,y}$		
Northeast regional power grid	1.1082	0.3310	1	913.90
North China regional power grid	0.9680	0.4578	1	840.45
East China regional power grid	0.8046	0.4923	1	726.53
Southern regional power grid	0.8367	0.2476	1	689.43

2.1.2 Technology Trend of Offshore Wind Project

In June 2019, the International Renewable Energy Agency released “The Renewable Energy Generation Cost Report for 2018”, proposed that the main driving factors for the reduction of offshore wind power costs are innovation and improvements of wind turbine technology, installation and logistics; expansion (install large wind turbines, offshore wind farm clusters); higher hub heights, better wind energy resources and larger rotor diameters. At present, the technical development and innovation of offshore wind power mainly includes six aspects:

(1) Large-scale wind turbines;

(2) Development and utilization of deep-sea wind power (such as floating offshore wind turbines);

(3) Offshore booster stations;

(4) Submarine cables;

(5) Offshore engineering technology (such as hoisting technology for large turbines);

(6) Layout and cluster distribution of wind farms.

> ***“Scale up turbine capacity is the development trend of offshore wind technology, as larger turbine could achieve a higher equivalent utilization hours and lower the levelised cost of electricity”***

At present, the single unit capacity of international commonly used offshore wind turbines ranges from 2MW to 8MW. 6MW offshore wind turbines in Europe have formed industrialization capacity and realized batch installation. 8MW offshore wind turbines have entered the prototype trial operation stage, and larger capacity offshore wind turbines are also being designed. The largest single unit capacity used in the project in Europe is 9.5MW (the same model has been upgraded to 10MW)[1].

[1] MHIvestasv164 Turbine

China's is developing large-scale wind turbines, intelligent digital wind power technology, grid friendly wind power. At present, China's offshore wind farms have successfully demonstrated 5MW models, and it is planned that the technology of 5 to 6 MW units will gradually mature after 2020, and will become the main model in the commercial. 8MW and above models will be tested soon. Many wind turbine manufacturers are developing models of 10MW or above. China's wind power market will enter the era of 10MW turbine in the future.

Due to the depth of water, the development of far-reaching sea wind energy resources is mainly realized by the floating wind power installations. The development of floating sea wind power suitable for deeper sea area is an inevitable trend in the future. According to the research of the Renewable Energy Laboratory (NREL) of the U.S. Department of Energy, more than 80% of the potential offshore wind energy resources in Europe are located in the deep-water area with a depth of more than 60 meters, with wind energy resources developed by floating wind turbines capable of reaching 4000GW. The development resources of floating wind turbines in the U.S. and Japan are 2450GW and 500GW respectively. The "Energy Technology Revolution and Innovation Action Plan (2016-2030)" jointly issued by NDRC and NEA also explicitly requires the development of wind power technology to put "deep sea wind energy" on the agenda.

In terms of site selection of offshore wind power plants, it is predicted that in the next decade, the scale of offshore wind power construction projects in China will expand rapidly and develop on the deep sea. In China, current offshore wind power is mainly concentrated in the offshore areas with short distance and shallow water depth. In the future, the offshore wind power will be expanded from the coastal intertidal zone within 10 km to the offshore area of 30-40 km from the coast. With the increase of offshore distance, the advantages of AC transmission technology will gradually weaken, and HVDC technology will become one of the effective methods for large-scale offshore wind power transmission. At present, large diameter single pipe piling will still be the mainstream construction technology of intertidal zone and offshore wind power; after 2025, China will gradually explore the development of deep-sea wind power, at which time floating installations will be the research focus.

2.1.3 Cost, Investment and Finance Model of Offshore Wind Project

The cost of offshore wind power technology is rapidly declining. The global weighted average levelised cost of electricity (LCOE or generation cost) for offshore wind power in 2018 was $0.127/kWh, which is about 20% lower than the $0.159/kWh in 2010. There is a big difference in the decrease of the cost of offshore wind power in different countries. In Europe, between 2010 and 2018, the generation cost fell by 14%, from $0.156/kWh to $0.134/kWh. The largest drop occurred in Belgium, with a 28% drop from 2010 to 2018, and a reduction in generation costs from $0.195/kWh to $0.141/kWh; Germany and the UK dropped by 24% and 14% respectively, and the generation cost in Germany and the UK dropped to US $0.125/kwh and US $0.139/kwh respectively. The recent auction of contract for differences contract in the UK shows the generation cost of offshore wind could reach grid parity in 5 years.

In Asia, between 2010 and 2018, the electricity generation cost decreased by about 40%, from US $0.178/kwh to US $0.106/kwh; the decline was mainly driven by China, which has more than 95% of the offshore wind power facilities in Asia. According to the International Renewable Energy Agency, the downward trend of the cost of offshore wind power will continue. It is predicted that by 2022, the cost range of global offshore wind power projects will be 0.06-0.14 USD / kWh, among which the projects in Europe will be 0.06-0.10 USD / kWh; the average cost of offshore wind power may decrease by 15% to 0.108 USD / kWh, with an annual decline of 4%.

From 2010 to 2018, the cost of offshore wind power construction in China has also been declining. The construction cost of the first phase of the Shanghai Donghai Bridge Wind Farm, which was put into operation in 2010, was 23,200 Yuan/kW. The cost of the second phase of the project completed in 2014 was reduced to 19,200 Yuan/kW. In 2017-2018, the investment cost of offshore wind power in Jiangsu Province is approximately 15,000-18,000 Yuan/kW.

The investment in the Fujian and Guangdong sea areas is relatively high, about 18,000-20,000 Yuan/kW. According to the statistics of the State Grid Energy Research Institute, offshore wind power projects approved and started in 2018 show an average investment cost of about 14000 to 19000 Yuan/kW, and the generation cost of offshore wind power is about 0.64 Yuan/kWh. However, compared with the construction cost of onshore wind power of about 7000 Yuan/kW. The capital cost for offshore wind is still relatively high, about twice of that of onshore wind power farms. In addition, the price of electrical equipment such as submarine cables and offshore booster stations is much higher than that of onshore wind, and the cost of wind turbine foundation and installation is far higher than that of onshore wind farms. However, this part of the cost might be offset in the future by higher generation hours and the lower land use cost of offshore wind power.

In May 2019, the NDRC issued “The Notice on Improving the On-grid Price of Wind Power” changing the benchmark on-grid tariff for offshore wind power to the guidance price, and determining on-grid tariff for all newly approved offshore wind power projects through competition. The newly approved guided price for offshore wind power will be adjusted to 0.8 Yuan/kWh in 2019 and 0.75 Yuan/kWh in 2020; the on-grid electricity price determined through competition for newly approved intertidal wind power projects shall not be higher than the guide price for onshore wind power in the resource area where the project is located. Wood Mackenzie Engineering Company of the United Kingdom believes that the current technical difficulty and development cost of offshore wind power is still the main factor restricting its development, and a tendering mechanism will prompt the LCOE of offshore wind power projects to decrease rapidly. The “China Offshore Wind Power Market Outlook” released in 2018 is expected the average level of offshore wind power tariffs to be reduced from 0.62 Yuan/kWh in 2018 to 0.41 Yuan/kWh in 2027.

The potential climate investment and finance model can refer to other renewable energy projects, such as onshore wind power and solar photovoltaic as they share similar cost structure with high capital cost, but low and stable operating cost. Innovative commercial financing mechanisms include project financing, asset securitization, the “build operate transfer” (BOT) model, financial leasing, etc., which can not only overcome the limitations of traditional financing methods, but also provide impetus for the implementation of projects and further promote the development of technology. In the UK, offshore wind operational asset is usually considered as low risk by investors which already attracted pension fund investment[2].

> ***"Scottish local pension fund Strathclyde invested 50 million in offshore wind asset through UK Green Investment Bank in 2015"***

The innovation of public sector support policy is also the embodiment of the optimization of investment and financing mode. Providing low interest loans for demonstration projects is conducive to reducing financing costs, and adopting wind farm bidding models is conducive to the efficient use of public sector resources. Offshore wind power projects can also issue green or climate bonds to publicize enterprises and projects.

2.1.4 Social Benefit of Offshore Wind Power

In addition to promoting the transformation of the local energy structure to low carbon and reducing greenhouse gas emissions, offshore wind power will also provide certain jobs for local residents and promote related industries (such as wind measurement and wind turbines) in local or neighboring provinces and cities. The development of design, manufacturing, engineering construction, transportation, etc., can bring certain tax revenues to the local government. At the same time, the impact of offshore wind power on the marine ecological environment is mainly reflected in the construction and operation period, the main impacts include marine life, birds and waterways. Among them, the impact on the environment during the construction phase will be less as the construction period ends.

[2] Strathclyde made first investment in offshore wind farm https://www.professionalpensions.com/news/2430226/strathclyde-makes-investment-uk-offshore-wind

2.2 Shenergy Lingang Offshore Wind Case Study

Shanghai Lingang offshore wind power project one of the first offshore wind farm in China. The project is located 10-16km to the east of Nanjiangzui, Pudong New Area, Shanghai. It is divided into the first and second phases as well as the first phase of Lingang offshore wind power prototype project. The first phase of the project is commissioned, and the second phase of the project was connected to the grid in 2018. The average water depth of the site is 5-10m, the project scale is 100MW in phase I, 100.8MW in phase II, applying 4MW turbine in phase I, 3.6MW turbine in phase II and 6MW turbine in prototype. The equivalent utilisation hours are 2672 hours for the first phase, 2642 hours for the second phase and 2680 hours for the prototype. The owner is Shanghai Lingang offshore wind power generation Co., Ltd. and the engineering construction company is CCCC third Harbor Engineering Bureau Co., Ltd.

Figure 2-3 Picture of Shanghai Lingang Offshore Wind Farm[3]

[3] Source: Shenergy

2.2.1 Climate Benefit of Lingang Offshore Wind Project

The main climate (environmental) benefits of offshore wind energy come from replacing fossil fuel power plants, and the operation of wind turbines will not directly emit greenhouse gases[4] (or other air pollutants). The annual emission reduction per unit investment and per unit installed capacity is 138.5g carbon dioxide equivalent / Yuan and 2.16 ton[5] carbon dioxide equivalent/kW, respectively, and the life cycle emission reduction cost is 288 Yuan/ton carbon dioxide[6].

According to the calculation of the project team, the total annual emission reduction of the first and second phases of the Shanghai Lingang Offshore Wind Power Project is estimated to be 444,000 tons. According to Shenergy data, compared with thermal power with the same power generation, Shanghai Lingang Offshore Wind Power Project Phase I and Phase II can avoid the emission of 2893.5 tons of sulfur dioxide, 116 tons of carbon monoxide, 2735.75 tons of nitrogen oxides, 16 tons of hydrocarbons, 1687.54 tons of soot, and 32497.5 tons of ash slag. Moreover, can also save 170212.6 tons of water, and reduce the corresponding amount of water ash discharge wastewater and warm drainage and other water pollutants.

2.2.2 Technology Innovation of Lingang Offshore Wind Project

The prototype project adopts a Shanghai Electric W3600-122-90 single-machine 6MW or more advanced turbine, D6 platform capacity design, in line with the trend of large capacity at sea. Operating in offshore areas with water depths of 5 meters to 10 meters, the estimated equivalent utilisation hours are 2,680 hours. The project uses the advanced technology and manufacturing technology of Siemens, and the reliability concept runs through the whole single machine development process.

[4] In the second phase of the offshore wind power project near the port, 0.69 to 0.82kg of carbon dioxide direct emission reduction can be achieved per kWh depending on the grid emission factor or the baseline assumed.
[5] All ton in this report will be in metric tonne
[6] The baseline for calculation is a supercrticial coal-fired power plant.

The prototype project uses an S84 blade independently developed by Shanghai Electric Co., Ltd., which is the longest fiberglass blade in China at present. It also uses a blunt trailing edge airfoil, and the separation point moves to the trailing edge of the blade to increase lift, improve aerodynamic efficiency, reduce fatigue and enhance blade stability. A vortex generator is used to reduce the trailing edge vortex, improve the utilization of wind energy and reduce aerodynamic noise. The coupling design of the bending and torsion adjusts the passive angle of attack of the blade for strong gusts, which reduces the load of the whole machine and prolongs the life of the unit. The blade shell, main beam and rib plate are respectively formed by vacuum infusion processes, and the mirror mold technology is used to improve the surface finish of the blade, further improving the efficiency of the blade.

The generator of the prototype adopts stator block technology, which is convenient for manufacturing, transportation and maintenance; the high residual magnetism of the rotor can improve efficiency and reduce loss; the magnetic steel sealing and anti-corrosion technology eliminates the risk of demagnetization. The full power converter used in the project has a broader reactive power regulation and support capacity for grid voltage. In addition, the internationally advanced load control technology adopted in the project has the characteristics of high wind speed crossing, high turbulence load reduction and high temperature crossing. Through big data analysis of the cloud center, intelligent operation and maintenance of the project can realize fault prediction and remote fault diagnosis.

2.2.3 Investment and Finance Model of Lingang Offshore Wind Project

The total investment of Shanghai Lingang offshore wind power project is 2.99 billion Yuan, including 1.22 billion Yuan for phase I, 1.57 billion Yuan for phase II and 200 million Yuan for prototype. It is estimated that the annual income of the second phase project is 200 million Yuan, the annual operating cost is 120 million Yuan, and the internal rate of return for the total capital of the project is 4.71%.

The debt to equity ratio of the second phase of the project is 80/20. The banks have provided 1.531 billion Yuan of preferential loans. The participating banks and their shares are: Bank of Communications (23%), China Development Bank (18%), Shenergy Finance Company (16%), Bank of China (14%), Construction Bank (14%), Shanghai Pudong Development Bank (14%) and Minsheng Bank (1%).

> ***"Although offshore wind is an emerging low-carbon technology, syndicated loan was provided by commercial banks and development banks in China at a favourable interest rate (90% of benchmark rate)."***

Shenergy Group Finance Company integrates internal and external resources for Shanghai Lingang Haifeng Project, providing comprehensive financial services including self-operated loans, syndicates, policy financing funds, financing guarantees, etc., in innovative service models and enriched financing. Significant results have been achieved in product variety, project construction fund, and project financial cost reduction. It provides financial institutions with the advantages of green credit, supports green clean energy projects, and provides replicable and scalable samples with significant demonstration effects.

The total amount of financing lease contracts signed in the first phase of the project was 648 million Yuan, and the accumulated drawdown was 379 million Yuan. Up to September 2019, the book balance was 370 million yuan. This financial lease is used to pay for the wind turbine, submarine cable and tower equipment of the first phase of the project. The total amount of financial leasing contracts signed for the second phase project was 686 million Yuan, and the accumulated drawdown was 577 million Yuan. The book balance as of September 2019 for the second phase was 563 million yuan. The signing of the second phase of the framework agreement was for a total of 461 million Yuan, and will also be used to pay for the wind turbine, submarine cable and tower equipment of the second phase of the project. The total amount of financing lease contracts signed by the prototype project was 85 million yuan, and the accumulated withdrawal amount was 17 million yuan. The book balance as of September 2019 was 16 million yuan. This financial lease is used to pay for the turbine and tower equipment of the prototype project.

2.2.4 Social Benefits of Lingang Offshore Wind Project

Shanghai Lingang offshore wind power project uses wind energy to generate electricity without fuel consumption or generating waste slag. At the same time of promoting economic development, the original local living environment will not be damaged, which is the optimal power supply selection for Shanghai to solve the energy shortage. It also subsidizes local fisheries.

Figure 2-4 Shanghai Lingang Offshore Wind Project Platform[7]

[7] Source: Sheneneng Energy

2.3 Yudean Wailuo Wind Offshore Wind Case Study

Guangdong Yudean Zhanjiang Wailuo Offshore Wind Power Project is the first large-scale offshore wind power project in Guangdong Province. It is located in the east coast of Xinyi Island and Wailuo, Xuwen County, Zhanjiang City, Guangdong Province. The site covers an area of about 29 square kilometers, with a design installed capacity of 198 megawatts (MW), 36 5.5MW wind turbines, 1 220kV sea rising pressure station, onshore centralized control center, and 1 offshore wind measuring tower. The power collection lines of the wind farm are for 35kV, and the 35kV power collection lines use 8 submarine cables, which are connected to the 220kV offshore boosting station, which in turn is connected to the land centralized control center of Wailuo town through one 220kV submarine cable. Both the owner and the engineering construction company are Guangdong Yudean Qujie Wind Power Generation Co., Ltd.

2.3.1 Climate Benefit of Wailuo Offshore Wind Project

According to estimates by the Guangdong Electric Power Design Institute, the annual carbon dioxide emission reduction of the Zhanjiang Wailuo offshore wind power project is 390,000 tons. According to the emission factors of Southern regional power grid and CCER methodology calculation, each kWh of offshore wind power can achieve 0.69 kg of carbon dioxide direct emission reduction in Guangdong. The annual emission reductions per unit investment and per unit installed capacity are 105g CO2 equivalent / Yuan and 1.99t CO2 equivalent / kW, respectively. The cost of life cycle emission reduction calculated based on the feed-in tariff of thermal power and emission factors of China Southern Power Grid is 380 Yuan / ton carbon dioxide.

2.3.2 Technology Innovation of Wailuo Offshore Wind Project

The project adopts the single-machine 5.5MW advanced Mingyang Intelligent My5.5-155 turbine, which is contracted by Guangdong Electric Power Design and Research Institute Co., Ltd. and operates in the sea area of 5 meters water depth. The equivalent utilization hours are expected to be 2375 hours. The project also uses the following three innovative technologies: Large diameter single pile turbine foundation, advanced offshore voltage booster station design, a smart offshore wind farm built based on big data.

In regard to turbine foundation design, the project appoints Zhejiang University to develop a professional program for pile-soil analysis, which can be used for rapid modeling and analysis of pile-soil model, and provide a P-Y curve, a key design parameter, for deformation and natural frequency analysis of large diameter single pile foundations.

For offshore voltage booster station, the project platform is surrounded by and connected to a circular outer corridor. The T-shaped internal corridor is set to ensure the transportation of equipment and the safe evacuation of personnel. The oil-containing equipment is located downwind to reduce the influence of fire accidents. The equipment with larger heat dissipation depends on the peripheral layout, which is convenient for ventilation and heat dissipation. The hoisting area of each floor and the position of the ship should be reasonably planned to improve the visibility and maneuverability of the hoisting operation. Three dimensional design is adopted to avoid collision between pipeline and steel structure and improve construction efficiency.

In terms of data collection, Zhanjiang Wailuo offshore wind farm is the foundation for developing the Guangdong offshore wind power big data center, an integrated intelligent monitoring and management information platform built to conduct in-depth analysis of massive data such as wind resources, power generation capacity of each fan, equipment status information, equipment failure rate, etc., and which can maximize the use of wind resources and optimize the maintenance cycle, and provide early warning and diagnosis of accidents and equipment failures.

2.3.3 Investment and Finance Model of Wailuo Offshore Wind Project

The project is financed by the Zhanjiang branches of Bank of China, China Construction Bank, Industrial and Commercial Bank of China, Agricultural Bank of China and Yudean Finance Company with 2.16 billion Yuan commercial syndicated loans, 69 million Yuan of low interest loans provided by the Clean Development Mechanism Center and financial leasing provided by Yudean Qujie Wind Power Generation Co., Ltd, effectively reducing the financing cost.

2.3.4 Social Benefit of Wailuo Offshore Wind Project

In addition to promoting the transformation of the local energy structure to low carbon and reducing greenhouse gas emissions, the construction and operation of offshore wind farms will also provide certain jobs for local residents, promote the development of relevant supporting industries (such as fan manufacturing, engineering construction, power transmission, etc.) in local or neighboring provinces and cities, and bring certain tax revenues to local governments. Guangdong Yudean Zhanjiang Wailuo offshore wind power project will improve local infrastructure and environment, stimulate local economic development and increase employment.

Chapter 3 Energy Storage Case

3.1 Energy Storage Industry Overview

Energy storage in this case refers to the storage of electricity. Dedicated energy storage plant is used to store energy when electricity is in surplus and release it when electricity supply is inadequate, thus adjusting the mismatch between energy supply and demand in time and intensity. Compared with traditional power systems, energy storage has the following effects:
(1) Improving the utilization level of renewable energy;
(2) Improving the flexibility and stability of power systems;
(3) Improving the level of intelligent use of energy.

According to the data from the US Department of Energy's Global Energy Storage Database[8], up to September 2019, the cumulative installed capacity of energy storage projects in the world was 187.80 GW, pumped storage capacity 181.19 GW (96.48%); electrochemical energy storage 3.30 GW (1.76%); heat storage 3.28GW (1.74%); hydrogen storage 0.02GW (0.01%); other mechanical energy storage 0.02GW (0.01%). China, the United States and Japan lead the global energy storage market where the cumulative installed capacity of energy storage projects is 31.7GW, 31.2GW and 28.1GW respectively. The sum of the three countries is equivalent to 50% of the global installed capacity. In 2020, China's energy storage market will reach nearly 42GW[9].

An energy storage project is mainly based on the development of the renewable energy industry and new energy automobile industry and is carried out in the mode of “storage energy + renewable energy”. Since the publication of China's Guiding Opinions on Promoting Energy Storage Technology and Industrial Development in 2017, the General Offices of the National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, and the

[8] US DOE. 2019. https://www.energystorageexchange.org/projects/data_visualization.
[9] Zhongguancun Energy Storage Alliance (CNESA) global energy storage project library.http://esresearch.com.cn/#/global_PDB/demoAnalysis. (Access: 2019.9.27).

Comprehensive Department of the National Energy Administration jointly issued the Action Plan of Guidance on Promoting Energy Storage Technology and Industrial Development 2019-2020, which set out a series of action plans around energy storage technology research and development, energy storage industry development, pumped storage enhancement, new energy vehicle power battery application and energy storage standardization, making a clear division of work promoting the energy storage industry of future stages, which greatly stimulates the vitality of the domestic energy storage market.

Table 3-1 Development Planning of Energy Storage Projects in Relevant Provinces of China

	Key Policy Document	Development Plan
Beijing	*Beijing Energy Development Plan of During the 13th Five-Year Plan*	Focus on key technologies such as large-scale energy storage, high-efficiency energy storage and intelligent fusion control. Strengthen the development of energy Internet infrastructure, encourage new models of energy storage operations, and carry out regional trials and demonstrations of energy Internet.
Jiangsu	*Jiangsu Energy Development Plan of During the 13th Five-Year Plan*	During the 13th Five-Year Plan period, the installed energy storage capacity on the user side will reach 1 GW. Combined with the decommissioning and reuse of vehicle batteries, construct a multi-mode electric energy storage system with pumped storage as the main energy and battery storage as the auxiliary energy; build 50 micro-grid demonstration projects; build smart energy system.
Henan	*Henan Energy Development Plan of During the 13th Five-Year Plan* and plans to promote the transformation and development of the energy industry in Henan	Promote the development of demonstration projects for complementary, integrated and optimised multi-energy projects, and promote the coordinated development and utilisation of traditional energy with wind, solar, geothermal and biomass energy; carry out demonstration applications of energy storage in the field of renewable energy.
Guangdong	*Guangdong Energy Mix Adjustment During the 13th Five-Year Plan* and *Guangdong peak load auxiliary service market trading rules (trial)*	Build pumped-storage power stations in Shenzhen, Qingyuan, Meizhou (Wuhua) and Yangjiang, with the installed capacity of pumped-storage generating capacity reaching 7.3 GW by 2020. Third party auxiliary service providers and power generation enterprises (units) are allowed to participate in the peak load auxiliary service market.

In the energy storage planning schemes of 25 provinces and cities, the provinces have different emphasis on energy storage development. Beijing, Sichuan and other provinces focus on the key technologies for energy storage; Jilin, Shanghai, Henan and other provinces promote energy storage demonstration; Hebei, Zhejiang, Guizhou and other provinces focus on the development of smart energy. Only Jiangsu Province has set clear targets for energy storage development (as shown in Table 3-1). In the deployment of energy storage projects, Jiangsu, Henan, Qinghai, and Guangdong provinces successively released information in 2018 on the building large-scale energy storage projects.

In the long-term, China's energy storage industry will maintain a rapid growth rate and move toward large-scale projects. According to China's NDC goal, the proportion of non-fossil energy will be increased to 20% by 2030, which means that China will add about 250 GW of wind, solar, nuclear and other near-zero emission capacity each year. With such a goal, the future additional power capacity will be dominated by renewable energy, and the intermittent nature of photovoltaic and wind power makes energy reserve and regulation a major challenge. Energy storage technology plays a role in this aspect and is the key to meeting the challenge.

3.1.1 Climate Benefit of Energy Storage Project

Energy storage will release greenhouse gases themselves during the commissioning process, and greenhouse gas emissions will increase as the load increases. The cliamte benefit of energy storage projects mainly come from reducing the phenomenon of abandoning wind and abandoning light and adjusting intermittent defects, increasing the ratio of renewable energy investment, reducing the proportion of fossil fuel power generation and reducing greenhouse gas emissions. According to estimates, the average direct carbon emissions from crystalline silicon solar cells are only 42 grams of carbon dioxide equivalent / kWh[10], and the direct carbon emissions estimates for offshore wind power are around 14 grams of carbon dioxide equivalent / kWh[11]. According to the

[10]CREIA. 2012.《中国光伏产业清洁生产研究报告》http://www.creia.net/d/file/publish/report/2016-01-14/fdaa57be19b3d17c5e03264304232ebe.pdf. (Access: 2019.10.9).
[11] IPCC.2011. <Renewable sources and climate change mitigation>. https://www.ipcc.ch/report/renewable-energy-sources-and-climate-change-mitigation/.

research results of scholars in recent years[12,13,14], the carbon emission of various energy storage projects is 256 grams of carbon dioxide equivalent / kWh on average. Combined with renewable energy, the projects are still more effective than fossil fuel energy generation in terms of emission reduction (as shown in Figure 3-1).

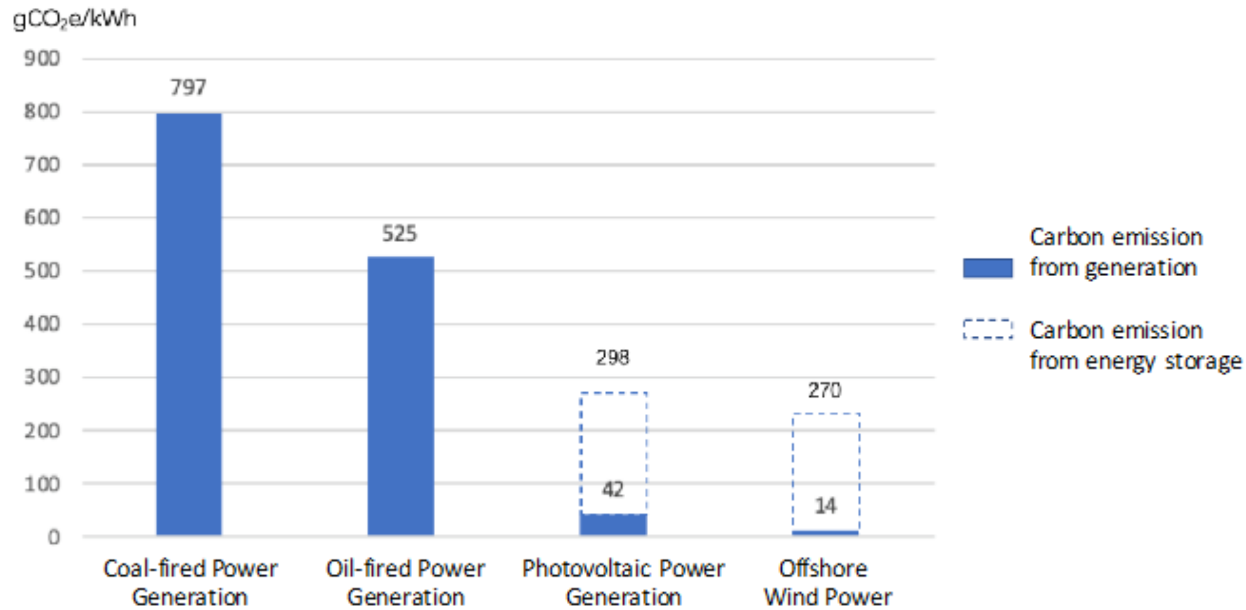


Figure 3-1 Estimated Carbon Emissions of Different Technologies at the Same Level of Generation Quality

3.1.2 Technology Development Trend of Energy Storage

The application of each energy storage technology is limited by its own inherent characteristics, for example, different discharge times, energy densities and power densities. However, no single indicator can completely determine their applicability to specific applications[15]. At present, pumped storage is the most mature technology in global energy storage technology and electrochemical energy storage technology has

[12]Condon, M. Revesz,R.L. and Unel, B. (2018). <Managing the future of energy storage>. https://policyintegrity.org/files/publications/Managing_the_Future_of_Energy_Storage.pdf.
[13] Hittinger, E. and Azevedo, I. 2015. <Bulk Energy Storage Increases United States Electricity System Emissions>. 49 Environ. Sci. Technol., 3203, 3208 (2015).
[14] Hittinger, E. and Azevedo, I. 2017. < Estimating the Quantity of Wind and Solar Required to Displace Storage-Induced Emissions>. https://pubs.acs.org/doi/suppl/10.1021/acs.est.7b03286/suppl_file/es7b03286_si_001.pdf.
[15]IRENA.2017. <Electricity Storage and Renewables: Costs and Markets to 2030>. https://www.irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets. (Access: 2019.9.25).

the greatest potential. According to McKinsey's latest research, the core driving force behind the cost reduction of energy storage is the global demand for electronic consumer products and electric power vehicles, which has spurred the cost reduction of batteries and supporting systems. The current technological developments and innovations in energy storage projects mainly include advances in battery technology and system integration capabilities[16].

The decline in battery cost comes from the innovation of the battery technology which has six technology connotations:
(1) Material;
(2) Structure;
(3) Manufacturing;
(4) Application;
(5) Regeneration,
(6) Recycling.

In 2015, the State Council issued *Made in China 2025*, which clarified the development plan of the power battery: in 2020, the battery energy density should reach 300Wh/kg, and in 2030, the battery energy density should reach 500Wh/kg. In the limited space where the cost of materials is reduced, the manufacturing cost should be reduced by innovative battery structure design. Cost reduction and the safety pressure faced by external systems through the subversion design of internal structure, such as horizontal battery design, is the main direction of current design technology innovation. The innovations in application and regeneration technologies lead to longer battery life and improved energy storage batteries and reduced maintenance costs. In 2016, the Ministry of Ecology and Environment revised the *Technical Policy for the Prevention and Control of Waste Battery Pollution*, including the replacement and disposal technology of used batteries, safe transportation technology, recycling technology and resource recycling technology, and also included lithium batteries, solar cells and fuel cells in the policy.

[16] Mckinsey & Co. 2019. <The new rules of competition in energy storage>. https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/the-new-rules-of-competition-in-energy-storage#.(Access: 2019. 10.8).

Energy storage projects tend to be large-scale, and the large-scale integration of energy storage systems is a necessary condition for realizing large-scale energy storage power stations. At present, many of the energy storage demonstration projects are directly connected by the battery production supplier to the power grid company, which, coupled with a lack of responsibility identification standards and application technical standards, brings difficulties to the later system operation, maintenance and possible accident identification. The energy storage project system integration capability is mainly enhanced by BMS (Battery Management System), PCS (Power Control System) and EMS (Energy Management System). In *Guidance on Promoting Energy Storage Technology and Industrial Development*, released in 2017, the promotion of energy storage technology and industrial development is one of the key points.

In addition to the electrochemical energy storage innovation, other technological innovations include pumped storage and heat storage. According to the *Action Plan of Guidance on Promoting Energy Storage Technology and Industrial Development 2019-2020*, promoting pumped storage development is one of the six major action plans. The innovative pumped storage technology using seawater will be the next breakthrough. Several innovative heat storage technologies at home and abroad have gradually replaced the molten salt heat storage technology, making up for the defects of high freezing point and easy freezing of pipes. One well-known example is the high-efficiency energy storage technology for carbon-containing chemical liquids, verified by Chalmers University of Technology, Sweden.

3.1.3 Cost, Investment and Finance Models of Energy Storage Project

The Levelised Cost of Storage (LCOS, referred to as "storage cost") is generally declining, but the degree of decline is different from the maturity of different technologies. As shown in Figure 3-2, the pumped storage technology is relatively mature. The cost trend will remain at US$20/MWh for the next few years; compressed air will be reduced from US$55/MWh to US$44/MWh; and flywheel technology will be reduced from an average of $3,700/MWh to $2,450/MWh.

The cost of electrochemical energy storage technology is falling fast because of the decrease in battery cost. The average price of Lithium-Ion batteries in 2017 has dropped to US$209/MWh. By 2030, the average price will be around US$70/MWh; the average battery price of the Lead-acid batteries will drop from $290/MWh to $145/MWh; the average cost of the liquid flow battery will drop to $342/MWh, a drop of more than two-thirds. Although differences between the cost of various technologies is significant, most energy storage technologies have the prospect of achieving significant cost reduction through technological innovation.

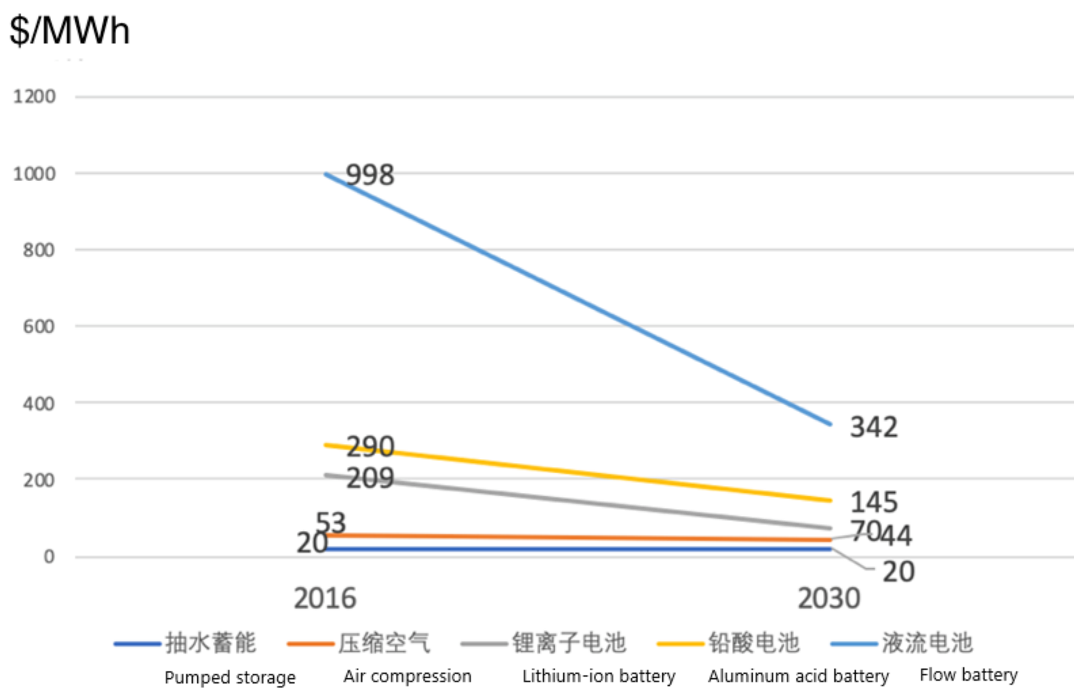


Figure 3-2 Trend of Levelised Cost of Storage for Different Types of Storage Technology

With declining energy storage costs, the value of energy storage will be reflected in more application scenarios and provide value-added services. Therefore, ‘energy storage projects + other energy projects’ is a business model with investment value in the future. It takes into consideration China's national conditions and technical status. ‘Photovoltaic power station + energy storage’ project is one of the investment and financing models that is currently being explored. For a single energy storage project, financial leasing is a more convenient and common investment and financing model in the Chinese market compared with direct investment. Direct leasing and rentback are two common leasing models used in the energy storage industry. Business leasing is more common abroad but is in its infancy in China. Energy storage projects can also expand publicity through labelling assets with green or climate credit, bonds, and funds.

3.1.4 Social Benefit of Energy Storage Project

The primary benefit for society of energy storage projects is to ensure adequate supply of electricity in peak demand period and reduce the need for investing in peak-load power plant. Energy storage, planned in an effective way, could enable more renewable energy to replace fossil fuel power plant, as a result reducing air pollution, and minimizing public health pressures and the negative effects on local health. The construction of energy storage projects also brings in abundant job opportunities to the local area, bringing tax revenue to the local government.

3.2 Dalian Liquid Flow Battery Energy Storage Peaking Power Station Demonstration Project

Dalian Liquid Flow Battery Storage and Peaking Power Plant Demonstration Project (Phase I) is in the west of Dalian Beihai Thermal Power Station. The southwest of the site is adjacent to Xiangzhou Road, the east part is close to Chunguang Street in the east, and the west and north of the site is close to Chunliu River in Dalian. The service target is Liaoning Power Grid and the first phase design installed capacity is 100 MW / 400 MWh, currently in the process of construction. The peaking power station uses a 17watt hour/litre density liquid flow battery with a conversion efficiency of 70% or more and a charge-discharge rate ratio of 1.5:1. The project is the first national large-scale chemical energy storage national demonstration approved by the National Energy Administration.

2.1 Climate Benefit of Dalian Energy Storage Project

The project can improve the output of new energy and improve its grid-connected capacity; it can serve as the system backup capacity and reduce the standby demand and power outage loss; It is beneficial for peak cutting and valley filling for the power grid to solve mismatches between power supply and use; it can be used as the auxiliary power supply to improve the power quality and power supply stability, and ensure the safe and stable operation of the power grid, whilst having a small impact on the environment around the power station. The development and application of energy storage technology will have far-reaching influence and play an important role in modern energy production, transportation, distribution, utilization and environmental protection. It is an important way to achieve sustainable development of energy, economy and society, bringing climate benefits.

3.2.2 Technology Innovation of Dalian Energy Storage Project

The project uses an electrolyte with a density of 17 watt-hours per litre and the material can be fully recycled. According to different modes, the life cycle performance decay rate is about 1-3% attenuation per year, 100% recovery, and the life cycle charge and discharge capability is more than 12000 times.

The ion exchange membrane in the project equipment is from American Chemours Chemical Co., Ltd. and the energy storage converter is from Nanjing Nairui Jibao Electric Co., Ltd. The ion pass rate, selectivity and lifetime of the ion exchange membrane are important factors that directly affect the performance of the battery. The current lifetime, price of all-fltmsulphonie acid ionic exchange membrane and the loss of battery capacity caused by self-discharge are important factors that restrict the development of all-vanadium flow batteries.

Exploiting new replacement membranes will be one of the development directions of vanadium redox flow batteries. With the advancement of new energy projects, energy storage converters have formed a product system with mature products ranging from 10kW to 500kW. Since power conversion systems (PCS) work in both charging and discharging modes, different modes have different performance requirements for the device. In the charging mode, it is necessary to consider the charging voltage, DC steady current accuracy, current ripple performance and other properties; in the discharging mode, it is necessary to consider the output AC voltage, frequency range, active and reactive power range of adjustment, current waveform distortion rate, etc. An energy storage converter of 500kW is used in this project.

This project selects an all vanadium redox flow battery as the energy storage media for the large-scale battery energy storage demonstration project, which will perform a good demonstration role and accumulate valuable experience of large-scale application of all-vanadium liquid battery, laying a foundation for the further development of power storage engineering. At the same time, according to the technical strength and production scale of the world's major vanadium-fluid battery manufacturers, Dalian Rongke Energy Storage Technology Development Co., Ltd. is determined to be the supplier of energy storage batteries for the demonstration power station. The company relies on the basic technical support of the Dalian Institute of Chemical Physics of the Chinese Academy of Sciences. Through independent research and cooperation with the Dalian Institute of Chemical Industry, it has mastered the leading core technologies of battery materials, stacks and systems, and operation management control, and accumulated a number of patents.

The total capacity for the first and second phases of the project are 200 MW/800 MWh. The battery configuration scheme of the energy storage power station is as follows: the single battery capacity is 31.5 kW, adopting 8-string-2-parallel 31.5 kW battery wiring schemes to form a 500kW battery container, corresponding to a PCS with a power of 500 kW. Four 500 kW energy storage converters are connected to a 2000 kVA low-voltage step-down-side four-split 35/0.315 kV energy storage transformer. Each 10 energy storage transformer is connected in series to a 20 MW energy storage unit, collected by the volt-collecting line and connected to the 35-kV busbar of the substation. The high-efficiency battery management system and high-quality battery optimize the battery system structure design and operation mode, reducing system internal friction. However, the cost of all vanadium redox flow batteries is higher than that of Lead-Acid, Sodium-Sulfur and Lithium-Ion batteries. Therefore, the economic feasibility remains to be considered.

3.2.3 Investment and Finance Model of Dalian Energy Storage Project

The total investment in the liquid flow battery energy storage peaking power station demonstration project in Dalian (Phase I) is 357.93 million Yuan, and unit cost is 17897 Yuan / kW. Among them, the construction cost is 280 million Yuan, the equipment purchase cost is 3.05 billion Yuan, the installation engineering cost is 69.61 million Yuan, and other expenses are 170 million Yuan. The project capital ratio is 20.8%, and the bank provides 1.5 billion Yuan of loans. The financing syndicate includes: China Postal Savings Bank Co., Ltd. Dalian Branch, China Development Bank Dalian Branch, China Agricultural Development Bank Dalian Shahekou District Branch. The loan interest rate implements the current national regulations, which means the loan interest rate is 4.9%, and the loan repayment period is 15 years with payments amortized.

The project operation period is expected to be 15 years, and the financial evaluation will be calculated according to the equivalent power generation hours of the power station of 1168h and the benchmark yield of 7%. Annual operation and maintenance costs are considered to be 0.28 billion Yuan/ year (in which the annual operating cost of the battery body is 0.24 billion Yuan/year, other equipment operation and maintenance costs and labour costs are 2 million Yuan/year, and the annual rental cost is 2 million Yuan/year). Considering that the income of the energy storage power station is 440 million Yuan/year, when the capacity electricity price reaches 2.23 Yuan/kW, it can recover the fixed cost after 9.82 years (after income tax). The internal rate of return on project investment is 5.55%, and the financial internal rate of return of all parties to the investment is 6.04%, achieving the goal of project capital return rate of 10% (after income tax). The biggest risk of the current project is the price of electricity.

At present, the benchmark price of coal-fired units in Liaoning (the standard of environmental protection including desulfurization, out-of-sale, dust removal, etc. is 0.3685 Yuan / kWh), and the low-cost electricity price purchased by the energy storage power station from the system is set at 0.2579 Yuan / kWh (0.3685 Yuan / kWh × 70%) (including taxes). The annual charging needs 333.7 million kWh electricity, which means the operating cost will increase by 74 million Yuan per year (excluding tax). At that time, if the energy storage power station buys electricity at a low price, it will be sold at the peak time with reference to the benchmark price. If the energy storage power station buys electricity at a low price and sells it at the peak time with reference to the benchmark electricity price level without government policy support, the energy storage power station will suffer significant losses. To achieve the condition that the internal rate of return of all investments reaches 7% (after income tax), the price of electricity purchase price from the project needs to reach 2.5588 Yuan / kWh (including tax), the investment payback period will be 9.95 years (after income tax), the net present value of all investments (after income tax) should be 499,700 Yuan, and the total investment yield will be 5.15%.

3.2.4 Social Benefit of Dalian Energy Storage Project

The biggest social benefit of energy storage projects is the first demonstration of the large-scale liquid energy storage technology in China. The construction of this project will drive or promote the development of local economy and related industries, such as transportation and building materials industry. In addition, it provides a stable supply of electricity and heat to the area and co-ordinating the developments of local economy and environmental protection brings better social benefits.

Chapter 4 Low Carbon Building

4.1 Overview of Low Carbon Building Industry

Low carbon building refers to carbon emissions in the whole life cycle, from planning and design of construction, operation and demolition recycling at various stages (such as by reducing carbon sources and increasing carbon sinks) in order to realize building lifecycle carbon emissions performance optimization. The building construction industry is a large energy consumer, direct and indirect carbon emissions accounting for 50%[17] of total carbon dioxide emissions. This proportion is much higher than the transport and industrial sectors.

Low-carbon buildings can be further categorised as a sub-category of green buildings based on carbon emission levels. Nearly half of respondents from Europe, Australia and the United States stated that at least 30 percent of all new and existing construction projects are green buildings, according to Dodge Data & Analytics' global green building trends 2018 report[18]. According to the latest data from China Real Estate Chamber, by the end of 2018, there were 14.3 thousand projects labeled as green buildings. A total area of green buildings is more than 1.2 billion m^2. Compared with 2017, the number of projects and total area in 2018 increased by 30% and 20%. However, the number of identified green building projects is not enough. In 2018, compared with the previous years, the number of projects that received the green building two-star and three-star operation logos had increased, but the overall proportion is still less than 10%[19].

the world has different green building standard evaluation systems. As shown in Figure-4-1, the most influential international green buildings assessment systems include
- BREEAM in the UK
- DGNB in Germany

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[17] Liu S, Tao R, Tam C.M. Optimizing cost and CO2 emission for construction projects using particle swarm optimization. Habitat International, 2013: 155 -162.
[18] Dodge Data & Analytics. 2019. 《2018 年全球绿色建筑趋势报告》. https://www.construction.com/toolkit/reports/world-green-building-trends-2018.
[19] 标准排名.2019.《2019 年中国绿色地产指数 TOP30 报告》. http://biaozhunpaiming.com/articles/7da64455d94d3db0.html.

- LEED in the US
- NABERS in Australia
- Japan's CASBEE
- Canadian-led multinational GBC's GBTool

Almost all of the assessment systems include site environment, energy use, water use, materials and resources, interior physical environment. Germany's DGNB initially proposed a complete and accurate calculation method for building carbon emissions. In 2006, the Ministry of Housing and Urban-Rural Development issued a "green building assessment standards". This standard of assessment established a system of green building evaluation criteria relevant to China's own situation.

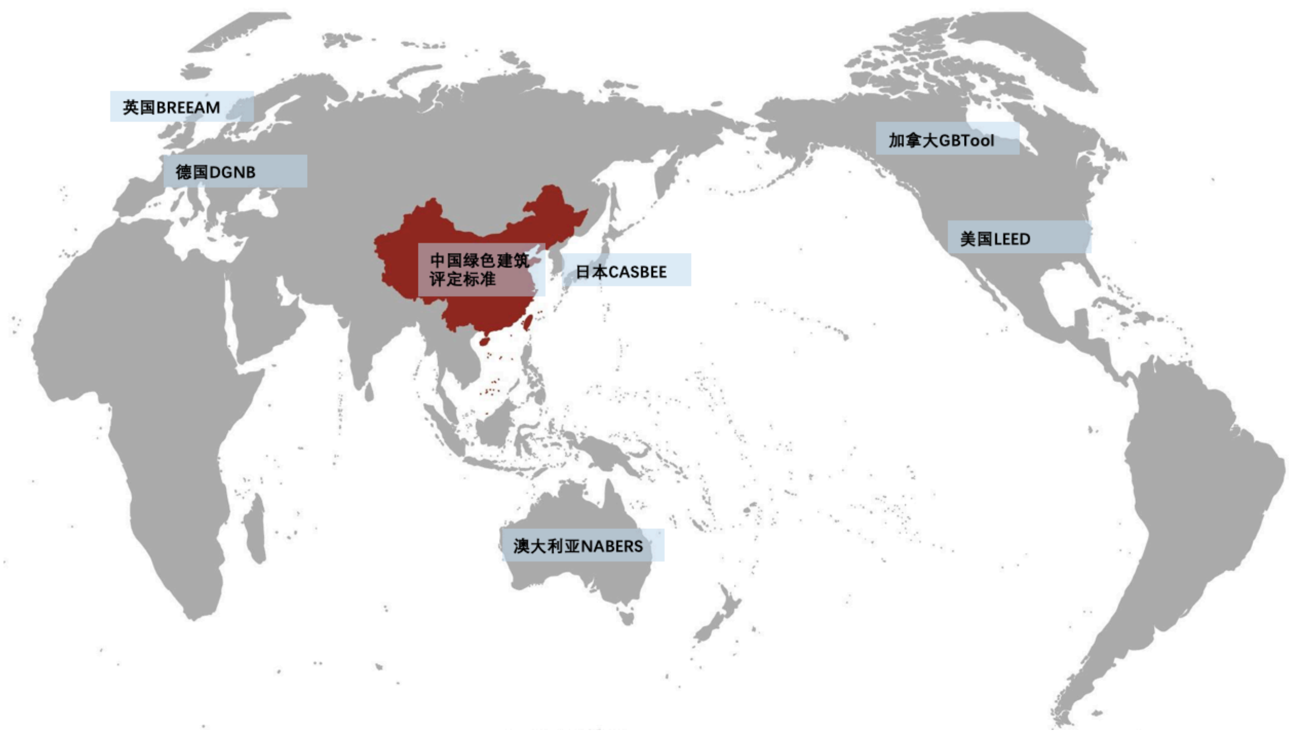

Figure 4-1 Green Building Standards around the World

The 13th Five-Year Plan of construction industry development states that by 2020, national urban green buildings should account for 50% of all new buildings. Each province released low carbon buildings program and plans (Table 4-1), and each local government made specific investment incentives for green building.

Table 4-1 Development planning of low-carbon buildings in relevant provinces of China

	Key policy document	Development plan
Shandong Province	Shandong Province Green Building Promotion Measures	Large public buildings should be built according to the standards of two stars and higher standards; residential projects with solar energy can enjoy preferential electricity price policies, and buildings which don't conform to green building standards, will face a maximum penalty of 200,000 Yuan.
Hebei Province	"Hebei Province Promoting Green Building Development Work Project"	Green building standards will be implemented in all new urban civil buildings. In 2019, green buildings accounted for more than 50% of new buildings, and in 2020, we will strive to reach up to 55%; develop ultra-low-energy buildings; promote the development of fabricated buildings; and vigorously develop new technologies and new materials; Strongly implementing energy performance contracting.
Anhui Province	" Main Requirements for Building Energy Efficiency and Science and Technology in the Province in 2019 "	In 2019, green buildings account for 45% of the total area of new civil constructions in the province. The proportion of prefabricated buildings in the new construction area will aim to reach 10%; publishing "Anhui Green Building Development Rules (draft)" to start green building legislation.

4 .1.1 Climate Benefit of Low Carbon Building

Building construction relies on transportation to deliver building materials. The lighting, refrigeration and the production of building materials need to consume electricity. In the winter, central heating, kitchens and sanitary ware use coal or natural gas for combustion. Low-carbon buildings can replace traditional buildings effectively saving energy and reducing emissions on building heating, air conditioning, ventilation, lighting, etc. The factors that constrain the carbon emissions of buildings are the scale of construction, the energy consumption per unit of floor space, and the CO_2 emission index of unit energy consumption in building use. It also depends on the replacement rate of renewable energy to traditional energy in building use[20]. A commonly used measure of building carbon emissions is life cycle carbon dioxide emissions (Lifecycle CO_2 emissions, $LCCO_2$)[21].The carbon dioxide emissions in the production stage

[20] 陈飞,诸大建.低碳城市的内涵、目标及对策措施确定.城市规划学刊,2009,4.

[21] Life cycle carbon dioxide emission ($LCCO_2$) is based on the CO_2 emission during the whole life cycle of a building to assess its impact on the environment, which represents the carbon emission per square meter of a building per year (generally 100 years)

of building materials account for the vast majority of the whole life cycle. Under the existing scientific and technological conditions, compared with the traditional building $LCCO_2$, the buildings which use the low energy-consuming building materials, the $LCCO_2$ of low-carbon buildings show a significant decrease.

4.1.2 Technology Option for Green and Low Carbon Building

Technologies implemented in low-carbon buildings include low-emissivity glass, medium water treatment systems, exterior and interior insulation systems, solar, indoor fresh air systems and storm water recycling systems. These technologies can achieve the effect of energy saving and emission reduction for low-carbon buildings. However, if these technologies can be connected with each other, and connected with other sensors, monitoring equipment, and communication equipment to form an IoT system, they can work better. For example, under the guidance of the IoT system, according to the temperature information obtained by the temperature sensor, the fresh air system and the solar energy equipment work together to effectively maintain the indoor temperature and control the concentration ratio of oxygen and carbon dioxide. The application of each technology is adjusted depending on the geography, climate and living habits of the building. For example, the north area needs to strengthen the insulation measures more than the south area, and the humid area needs to upgrade the rainwater circulation system more than the arid area.

The effective energy-saving and emission reduction of low-carbon buildings requires technical improvement at all stages of the life cycle. In 2017, the Ministry of Housing and Urban-Rural Development compiled “10 New Technologies in the Construction Industry (2017 Edition)”, which mentioned green construction techniques, including

- Construction waste reduction,
- Quantification and resource utilization technologies
- Construction site solar energy
- Air energy utilization technology
- Green construction online monitoring and evaluation technology, etc.

Compared with the 2010 edition, the 2017 edition has updated the related content of green building and building energy conservation with technologies such as steel and concrete, formwork scaffolding, fabricated concrete structure, the mechanical and electrical installation engineering etc. The awareness of green building concepts such as “passive technology priority and active technology optimization” has been deepened, and many green building technologies with low incremental cost, good regional adaptability and mature technology systems have gradually been accepted by the market.

In 2019, the newly revised "green building rating standards" set out technical requirements in six areas:

(1) Increase the ratio of the thermal performance of the building envelope or reduce the ratio of building heating or air conditioning load;

(2) Reduction of the heat transfer coefficient of the external windows of the residential building in cold areas;

(3) Increase the water efficiency level of the water-saving appliances;

(4) Develop sound insulation performance of the residential building;

(5) Increase the proportion of the indoor air pollutant concentration reduction;

(6) Develop outer window airtightness performance.

In the future, the low-carbon construction industry will focus on improving the requirements of the star rating in terms of low-carbon building materials and low-carbon building design. Low-carbon buildings are accompanied by a certain incremental cost. In order to reduce costs, negative incremental cost, zero incremental cost and low incremental cost technologies are utilised.

4.1.3 Investment and Finance Model for Low Carbon Building

Low-carbon buildings have a certain incremental cost compared to traditional buildings. However, low-carbon buildings are not simply ordinary buildings stacked with energy-saving technologies. Low-carbon building technologies can be divided into negative, zero, low and high incremental cost technologies based on incremental cost. With the increasing use of zero incremental cost and low incremental cost technology, high incremental cost technology is relatively less used.

There are no specific statistics on the decline in low-carbon construction costs, and the downward trend in the cost of green buildings can provide a reference for the cost reduction of low-carbon buildings. The incremental cost of one-, two- and three-star green buildings in residential buildings is 23 Yuan/m^2 , 66 Yuan/m^2 , 121 Yuan/m^2 , and the increment cost of one-，two- and three-star green buildings in public buildings is 44 Yuan/m^2 , 102 Yuan/m^2 , 161 Yuan/m^2 respectively. The cost also declined after 2011 (as illustrated in Figure 4-2).

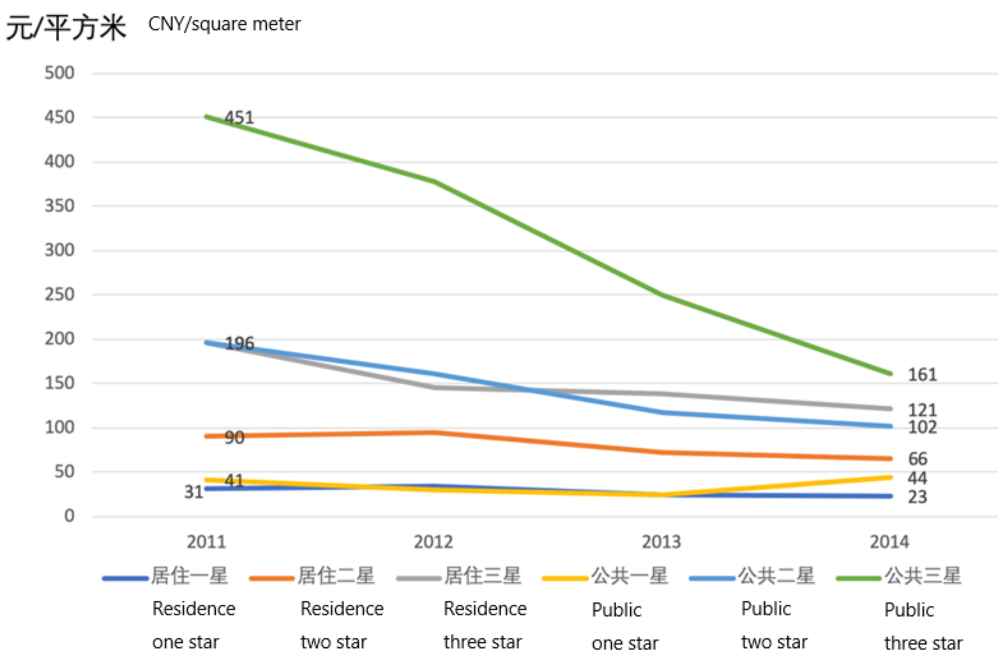

Figure 4-2 Trend of Incremental Cost for Developing Green Buildings

The government's investment policy for subsidising low-carbon buildings also offset certain incremental costs. Beijing has a subsidy of 225,000 Yuan for two-star green buildings and 400,000 Yuan for three-star construction; Tianjin has a ceiling of 50,000 Yuan for green buildings; Shanghai has 150,000 Yuan for one-star buildings and 300,000 for two-star buildings, and 500,000 Yuan for three-star buildings; Guangdong Province subsidizes 250,000 Yuan for two-star buildings and 450,000 Yuan for three-star buildings. In addition, Fujian, Guizhou and other provinces introduced incentive policy for green building floor area ratio. Inner Mongolia and Hai Nan provinces have incentive policies with reduction of city supporting fees, which effectively reduce the green construction costs and increase the economics.

Project financing is the main financing model for the low-carbon construction industry. The more commonly used models include the "facility use agreement" model, the leveraged leasing model, the BOT (build - operate - transfer) model and the PPP (public-private partnership) model. In addition to the above four project financing models, credit guarantees, corporate bonds and government subsidies are also the main investment and financing models for the low-carbon construction industry, while a series of emerging green financial products including green bonds, green credit, green funds and green insurance played a catalytic role in these financing models.

4.1.4 Social Benefit of Low Carbon Building

The benefits of low-carbon buildings for society include the creation of jobs, tax revenues, industrial synergies, and increasing the comfort of building users. There are currently no macro statistics on the benefits of these four aspects. According to researchers' predictions, if the low-carbon buildings replace traditional architecture, throughout the whole life cycle 250 thousand jobs will be created in the country and lot of tax revenue will accrue to the local government. Moreover, it will bring synergies to related industries such as industry, building materials, real estate, transportation, post and telecommunications, and promotes the overall development of the industrial chain. The requirements of low-carbon buildings for indicators such as health and comfort and convenience of living have improved the quality of life and work of building occupants and reduced the cost for users.

4.2 Landsea Green Center Low Carbon Building Case

Landsea Green Center (Figre 4-3, 4-4) is located at 5 Block 280 Linhong Road, Changhong District in Shanghai. This project site abuts to the north Linxin Road, to the east Xiehe Road, south Linhong Road, west Guangshun North (Figure 4-3). It consists of 4 floors and a basement floor, a land area of 3391 m^2 of total floor area of 5724 m^2, ground floor area of 3969.22 m^2, underground floor area of 1755.14 m^2. The building is a self-sustaining commercial building of the Landsea Green Group Co., Ltd,. It is supplied with municipal power with an energy consumption per unit area of 69.46 kWh / m^2. The project has achieved five core values of "healthy environment, comfortable office, energy saving and environmental protection, intelligent management and customer-friendly design".

4.2.1 Climate Benefit of Landsea Green Center

According to the calculation of Landsea Technology, the Landsea Green Center has an emission reduction of 1,406 ton of carbon dioxide and of 18015 ton of carbon dioxide on a life cycle carbon budget. The factors that constrain the carbon emissions of buildings are the scale of construction, the energy consumption per unit of floor space, and the CO_2 emission index of unit energy consumption in building use. It also depends on the replacement rate of renewable energy to traditional energy in building use. According to the "Construction Carbon Emission Measurement Standards", the total carbon emissions of the project life cycle is 18015.8 tons, and the unit construction area carbon emission is 3.26 ton of carbon dioxide per m^2. Assuming 8 hours daily sunshine, the solar photovoltaic panels with an installed capacity of 16.5 KW can generate 19,800 KW over a theoretical year, and the solar power standard coal emissions will be 10.8 ton per year.

According to the building energy consumption simulation report of Shanghai Langsea Green Center Project, the cooling / heating load of this project is reduced by 35.36% compared with the reference building. The annual energy consumption was reduced by 25.62% compared to the reference building. Compared to the reference building, it is expected that the carbon emissions from energy consumption during the operational phase will be reduced by 10%.

4.2.2 Technology Innovation of Langsea Green Center

This project is designed for the local climate and the characteristics of the building in Shanghai, and selects the matched green eco-energy-saving technology. It uses energy-saving materials that meet the requirements of green buildings from the aspects of land saving, energy saving, water saving, material saving, indoor environmental quality, improvement and innovation. building. Five innovative technologies are mainly used:

This program uses a solar photovoltaic power generation system. A total capacity of PV modules is 16.5KWp, with two 9KW inverters. The total power supply of the building is 699 KW, and the solar power supply is 2.36% of the total. PV modules are installed on the roof, using 60 275W polycrystalline cell modules, with 12 parallel lines of 5 modules. The PV group series entering the combiner box uses 12 incoming and 1 outgoing connection, with 1 combiner box.

The project is located in a hot summer and cold winter zone. Taking energy saving measures into full consideration, the curtain wall in the east and west direction of levels two to four of the office building can be adjusted for external shading, so as to shade the building in summer and reduce the air conditioning load.

The enclosure structure of the project is energy saving. The curtain wall of the outer window is made of broken heat steel (aluminum) window frame. Some shutters are placed in the rooms from east to west, which can automatically open 100 folds and the heat transfer coefficient is 1.6W/㎡·K. Compared with the national standard GB50189, the heat transfer coefficient of building doors and windows is all better than 20% of the corresponding design value of the national standard GB50189. Through simulation calculation of comprehensive energy consumption, the average energy saving rate of the project is over 75.32%.

The air conditioner of this project is divided into two sets of upper and lower systems. The cold and heat sources are both modular air-cooled heat pump units, which are placed on the floor of the roof machine room. From the underground floor to the ground floor, three sets are configured. Cooling capacity of each unit is of 65kw and the heat capacity is of 66kw. The air conditioning systems use the underground floor "heat exchangers + fan coil" form, provided 3 sets of 1000m3/h air flow total heat exchangers.

The new air exchanger is set with initial effect + activated carbon + efficient triple filtration. The fan coil unit is a high static pressure type, and adopts the top-feed top-return air supply mode. The first floor is equipped with a primary air return all-air air conditioning system. The air treatment unit is equipped with initial effect + static electricity + medium effect filtration section. The return air on the first floor is concentrated in the corridor, and some functional rooms are supplemented by a fan coil for use in case of heavy load, which uses a downward return air supply.

From the second floor to the fourth floor, four new fans + ground table fan coil + top capillary are used, divided into four zones. Four new fans are used to deal with the fresh air. The new fans use condensation heat recovery technology to send dehumidified fresh air through the fresh air tube into the room, and the indoor side uses floor air supply. When the load is large, the wet air disk mode is adopted. When the cold load and wet load are small, the dry air disk mode is adopted. Some rooms are topped with capillaries.

Figure 4-3 Photo of Langsea Green Center

The roof rainwater of the project is collected by the rainwater riser, and the ground rainwater is collected by the outdoor rainwater pipe network of the community. Rainwater riser rear lower to the ground manhole connected in series through the rainwater pipe, and rain is finally pooled the rainwater diversion well before it reaches a water collection pool. The rainwater diversion well will also discharge early stage rain into the municipal sewer as early stage rain is usually quite dirty.

In the middle and later stages, the relatively clean rainwater enters the rainwater regulation tank, and the large sediment is precipitated by adjusting the pool. The rainwater is then pumped from the regulating pool, filtered by the automatic self-cleaning filter, sterilized, and stored in the rain water cleaning pool. Finally, clean rain water is supplied to the outdoor road and site green irrigation system of the community through a constant pressure and frequency conversion pump.

4.2.3 Investment and Finance Model of Langsea Green Center

The Landsea Green Center has a total investment of 35 million Yuan and the investment cost during the development period is 126.5 million Yuan. It is estimated that the rental income of the project is 4.5 Yuan per square meter per day. Langsea provides 15% return on the total capital threshold of the project, 40% of which is project capital, and 60% of which is debt financing. It has applied for the acquisition loan from the Bank of East Asia, secured through asset securitization pledging equity and mortgaging assets. The project is also planning to finance through issuing Asset Back Securities (ABS) at the next step.

4.2.4 Social Benefit of Langsea Green Center

The Landsea low carbon construction project will enhance the comfort of building users. According to electricity price of 0.8 Yuan per kWh, the building users will save 5000 Yuan per thousand square meter of energy cost per year.

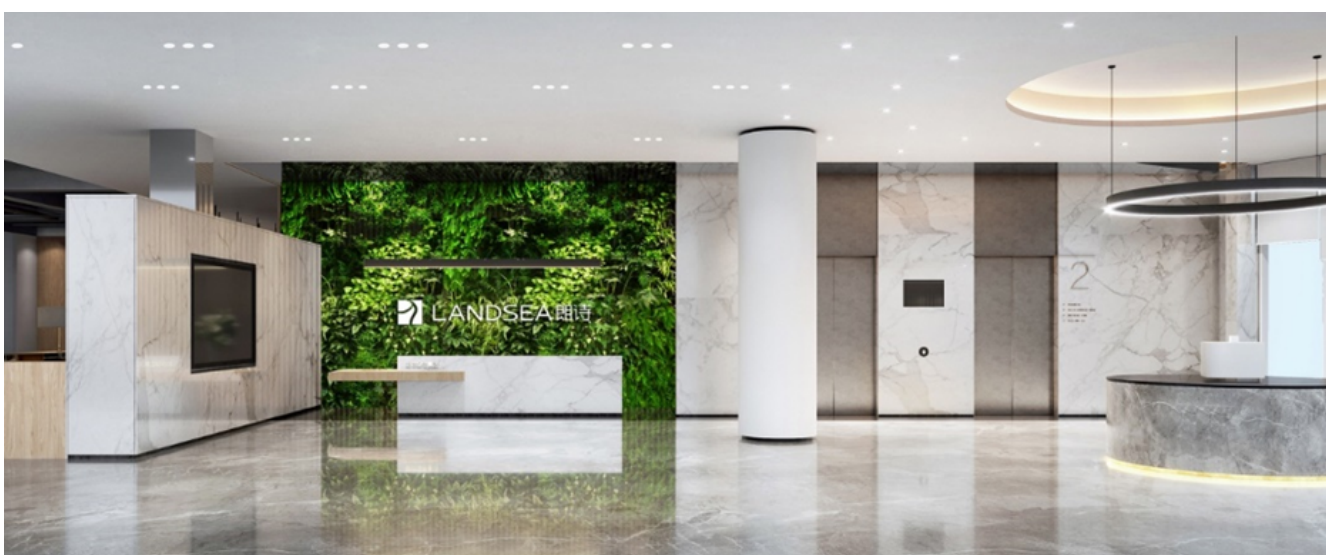

Figure 4-4 Photo of Langsea Center Lobby

Chapter 5 Energy Saving in the Iron and Steel Sector Case

5.1 Overview of Energy Saving in the Iron and Steel Sector

In the past decade, with developing countries rapidly industrializing, the demand for steel is also growing rapidly. As shown in Figure 11-1, from 2000 to 2016, the energy consumption of China's iron and steel industry first increased and then decreased. From 2000 to 2013, it increased from 172.66 million to 696.61 million tons of standard coal, and then decreased to 649.01 million tons in 2016[22]. From 2000 to 2016, the average annual growth rate was 11.9%, and the proportion of steel industry in national energy consumption increased from 11.3% to 16%.

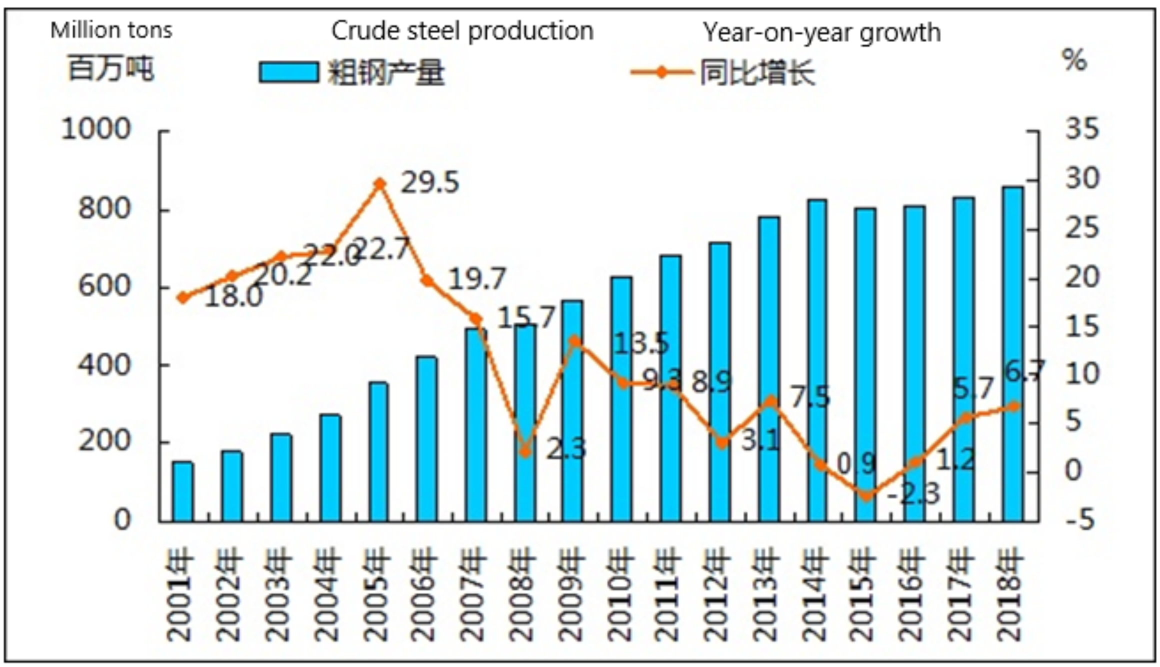

Figure 5-1 Change of crude steel output and year-on-year growth rate from 2001 to 2018

[22] 齐晔，张希良. 2018. 中国低碳发展报告(2018). 社会科学文献出版社. ISBN:9787520137225

In China, coal is the main energy source for the iron and steel industry, accounting for about 70% of its total energy consumption; electric power for energy intensive production is the second largest energy source, accounting for about 26.4% of its total energy consumption [23]. In recent years, China has successively formulated and implemented policies including eliminating low efficiency production capacity, limiting energy consumption, releasing energy-saving technology promotion catalogues, etc. At the same time, with measures such as adjustment of energy structure consumed by iron and steel industry, it has promoted the continuous transformation of the iron and steel industry to a resource-saving and environment-friendly development mode, and the comprehensive energy consumption and main process energy consumption of crude steel have basically declined. Among them, the promotion and application of energy-saving technology is the main way to promote carbon emission reduction in the iron and steel industry.

5.1.1 Carbon Emission in the Iron and Steel Industry

Among all industrial production, the steel industry is one of the most intensive industries in terms of energy and carbon dioxide emissions. Its production process is heavily dependent on fossil fuels (especially coal) and emits a large amount of carbon dioxide into the atmosphere. In 2012, energy use in the global steel industry accounted for 22% of the total industrial energy use, and carbon emissions accounted for 31% of the total industrial direct emissions[24].

Carbon dioxide emission of iron and steel industry comes from two aspects, one is carbon emission caused by energy activities, the other is carbon emission caused by industrial production process. Compared with the carbon dioxide emissions caused by energy activities, the industrial process emissions account for a small proportion of the total emissions of the steel industry. Carbon dioxide emissions caused by energy

[23] Wang J., Zhang X. 2017. Analysis on economic growth, energy consumption and carbon emissions decoupling in China's iron and steel industry. Journey of Hebei University of Economic and Business. 38(4), pp: 77-82

[24] IEA, 2015. ETP 2015: Iron & Steel Findings. OECD Steel Committee Meeting. Available at: https://www.oecd.org/sti/ind/Item%208b%20-%20IEA_ETP2015_OECD%20Steel%20Committee_final.pdf [Apr 7, 2019]

activities include steel production, process energy consumption and other emission factors.

At present, the energy consumption level of advanced domestic iron and steel enterprises is close to or even higher than the world's advanced level[25]. However, from the perspective of the steel industry as a whole, the average energy efficiency level of the industry is still far from the world's advanced level.

5.1.2 Energy Saving Technology Options in the Iron and Steel Sector

The effective means of carbon emission reduction in iron and steel industry are as below[26]:

1) Upgrading the production route with higher energy efficiency and improving the utilization rate of waste energy in the EAF process;

2) Improving the recovery rate of waste gas and waste heat from blast furnace – basic oxygen furnace (BF-BOF) steelmaking;

3) Adopting effective casting rolling method in the final rough steel production.

and 4) Carbon capture, utilization and storage

Energy saving is the most important carbon emission reduction technology in the current steel production process. Energy saving mainly includes waste heat recovery, link optimization and energy management of each process, as well as thick material sintering, dry quenching, coal moisture control, blast furnace mixed injection, top burning hot blast furnace, IGCC, TRT, dry dedusting, continuous casting, hot charging and hot delivery of continuous casting slab, etc.

[25] CISA, 2019。In 2018, China's average energy consumption per ton of steel produced was 555.24 kg of standard coal, lower than the global average of 692.60 kg of standard coal/ton of steel.

[26] Napp et al. (2014). A review of the technologies, economics and policy instruments for decarbonising energy-intensive manufacturing industries. Renewable and Sustainable Energy Reviews, 30, pp: 616-640.

Table 5-1 Overview of 33 energy saving and emission reduction technologies in iron and steel industry (tcs: tonne crude steel)

No	Technology		Fuel Saving (GJ/tcs)	Electricity Saving (GJ/tcs)	Primary Energy Savings (GJ/tcs	Share of Measures Applied (%)
	1. Sintering & Pelletising					
1	1.1	Power Generation using waste heat in Sintering	0.35	0	0.35	100
2	1.2	Vertical Tank Waste Heat Recovery System	0.25	0	0.25	90
3	1.3	Thick Layer Sintering	0.21	0	0.21	100
4	1.4	Waste heat from sintering produces steam	0.09	0	0.09	100
	2. Coking					
5	2.1	Coke Dry Quenching	0.38	0	0.38	80
6	2.2	Coke Oven Rising Tube Heat-recovering Technology	0.08	0	0.08	5
7	2.3	Coal Moisture Control	0.14	0	0.14	15
	3. Iron-making BF					
8	3.1	Pulverized Coal Injection and Oxygen Enrichment	0.62	0	0.62	100
9	3.2	CCPP	0.90	0	0.90	90
10	3.3	Blast Furnace Control	0.36	0	0.36	30
11	3.4	Top Combustion Stove	0.30	0	0.30	50
12	3.5	TRT	0.17	0.09	0.26	100
13	3.6	Waste Heat Recovery from BF Slag-washing Water	0.23	0	0.23	5
14	3.7	Dry Dusting Dust Transport System of Blast Furnace Gas	0.18	0	0.18	80
15	3.8	Waste Plastic Injection	0.11	0	0.11	3
	4. Steelmaking BOF					
16	4.1	Negative Energy Consumption on Converter	0.50	0	0.50	100
17	4.2	Heat Recovery of BOF Gas	0.50	0	0.50	10
18	4.3	LT-PR of Converter Gas	0	0.14	0.14	20
	5. Steelmaking EAF					
19	5.1	Waste Heat Recovery	0.72	0	0.72	10
20	5.2	Scape Preheating System	0.44	0.22	0.66	5
21	5.3	Twin Shell Direct Current Arc Furnaces	0.25	0.13	0.38	10
22	5.4	EAF Process Optimization	0.22	0.11	0.33	50
23	5.5	Eccentric Bottom Tapping	0.19	0.09	0.28	30
	6. Casting					
24	6.1	Thin Slab Casting	1.18	0.09	1.44	100
25	6.2	Continuous Casting	0.25	0.06	0.42	100
26	6.3	Process control in hot strip mill	0.26	0	0.26	100
27	6.4	Waste heat recovery in casting	0.03	0	0.03	80
28	6.5	Efficient ladle preheating	0.02	0	0.02	100
	7. Rolling and Finishing					
29	7.1	Regenerative Reheating Furnace	0.70	0	0.70	50
30	7.2	Hot Delivery and Hot Charging of Continuous Casting Billet	0.65	0	0.65	5
31	7.3	Automated Monitoring and Targeting System	0	0.38	0.38	5
32	7.4	Low Temperature Rolling Techniques	0.23	0	0.23	80
	8. Energy Management System					
33	8.1	Energy Management System	0.32	0.03	0.35	90

Table 5-2 energy conservation and carbon dioxide emission reduction of 33 energy conservation and emission reduction technologies in China's iron and steel industry (tcs: tonne crude steel)

No	Technology		Primary Energy Savings (GJ/tcs)	CO_2 Emission Reduction ($kgCO_2$/tcs)
	1. Sintering & Pelletising			
1	**1.1**	**Power Generation using waste heat in Sintering**	**0.35**	**31.68**
2	**1.2**	**Vertical Tank Waste Heat Recovery System**	**0.25**	**22.52**
3	**1.3**	**Thick Layer Sintering**	**0.21**	**18.92**
4	**1.4**	**Waste heat from sintering produces steam**	**0.09**	**7.66**
	2. Coking			
5	**2.1**	**Coke Dry Quenching**	**0.38**	**34.23**
6	**2.2**	**Coke Oven Rising Tube Heat-recovering Technology**	**0.08**	**7.21**
7	**2.3**	**Coal Moisture Control**	**0.14**	**12.61**
	3. Iron-making BF			
8	**3.1**	**Pulverized Coal Injection and Oxygen Enrichment**	**0.62**	**55.85**
9	**3.2**	**CCPP**	**0.90**	**81.07**
10	**3.3**	**Blast Furnace Control**	**0.36**	**32.43**
11	**3.4**	**Top Combustion Stove**	**0.30**	**27.02**
12	**3.5**	**TRT**	**0.26**	**36.03**
13	**3.6**	**Waste Heat Recovery from BF Slag-washing Water**	**0.23**	**20.72**
14	**3.7**	**Dry Dusting Dust Transport System of Blast Furnace Gas**	**0.18**	**16.21**
15	**3.8**	**Waste Plastic Injection**	**0.11**	**9.91**
	4. Steelmaking BOF			
16	**4.1**	**Negative Energy Consumption on Converter**	**0.50**	**45.04**
17	**4.2**	**Heat Recovery of BOF Gas**	**0.50**	**45.04**
18	**4.3**	**LT-PR of Converter Gas**	**0.14**	**12.61**
	5. Steelmaking EAF			
19	**5.1**	**Waste Heat Recovery**	**0.72**	**64.86**
20	**5.2**	**Scape Preheating System**	**0.66**	**59.45**
21	**5.3**	**Twin Shell Direct Current Arc Furnaces**	**0.38**	**34.23**
22	**5.4**	**EAF Process Optimization**	**0.33**	**29.73**
23	**5.5**	**Eccentric Bottom Tapping**	**0.28**	**25.22**
	6. Casting			
24	**6.1**	**Thin Slab Casting**	**1.44**	**129.72**
25	**6.2**	**Continuous Casting**	**0.42**	**37.83**
26	**6.3**	**Process control in hot strip mill**	**0.26**	**23.42**
27	**6.4**	**Waste heat recovery in casting**	**0.03**	**2.70**
28	**6.5**	**Efficient ladle preheating**	**0.02**	**1.80**
	7. Rolling and Finishing			
29	**7.1**	**Regenerative Reheating Furnace**	**0.70**	**63.36**
30	**7.2**	**Hot Delivery and Hot Charging of Continuous Casting Billet**	**0.65**	**58.10**
31	**7.3**	**Automated Monitoring and Targeting System**	**0.38**	**34.23**
32	**7.4**	**Low Temperature Rolling Techniques**	**0.23**	**21.12**
	8. Energy Management System			
33	**8.1**	**Energy Management System**	**0.35**	**31.53**

In 2018, the University of Edinburgh, North China Electric Power University and China UK (Guangdong) CCUS Center studied 33 domestic and international energy saving and emission reduction technologies that can be used in the steel industry[27]. These technologies cover the whole steel smelting process, as well as the general energy management technology scheme. The specific energy saving effects are shown in the table below. At present, more than 70% of energy-saving technologies have been widely applied in China.

If 25 (out of the 33) energy conservation and emission reduction schemes that can be applied at the same time are applied, the total annual carbon dioxide emission reduction potential will reach the significant reduction of average carbon emission per ton of steel in 2018 (Table 5-2). Among them, the carbon dioxide emission reduction potential of the nine most cost-effective technologies is about 24% of the carbon dioxide emission without these technologies.

5.1.3 Investment and Finance Model of Energy Saving in the Iron and Steel Sector

According to the research (mentioned in 5.1.2 above) on cost reduction of energy-saving technology of iron and steel by the University of Edinburgh, North China Electric Power University and China UK (Guangdong) CCUS Center, thin slab continuous casting, CCPP and EAF waste heat recovery technology rank the top three in carbon emission reduction. The annual investment cost of ladle preheating is the lowest, and it has great potential in saving the annual operation and maintenance cost.

At present, most of the domestic iron and steel energy-saving projects are funded by traditional financing methods, which are self financed by enterprises and mainly supported by government finance, using credit financing from commercial banks as a supplement. However, at present, China's commercial banks lack financial products

[27] Ren, L., Wang, L., Lu, D. Liang, K., Liang, X., Lin, Q., Ascui, F., Muslemani, H., Jiang, M., Chen, X., Jia, Z. (2018). Lower Carbon Technology Approaches for Steel Manufacturing in China. Working Paper 4.7 for the BHP Industrial CCS Project 'Unlocking the Potential of CCUS for Steel Production in China'. The UK-China (Guangdong) CCUS Centre, Shandong Energy Conservation Association and The University of Edinburgh, Edinburgh.

specifically for energy-saving and emission reduction projects, and energy-saving and emission reduction projects can only be funded by traditional loan channel[28].

Table 5-3 carbon emission reduction technical scheme of China's steel industry (sorted by carbon emission reduction cost) (tcs: tonne crude steel)

No	Technology	CO_2 Emission Reduction ($kgCO_2/ts$)	Abatement Cost ($yuan/kgCO_2$)
6.2	Continuous Casting	27.93	-36.80
6.1	Thin Slab Casting	114.40	-6.27
5.4	EAF Process Optimization	29.73	-5.87
3.1	Pulverized Coal Injection and Oxygen Enrichment	55.85	-2.73
7.3	Automated Monitoring and Targeting System	34.23	-0.79
3.5	TRT	23.42	-0.28
7.2	Hot Delivery and Hot Charging of Continuous Casting Billet	58.55	-0.07
1.3	Thick Layer Sintering	18.92	-0.07
7.1	Regenerative Reheating Furnace	63.06	0.00
6.3	Process control in hot strip mill	23.42	0.09
5.5	Eccentric Bottom Tapping	25.22	0.13
4.2	Heat Recovery of BOF Gas	45.04	0.16
8.1	Energy Management System	31.53	0.25
2.1	Coke Dry Quenching (CDQ)	34.23	0.44
3.4	Top Combustion Stove	27.02	0.49
5.1	Waste Heat Recovery	64.86	0.50
3.3	Blast Furnace Control	32.43	0.61
6.5	Efficient ladle preheating	1.80	0.84
7.4	Low Temperature Rolling Techniques	20.72	0.86
3.2	CCPP	81.07	1.07
4.3	LT-PR of Converter Gas	12.61	1.10
2.3	Coal Moisture Control (CMC)	12.61	1.29
3.6	Waste Heat Recovery from BF Slag-washing Water	20.72	1.38
1.1	Power Generation using waste heat	31.53	1.55
2.2	Coke Oven Rising Tube Heat-recovering Technology	7.21	4.12

[28] Wang Yu，2014（王玉．2014．基于市场机制的我国节能减排项目融资模式探究．项目管理技术．12(5):29-32.）

5.1.4 Social Benefit of Energy Saving in the Iron and Steel Sector

The energy-saving benefits of iron and steel accelerate the low-carbon transformation and promote the realization of national emission reduction goals. Iron and steel enterprises use waste heat to provide heat for surrounding areas, improve people's livelihood, achieve social benefits, and improve the quality of life of residents.F

5.2 TISCO Waste Heat Recovery and Utilisation Case

The project is located in the plant area of Jiancaoping TISCO, at an altitude of about 800m and flat terrain. The project includes recovery of waste heat from the exhaust steam of 2 × 300MW generator sets on the air cooling island of the TISCO energy power plant and a further waste heat recovery project from blast furnace slag flushing water from the plant. It was designed and planned by Shanxi TISCO Engineering Technology Co., Ltd. and constructed by Shanxi TISCO Stainless Steel Co., Ltd.

The project technology utilises the large temperature difference in heat supply and is based on absorption heat exchange proposed by Tsinghua University, which will introduce steam from dn1400 pipe from Taiyuan No 2 thermal power plant. After the return water temperature of the Taiyuan central heating system is raised by 20 ℃, it will be sent to Taiyuan No.2 Power Plant for heating.

The waste heat recovery project recovers heat from 4350m3 of blast furnace slag washing water (from 5 blast furnaces) to heat the water returned from the urban heat network with a special heat exchanger, and then sent it back to the urban heat network.

5.2.1 Climate Benefit of TISCO Waste Heat Recovery Project

The TISCO project recovers and utilizes the waste heat of water system. There is no fuel combustion, dust and other processes in the production process, so there is no waste gas. The blast furnace slag washing water is indirectly cooled by the slag washing water heat exchanger and returned to the cold-water pool for recycling, so no waste water is discharged. The secondary low-grade energy is fully utilized, which reduces the consumption of new steam and increases the area of central heating in Taiyuan city. All the projects use technical means to recycle the waste heat, and use energy-saving technology in many aspects. For example, in the design of cooling water system, if the circulating water pressure can meet the requirements, it will be directly connected from the circulating water inlet pipe without boosting by booster pump, so as to save auxiliary power.

According to the estimates of the project party, the annual available external heating capacity of the plant was 4.206 million GJ. After the operation of the blast furnace slag washing water waste heat recovery project (85 ℃ / 55 ℃), 678000 GJ of external heat can be supplied annually (because the waste heat recovery of blast furnace slag washing changes with the production process of blast furnace). The total waste heat recovery of the project is 4.88 million GJ which is equivalent to 0.6 million ton CO2 avoidance[29] per year. Thus, the annual emission of sulfur dioxide can be reduced by about 4624 tons and that of smoke and dust by about 9248 tons.

5.2.2 Technology Innovation of TISCO Waste Heat Recovery Project

The 2 × 300MW generating units of TISCO complies with the requirements of the overall urban heat supply planning of Taiyuan city. Adopting the large temperature difference heat supply technology based on absorption heat exchange proposed by Tsinghua University, the return water of the heat supply network of Taiyuan No. 2 thermal power plant. This technology takes the heat of the primary network water supply as the driving force, uses the heat pump to absorb the heat of the return water of the heat network, reduces the return water temperature, enlarges the temperature difference between the supply and return water of the heat network, improves the heat transmission capacity of the heat network, effectively reduces the power consumption of the circulating pump transmission, and saves the construction investment of the network.

The direct heat exchange technology used here was originally put forward as the design idea of "contactless single channel heat exchange process" blast furnace slag washing water heat exchanger, which adopts the combination of special plate type, plate material and stable heat exchange plate. It effectively solves heat exchanger blockage

[29] Assume 3.7 tCO2 /ton metric coal, 80% efficiency of boiler.

and plate wear and pressure deformation caused by unfiltered water under various slag washing process condition, and other technical problems in order to achieve efficient direct heat exchange.

5.2.3 Investment and Finance Model of TISCO Waste Heat Recovery Project

At present, most of the domestic iron and steel energy-saving projects are funded by traditional financing methods, that is, enterprise self-financing and government financial support, while using commercial bank credit financing as a supplement, but the financing of energy-saving and emission reduction projects of high-energy consumption enterprises is often limited by policies. The total investment of the project is 170 million Yuan, 40% of which is self-raised by the enterprise and the rest is a loan from the Bank of Communications.

5.2.4 Social Benefit of TISCO Waste Heat Recovery Project

TISCO's heat recovery and comprehensive utilization project implements the comprehensive utilization of heat recovery and has developed a new heat source, i.e. recovery of the waste heat from both the exhaust steam of 2 × 300MW units and the waste heat from 4350m^3 of slag flushing water from 5 blast furnaces, which can increase the heat supply area by 2 million square meters.

Chapter 6 Carbon Capture Utilisation and Storage (CCUS) Case

6.1 Overview of CCUS industry

Carbon capture, usage and storage (CCUS) is currently recognized as a technology that can significantly (up to 90%) reduce electricity and industrial carbon dioxide (CO_2) emissions while continuing to use fossil fuels. According to the International Energy Agency (IEA)[30], CCUS is an essential emission reduction technology to meet the goal set by the Paris Agreement in 2060 of restricting the temperature rise to 2°C. CCUS will contribute 14% of the overall reduction to this goal. The contribution of CCUS is ranked third after improving energy efficiency (40%) and developing renewable energy (35%). According to the estimation of the Asian Development Bank, if China does not adopt CCUS, the overall cost of achieving the national climate change mitigation target will increase by 25%[31]. In addition, CCUS is also the only option to reduce carbon dioxide emissions in coal-intensive industries such as coal chemical, steel, and cement.

According to the CCS Research Report of the Global Carbon Capture and Storage Institute 2018, there are 43 large CCS projects worldwide as of 2018 (Figure 6-1): 18 projects have entered commercial operation, 5 projects are under construction and the other 20 projects are at different stages of deployment[32]. Due to the feature of the low price of coal, abundant reserves and wide distribution, coal resources are still the dominant energy supply in China and it will not be replaced in a short time. The CO_2 emitted by fossil fuel combustion accounts for more than 80% of the total emissions, and the CO_2 emissions from coal combustion account for 75% of the total emissions. Coal-fired generating units accounted for 70% of China's power industry and coal accounted for 80% of the power generation. CCUS is therefore very important for China's industrial restructuring and reduction of carbon emission. The Chinese government and

[30] IEA.2017. Energy technology perspectives 2017. p20, p4. https://jp.globalccsinstitute.com/sites/jp.globalccsinstitute.com/files/content/mediarelease/122878/files/s2presentation.pdf
[31] Asian Development Bank. 2014. https://www.adb.org/sites/default/files/publication/179015/roadmap-ccs-prc-zh.pdf
[32] GCCSI. 2018. The Global Status of CCS.

industry has invested more than CNY 3 billion to develop CCS since 2008. The early CCUS demonstration projects were critical to validating technology, increasing public awareness, and especially building capacity to reduce costs. Currently, more than 20 CCUS projects have been carried out with the support of national and local governments.

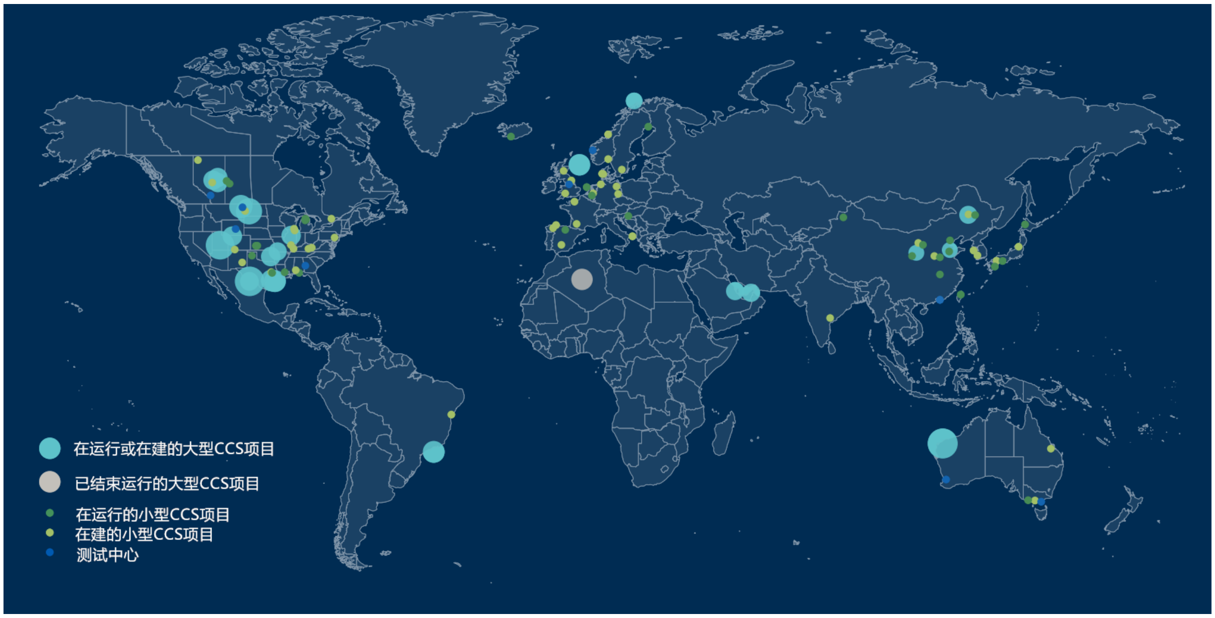

Figure 6-1 Status of global CCS project deployment by 2018 [33]

6.1.1 Climate Benefit of CCUS

The international recognition of CCUS as an important measure to achieve long-term carbon emission reduction increases gradually. As mentioned above, to achieve a reduction in emissions so as to restrict the temperature rise to 2°C, the International Energy Agency calculates that CCUS should account for 14% of the total global emission reductions between 2015 and 2050 and China's CCS projects should account for about one-third of the total global emission reductions.

According to the calculation of the Wuhan Institute of Rock and Soil Mechanics of the Chinese Academy of Sciences, there are more than 1,600 large-scale CO_2 emission sources in China (including thermal power plants, cement plants, steel plants, etc.,).

[33] Source: GCCSI

Theoretically, carbon capture could exceed 38 billion tons. In terms of storage, CO_2 can be stored in depleted oil and gas fields, deep coalbeds, and saline aquifers. The capacity of CO_2 storage of these three methods is 1 billion, 1 billion and 100 billion tons respectively. In addition, the study shows that China's CO_2 sources are favorably positioned; the distance between more than 90% of the large carbon sources and the nearest potential storage sites being less than 200 kilometers, which is very beneficial for CO_2 transportation.

6.1.2 Investment and Finance Model for CCUS

There are more than 40 million tons of carbon dioxide stored worldwide each year, but most projects rely on the income from enhanced oil recovery (CO_2-EOR) as the main business model. Those projects transformed and utilized existing oil and gas pipelines to inject carbon dioxide into waste oil and gas fields to improve oil recovery while sequestering carbon dioxide. The additional crude oil can provide economic support to the CCUS project. The return rate depends on the oil price. In the past few years, oil prices have stayed low, but there is a recent trend of recovery and a steady rise in the oil price. If the oil price can be raised to a certain level, and the synergy between carbon capture technology and CO_2-EOR technology becomes more mature, then the financial difficulties of CCUS projects will be reduced greatly.

Currently, domestic CCUS has not yet entered large-scale commercial operation, and there are no projects that reduce emissions by more than 500,000 tons per year. The relevant market and industrial chain of CCUS have not been formed. However, in contrast to the countries with developed CCUS (USA, Canada, and Norway), China is benefiting from the source/sink matching conditions and the low cost of construction. Therefore, China has the potential to have rapid developed technologies in the future. The majority of the current establishing CCUS projects in China are self-sponsored projects. The two major goals of these projects are to (a) actively respond to the policy of energy conservation and emission reduction and demonstrate potential new low-carbon technologies, and (b) accelerate the development of CCUS to prepare for full scale CCUS deployment. Domestic commercial and financial institutions have not yet raised funds for CCUS projects, and venture capitalists have not paid attention to the CCUS industry. Multilateral institutions (such as the Asian Development Bank) support the early development of the CCUS project through special funds and strive to reduce the financial burden of early stage project development.

> ***"Commercial capital needs to be introduced for financing CCUS projects in China, for achieving rapid cost reduction and enabling CCUS as a key technology option for China's climate change objectives"***

6.1.3 Social Benefit of CCUS

The dominant long-term social benefits of CCUS are to drive the development of Chinese industries and strengthen energy security. The Chinese government considers CCUS as an important technology and invested a lot of research funding to promote its development in the past ten years. At present, China is already close to the level of developed countries in terms of CCUS development. If we can further increase CCUS demonstration in the future, it will continuously reduce the costs of this technology, and gradually achieve its large-scale application. This will not only help China to reach an international leading position in CCUS but also to drive the development of relevant industries.

CCUS is a positive driving force for improving China's energy security. The Chinese government has repeatedly emphasized the need to strengthen the development of carbon dioxide utilization technology to enhance the contribution of carbon emission reduction. At present, CO_2-EOR and CO_2 enhanced coalbed methane (CO_2-ECBM) are widely recognized as the main technologies which are suitable for the use of CO_2 in China. These will benefit the nation through achieving a stable production and stimulation of some oilfields in China and upgrading of coalbed methane.

According to the analysis of the national key technology research plan "Resource utilization and underground storage of enhanced greenhouse gas recovery", there are about 13 billion tons of crude oil reserves in China that are suitable for CO_2-EOR. Even if the overall recovery rate can be improved by 15 %, it can increase the oil recoverable reserves by 1.92 billion tons, and at the same time, it can store about 4.7-5.5 billion tons of CO_2. If CO_2-EOR technology can be widely used, it can increase oil production while achieving substantial CO_2 emission reduction. This not only helps to improve the economic benefits of the oil and gas industry but also helps to reduce the security challenges which result from the rising dependence of oil.

Figure 6-2 Yanchang Yulin Coal Chemical’s 50,000 tonne Carbon Capture Facility

6.2 Yanchang Integrated CCUS Project Case

Yanchang Petroleum 360,000 tons coal chemical CCS project is located in Yulin, Shaanxi Province (Figure 6-2). This project is designed by the Yanchang Petroleum Group Research Institute. The project is divided into three parts: the capture project, the pipe transport project, and the injection project. The project is constructed by four production units, namely, Yunenghua, Pipeline Company, Oilfield Company of Jingbian Oil Production Plant and Xingzichuan Oil Production Plant. The carbon source of the project comes from the CO_2 by-product gas of the low-temperature methanol washing process of the 1.8 million ton/year methanol plant in the start-up project of the coal at the Comprehensive Zone in Jingbian Energy and Chemical Industry.

The CO_2 concentration of the product gas is over 95%. The pipeline transportation project conveys CO_2 between the first station at Yu Petrochemical plant and the last station at Huazipingmo, with a total length of 105km. The injection project includes: the gas injection of 50,000 tons/year in the Jingbian Qiaojiawa injection area which include 97 deployed wells (21 gas injection wells, 76 benefit wells), and gas injection of 310,000 tons/year in the Xingziping injection area which include 557 deployed wells (159 gas injection wells, 398 benefit wells). This project is a co-operation between China, Australia, and the United States, and it has also received grant commitment from the Asian Development Bank.

6.2.1 Climate Benefit of Yanchang CCUS Project

The Yanchang Petroleum CCUS project was created under the policy of "a big advantage, two needs". "A big advantage" refers to the extension of the comprehensive utilization of petroleum oil, gas, and coal in the same area, and the advantage of high source and sink matching, which is significantly lower than the traditional single coal chemical CO_2 emission; "two needs" refer to (a) the need for environmentally friendly technology to reduce the huge water consumption required for water injection in low-permeability oilfields, and (b) the need for CO_2 for the effective development of low-permeability, ultra-low permeability reservoirs in oil fields and improved oil recovery in Yanchang.

With the rapid development of energy and chemical bases in Shaanxi Province, a large amount of carbon dioxide emissions will be generated. Yanchang Petroleum utilize coal chemical project and the comprehensive utilization of the oil and gas chemical industry, will increase the sequestration of CO_2, whilst complementing the oil and gas industry, and will greatly reduce carbon dioxide emissions and benefit the development of CCUS.

6.2.2 Technology Innovation of Yanchang CCUS Project

The Yanchang CCUS project (illustrated in Figure 6-3) uses Linde's low-temperature methanol washing process to capture the carbon dioxide waste gas (concentration is about 81%) generated during the acetic acid production process. The purity can be as high as about 99%, and the capture cost is about 20 US dollars per tonne CO_2. It is used in oil field gas flooding. Because of its high purity, it will not cause waste problems, and the oil displacement effect is better.

The capture and oil displacement end belong to the same internal extension of the oil group, the cost of the oil displacement end is also reduced, which is helpful to the project. Because of the relatively low CO_2 concentration during the CO_2 flooding process, the extended petroleum CCUS project selected the high-efficiency amine absorption system and completed the process package development and the pilot plant construction and innovated CO_2 recycling and re-catch technology. The technology has the following characteristics: the range of gas source is wide; the CO_2 concentration can be between 30%-50%; the energy consumption is reduced by 30.95% compared to conventional low-temperature ethanolamine methods.

In terms of the capture process, the project aims to meet the needs of the extended petroleum CCUS demonstration project. After supercharging to the supercritical phase, the CO_2 by-product gas is piped to two CO_2 flooding and storage demonstration zones in the Jinbian Oilfield and the Xingzichuan Oilfield. These products will be distributed to the wellhead through the ground distribution system, and CO_2 will also be recycled.

The project is designed to adapt to the pipeline transportation mode. The project will design and construct a 105km pipeline and this pipeline will become the first CO_2 supercritical long-distance pipeline in China.

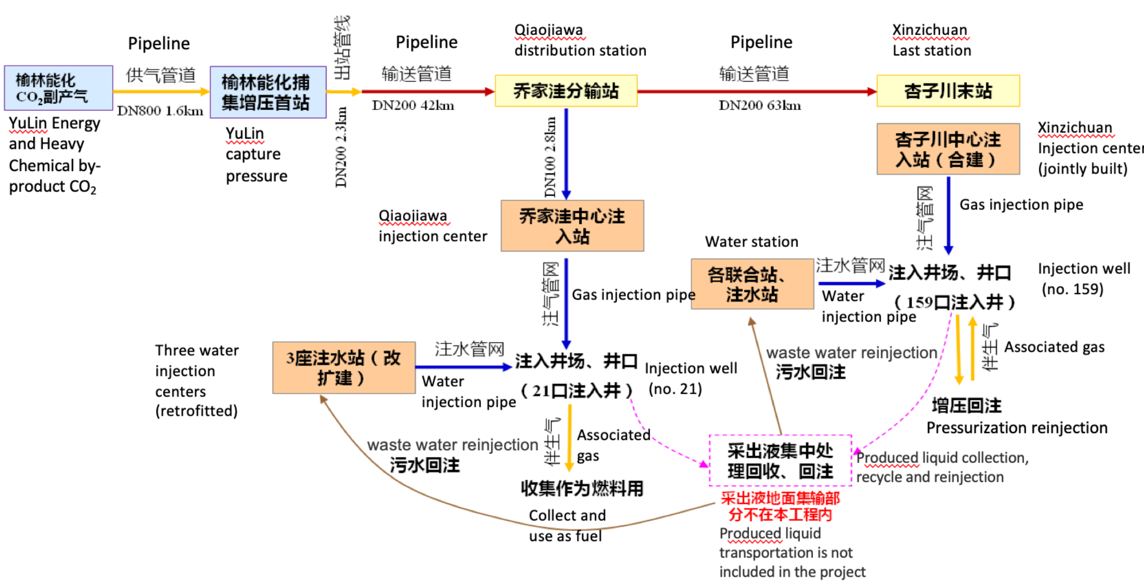

Figure 6-3 360,000 tons CCUS Project Illustration

Furthermore, CO_2 fracturing has the advantages of increased production, water-saving, environmental protection, and emission reduction. For unconventional oil and gas reservoirs, CO_2 mixed fracturing technology, VES-CO_2 foam fracturing technology, and pure liquid CO_2 fracturing technology have been developed.

6.2.3 Investment and Finance Model of Yanchang CCUS Project

The investment in the construction of a 360,000-ton coal chemical carbon capture project for Yanchang was 850 million Yuan. This includes 580 million Yuan of construction cost, 200 million Yuan of relevant expenses, and 60 million Yuan of the reservation fees. It is estimated that the annual operating income of the project will be 200 million Yuan and the annual operating cost will be 120 million Yuan. The project's economic evaluation is that when the oil price reaches $60/barrel (or 3024 Yuan/ton), the project will achieve the 8% post-tax financial benchmark rate of return requirement.

The project capital ratio is 40%. In addition to undertaking a number of national and provincial projects, the project has been carried out by China, Australia, and the United States, and has received a US$4.17 million aid fund from the Asian Development Bank. The project will also need government-guaranteed low-interest loans or financial support in the future to promote final investment decisions.

6.2.4 Social Benefit of Yanchang CCUS Project

CCUS technology will be an important support for promoting the development of China's low carbon industry in the long-term. China has been at the same level as developed countries in terms of the technical level of CCUS. The increase of the CCUS technology demonstration in the future will benefit through two aspects which are reducing the cost of technological application of CCUS continuous and achieving the large-scale application of the technology gradually.

This will not only help China to reach an international leading position in the field of low-carbon technology, but also to facilitate the development and growth of low-carbon related industries. The project provides 500 jobs to the local area. The annual tax revenue will be approximately 8 million Yuan. This project helps about 100 poor households to leave the poverty line through newly created jobs and training.

Annex: Review of Chinese and International Green Finance Standard and Guidance

The standard system of green finance generally refers to a series of classification methods and measurement indexes set up to identify, confirm and track green assets and green investment, guided by international, regional or national green development strategic objectives. Various international and domestic green credit, green bonds, green stock indices, green development funds, green insurance and other related financial products and services have widely established or adopted a variety of green financial standard systems with different connotations and denotations. Generally speaking, the green financial standard system includes the following six elements and six aspects:

（1）Sectoral Taxonomy/Classification;
（2）Identification and Standard;
（3）Proceeds Requirements;
（4）Incentives;
（5）Verification and Labelling;
（6）Post Investment Monitoring.

At present, there are three widely recognized green financial standard systems at home and abroad. One is a series of voluntary principles issued by financial institutions or organization associations, namely, Green Bond Principles (GBP), Equator Principles (EPS), Climate Bonds Standard (CBS), The World Bank Green Bond Process Implementation Guidelines[34], the Green Bond Framework issued by the Asian Development Bank and the Green Bond Standard to be issued by the European Union. The second is the evaluation system issued by financial service institutions, mainly formulated by evaluation and rating agencies, the Green Bond Assessment and the Green Evaluation System. The third is the standard system issued by regional or national authorities, including China's Green

[34] The World Bank, Green Bond Implementation Guidelines. http://pubdocs.worldbank.org/en/217301525116707964/Green-Bond-Implementation-Guidelines.pdf

Credit Guidance, Green Bond Issuance Guidance, Green Bond Support Project Directory (2015 version), Green Industry Guidance Directory (2019 version), etc.

The industry category evaluation of green financial standard is the first step to identify green financial assets. Industry categories include the first and second level catalogs. The contents of green financial standards have a high degree of overlap, for example, they cover renewable energy, energy efficiency, pollution control, water management, clean low-carbon transportation, green low-carbon buildings and other fields. There are two major differences in the classification of industries by green financial standards. Domestic green financial standards generally do not include climate change adaptation, while international green financial standards include climate mitigation and adaptation related fields. Whether coal, nuclear energy and rail transit are included in the green finance catalogue is controversial. The international green standards basically explicitly exclude fossil energy unless carbon capture, utilization and storage technology is used, and the green credit guidelines issued by China Banking and Insurance Regulatory Commission in 2012 didn't involve coal, but the green industry guidance catalogue issued by the National Development and Reform Commission (NDRC) in 2019 still includes the clean use of coal.

Compared with the international screening standards which are simply divided according to the field, some of China's green financial standards have strong guidance for the technical use standards, such as the NDRC's green industry guidelines, which set the scale or technical threshold of green financial projects in various industries, such as the minimum capacity of coal-fired generating units, the industry standards of energy-saving technical transformation projects, and the application of photovoltaic power generation projects. The photoelectric conversion efficiency and attenuation rate of polycrystalline silicon modules (monocrystalline silicon modules, high-power concentrated photovoltaic modules, thin film battery modules) all present clear quantitative indicators. Setting a threshold in the industry makes the certification process more complicated, but it can avoid identifying the low efficiency production capacity of various industries as green financial assets.

There are different ways to **identify green assets**, including identifying according to areas, adding threshold to areas, negative list / exclusion and scoring system. Among them, the scoring system can be further extended into two types of qualitative evaluation system (based on expert opinions) and quantitative evaluation system (based on quantitative data). Green Bond Principle, Climate Bond Standard and the Classification Scheme to be issued by the European Union are basically identified by different areas. For example, under these three principles, all wind power assets are simply classified as green assets. According to the field identification, the operation cost is low, but it is difficult to exclude the important influencing factors beyond the green attribute, such as social influence and low efficiency production capacity.

The Guiding Catalogue of green industries issued by the NDRC is based on the technology and scale threshold, which is conducive to eliminating low efficiency production capacity and projects not encouraged by the government. Moody's and Standard & Poor's, the world-renowned credit rating agencies, adopt a rating system, which includes not only green attributes but also information disclosure and other factors.

The **capital requirements** include the requirements for the use and management of the green funds raised, which are called capital requirements for short, including the investment fields or projects, the time of investment, the requirements for reinvestment, and whether it can be used to repay the debts of the enterprise. The CBS requires companies to raise funds to invest in green assets within two years. At present, most of the green financial standards require all or a certain proportion of the green funds raised to be invested in the green assets permitted by the relevant standards. The funds raised by the green bonds issued under the green industry guidance catalogue of the NDRC can be used to repay the existing liabilities of the enterprises. If the enterprises are involved in both green and non-green assets, it is difficult to supervise the use of the funds. The capital obtained by enterprises through green finance is invested in green projects and then reinvested, which is often not limited by green financial standards.

The important factor that distinguishes green finance from traditional financing is **incentive policy**, which directly affects the return rate of green financial products and non green financial products. Incentive policies include pre issuance incentives, in issuance incentives, and post issuance incentives, including discount and tax relief policies of the public sector, low interest loans of policy financial institutions, grants from multilateral institutions and other measures. The implementation of incentive policies is conducive to encouraging enterprises to increase green asset investment.

Due to the large scale of assets involved in green finance, the cost of screening and auditing system needs to be reduced, and financial subsidies (such as green bond discount) are more difficult. At present, in the global scope, the support policies of governments for green finance still have no significant impact on the income of green financial products. Singapore has adopted a policy of subsidising assessment fees for green bond issuance. The forthcoming EU green bond standard encourages Member States and financial institutions to directly link the standard with future financial industry standards. Central banks should increase their participation and enhance the market's acceptance and recognition of green finance. At the same time, it is suggested that Member States should implement preferential tax policies, including adopting "accelerated depreciation method[35]" for green assets and investment, so as to improve the competition of green assets.

In China, Huzhou City, Zhejiang Province took the lead in formulating local standards for green finance[36], building a green finance reform and innovation pilot zone, promoting financial institutions to carry out green rating, labeling and information disclosure, promoting the green construction industry and the marketization of environmental rights and interests, and comprehensively supporting the development of green finance[37]. In addition, in order to effectively reduce the cost of green investment and financing, Ma Jun, director of the green finance professional committee of the CFA and other experts suggested that by reducing the risk weight of green assets[38] (including green credit and green bonds) held by banks, the financing cost of green credit and bonds should be significantly reduced, and banks should be encouraged to increase green credit. According to relevant research, for example, the risk weighting of China's

35 https://www.irs.gov/publications/p946
36 http://field.10jqka.com.cn/20180904/c606935597.shtml
37 http://greenfinance.xinhua08.com/a/20190308/1802593.shtml
38 https://www.sohu.com/a/270746627_481887

green credit is reduced from 100% to 50%, and the financing cost of national green projects is reduced by 4% - 5% on average. At present, the preliminary research on this formulation at home and abroad shows that if it can be proved that the default rate of green assets is lower than that of non green assets, which is conducive to the overall stability of the financial system, it is reasonable to consider reducing the risk weighting of green assets and improving the risk weighting of brown (polluting) assets. At present, the proposal has not been fully adopted. In the future, commercial institutions also have conditions to give incentives according to the degree of risk reduction of green assets (such as lower default rate).

The **certification procedure** of green finance products (Figure A-1) mainly refers to the evaluation and certification of the internal process of the issuer of green financial products, including the selection of projects and assets, the internal process of tracking the raised funds and the fund delivery system, etc. The audit institution evaluates the preparation of the issuer and whether the proposed bonds meet the standards, and uses the general procedures (or lists) to evaluate whether the bonds to be issued meet the pre issuance requirements of the CBS.

Specifically, it includes the following steps: confirmation of green asset investment, certification application, second-party opinions or third-party evaluation (if any), green asset labeling, and green asset issuance, as shown in Figure A-1. Confirmation of green asset investment refers to the preliminary review of whether the submitted green financing applications (green credit, bonds, etc.) meet the definition and basic requirements of financial institutions for "green". For the projects identified and confirmed, the applicant shall formally submit the certification application to the financial institution, including project application qualification, fund use, supervision and reporting methods, etc. During this period, financial institutions may require applicants to submit second opinions or third party reviews. The second party's opinions are mainly carried out in the form of consultants, which generally summarize the project and are prone to lack of credibility. The third-party verification is that the issuer employs an independent institution to conduct a comprehensive evaluation on the industry standard, fund use, fund management and supervision report of the product according to the internally and externally recognized green financial standard system. After considering all the application materials, financial institutions decide whether to label and issue the green assets. In practice[39], the evaluation and certification standards mainly used in the world are the green bond principle (GBP) and the climate bond principle (CBS). China mainly adopts the catalogue of green bond support projects issued by the Green Financial Committee.

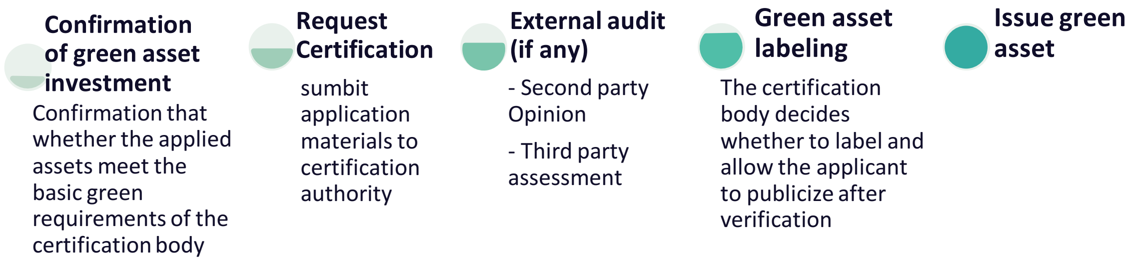

Figure A-1 flow chart of green financial product certification process

Post issuance monitoring is an important but difficult part of green financial standards, mainly because monitoring involves additional costs, and a strict monitoring system will restrict the investment opportunities of financing institutions, which may reduce the enthusiasm of enterprises to issue green financial products. Post issuance monitoring and tracking include reporting the use of funds and earnings, regularly disclosing the environmental and social impact of the project, post issuance certification and verification, and accepting the assessment of the third-party verification agency, etc. The principle of the CBS strictly stipulates the specific requirements and revocation of green bond issuance certification qualification. The Equator Principle requires that the annual total carbon dioxide emissions of direct greenhouse gas (scope1) and indirect greenhouse gas (scope2) based on the use of electric heating or thermal energy are expected to exceed 100000 metric tons, and the project must disclose the relevant information of greenhouse gas emissions every year.

The above relevant standards issued by mainstream international organizations, institutions and governments have strong authority and great influence. They are the practical and theoretical basis for the substantive development of green and climate

[39] http://www.tanjiaoyi.com/article-28329-1.html

around the world. However, there are some differences in details, reflecting different backgrounds and development demands.

First, the definition of "green" is different. This is due to the differences in the stages of regional social and economic development, key concerns and operation systems of different standard setting institutions. For example, the EU, the CBS, World Bank, Asian Development Bank and other institutions have gradually focused on climate change mitigation and adaptation in recent years; on this basis, green bond principle also pays extensive attention to biodiversity protection and other fields; China's green financing standard focuses more on energy conservation, clean energy, pollution control, green infrastructure, clean transportation and ecological protection. The prominent difference is the attitude of utilization, transformation and upgrading of coal and fossil energy. For example, the upgrading of waste coal plants is generally judged as a "Brown project" in international standards, which is not supported due to the extension of the time coal will be mined.

Second, the scope and fineness of standards are different. In terms of the scope of the standards, CBS, GBP, rating agency system and our current green standards basically do not include social benefits in the scope of screening and supervision. The Equator Principles, the World Bank and the Asian Development Bank cover ESG related indicators in the standards. The level of contents and technical details of the standard are quite different. CBS and China's green industry catalog both subdivide the industry into three categories and specify the technical threshold of the industry. The Green Bond Principles (GBP) and the World Bank set up a level-1 catalog, and the standards are relatively broad and lack operability. Most of the Equator Principles are described in principle, and the conceptual requirements for environmental risks are implemented. Other standards need to refer to the basic conceptual specifications of the World Bank. China's catalogue of green bond support projects (2015 Edition) and catalogue of green industry guidance (2019 Edition) both stipulate the specific projects and quantitative standards of loan investment, and separately explain the standards, which is of great guiding significance for the selection and evaluation of actual projects.

Third, the nature and enforcement effect is different. Most of the international standards are adopted and complied with voluntarily and have no force. Green project parties or financial institutions can obtain labelling or certification after voluntary application and review of standard setting institutions or third-party institutions. Moreover, the international standards have loose requirements for post issuance monitoring, reporting and disclosure. The role of government departments is inconsistent across countries. China's green financial standards are issued by the government regulatory authorities, which have the executive power for the involved industries and participants. At the same time, relevant departments are responsible for the approval and supervision of green investment and financing, and effectively regulate and promote the orderly development of green investment and financing.

We have noticed that with the increase of cross-border finance and international environmental cooperation, the global green financial standards are gradually converging. At the same time, due to the increasing awareness and attention of the global community on the issues of environment and climate change, a growing number of governments and institutions have realized that the current traditional green financial system may not be able to effectively support countries' efforts to achieve the Paris Agreement due to strong financial and institutional requirements for the NDC and the United Nation's 2030 sustainable development goals (SDGs). In the discussion and practice of green finance, due to the particularity of its nature, purpose and methodology, the concept and development demand of "Climate Investment and Finance" become more and more prominent, and climate effect is often the most important consideration factor of the international green finance.

Thanks for your attention, if you have any suggestion on our work, please contact us through the following email.

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