An Overview of Energy Conservation and Emission Reduction Policy for Conventional Boiler Power Sector

SATYA SHAH, RAN LI
Engineering Operations Management,
Royal Holloway University of London,
UNITED KINGDOM

Abstract: - This study follows the logic of policy transmission and begins with the characteristics of China's energy efficiency and emission reduction policy. Conclusions are drawn through a literature review, PESTEL analysis, and comparative analysis using German energy policies. The study then selected ABC Ltd. representing conventional boiler companies. Conclusions were drawn through literature review, CP/CI analysis, and comparative analysis of vapor and capacity parameters, boiler selection, and some emission technologies that meet ethical and sustainable standards, but Selective Non-catalytic Reduction (SNCR) technology is unethical and unsustainable. A-GROUP's ultra-supercritical power generation technology leads the industry and has a worldwide competitive advantage. The final analysis of the policy reaches down to grassroots participation. A literature review of A-GROUP's circulating fluidized bed technology and biomass combustion suggests that farmers can participate to some extent in boiler-related energy efficiency and emission reduction efforts but with a single means with limited information feedback channels. To conclude, energy efficiency and emission reduction policies are working smoothly for the boiler industry, but there is still much potential for improvement.

Key-Words: - Energy Conservation, Conventional Boilers, Power Sector, Emission Reduction, Global warming.

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1 Introduction

Global warming is a severe challenge to humanity in the 21st century. Academics consider excessive greenhouse gas emissions a principal factor in global warming. According to data analyzed by the International Energy Agency, total global greenhouse gas emissions have increased from 33.8 billion tonnes in 1990 to 59 billion tonnes in 2021, [1]. As the world economy rebounds strongly from the COVID-19 crisis and relies heavily on coal to drive growth, global energy-related CO2 emissions have increased by 6% to 36.3 billion tonnes in 2021, accounting for 61.5% of total global greenhouse gas emissions, [2]. The increase in global CO2 emissions of over 2 billion tonnes is the largest in history, [3]. Therefore, the environmental and emissions standards of the energy industry are essential indicators of affecting global warming.

Countries such as China been the world's top carbon-emitting country and are essential in reducing carbon emissions. As China is the only major economy to achieve economic growth in 2020 and 2021, the increase in China's emissions in these two years outweighs the rate of decline in the rest of the world over the same period, [4]. In 2021 alone, China emitted more than 11.9 billion tonnes of CO2, accounting for 33% of the total global emissions, [3].

[3], the increase in China's emissions is mainly due to a dramatic increase in electricity demand, which is heavily dependent on coal power, [2]. With rapid GDP growth and electrification of energy supply, China's electricity demand grew by 10% in 2021, higher than the 8.4% economic growth, [5]. Although China also saw the largest-ever increase in renewable energy production in 2021, the energy demand gap was forced to be supplemented by coal power as electricity demand outpaces the growth in low carbon-emitting energy.

To reduce carbon emissions, the government has committed to capping the country's peak carbon emissions by 2030, [6]. Although lowering the proportion of coal-fired power generation, replacing it with renewable energy is the key to realizing a low-carbon energy transition. However, despite the rapid growth of wind, hydro, and solar power over the past decade, it will still take time to replace coal-fired powerfully, [7]. What can be anticipated is that coal-fired power generation will be the most influential part of China's energy structure for a long time, [8]. Therefore, it is necessary to alleviate China's serious emission problem in the current phase through effective ECER policies to deal with the global warming problem. In the process of implementing ECER policy in China, three primary participants are involved. The Chinese government is responsible for issuing macro policies to regulate the coal-fired power industry. State-owned boiler design and manufacturing enterprises respond to national policies through production line management and R&D policy management. The public, mainly farmers, assisted with this process through biomass management. This research sets out three core research questions and contains five sub-questions based on the three main participants affecting ECER policy as described above.

Firstly, at the government level, which plays a macro-guidance role, t***he study's central question is whether ECER policy is on the right path.*** Considering the generalizability of the article for non-Chinese energy industry scholars to read, the study chose to include as the first sub-question what precisely ECER policies are. The study uses a literature review to summarise the core elements of the government's report. The objective is to answer what specific features and targets were set out in ECER policy in the four Five-Year Plans from 2006 to 2025 and how these policies have changed over several adjustments.

The evaluation of the justification of a country's energy policy requires an analysis of the subject itself and a comparative study with external subjects. After the reader has gained an initial understanding of ECER policy by sub-question one, the second sub-question is about how ECER policy compares to the experience of developed European countries. The research uses case studies and data analysis to select Germany as the country of comparison. The study is based on the German reform policy on coal-fired power generation over the past decades, summarizing the specific indicators of the German policy and comparing it with China. The comparative analysis focuses on the policy adjustments' time span, the indicators' degree of improvement, and the adjustment dimension of the specific indicator values.

Secondly, ***for the enterprises responsible for implementing the ECER policy, the study selects " ABC Ltd."*** This enterprise is a traditional boiler design and manufacturing enterprise in China. It has a long history, tremendous production, and much public data. The second core question of the research is whether the development strategies of Chinese traditional boiler design and manufacturing enterprises in response to the ECER policy meet the criteria of being proactive, ethical, and sustainable. The research further split this question into sub-questions three and four according to the short-term and long-term strategies of the enterprise.

Sub-question three is whether the short-term strategy of the A-GROUP meets the criteria of being positive, ethical, and sustainable. The research focuses on short-term rapid, one-year, or quarterly corporate transformations. The three specific areas include product, production line, and service scope transformation. The study presents a qualitative description of a company's product, product line, and service transformation strategies through data collection and analysis. Combining case studies of overseas boiler design and manufacturing companies helps increase the objectivity of the conclusions of sub-question three.

Sub-question four is like sub-question three but focuses on the long-term slow, years-long transition of the company's R&D strategy. It covers specific technological breakthroughs made by companies in the field of research on ultra super-critical power generation technologies and circulating fluidized bed boiler units, changes in the parameters of installed projects, and changes in the direction of research. The study uses CP/CI analysis and Floyd & Roussel's theory to answer sub-question four. The conclusions from sub-questions three and four are combined to evaluate whether the company's overall strategies align with policy requirements and maximize the company's benefits and whether these strategies are helping China to progress toward clean energy development, [9], [10]. It also forecasts the direction of the ECER policy for 2026-2030 and provides recommendations for the company's growth and strategy for the next Five-Year Plan. From a business perspective, policy forecasts and development recommendations are essential for traditional boiler companies to increase their profitability. From a social responsibility perspective, the analysis of the effectiveness of ECER policy is vital to the global environmental cause.

Finally, regarding the general public's participation level in ECER policy, the research selects the most representative agriculture and biomass fuels for analysis. ***Core question three focuses on how farmers contribute to the regulatory structure of the energy sector in the region.*** This discussion includes the organizational structure between government, enterprises, and farmers, the specific measures farmers take to participate in the production and combustion of biomass fuels, and the benefits and problems solved by these measures. The study uses a case research approach to illustrate this question.

The frame is followed in the methodology section by a detailed description of the three main analytical tools of the research: PESTEL analysis, comparative analysis, and CP/CI. At the same time, the study focuses on the links between key and core issues and the consistency of conclusions. Finally, the results, findings, and an analysis of the study's limitations are given. In the logical order of research, the research maintains a 'government-enterprise-people' argument sequence throughout the chapters. Firstly, the overall ECER thinking is presented from a macro perspective. Secondly, the correspondence of specific elements with enterprises and the measurement of policy implementation. Finally, the study introduced the role of the grassroots in the overall policy implementation process. Recommendations are given for each of the three main components individually while ensuring that the offers are consistent and reasonable for the general ECER thinking.

At the national level, a comparison between X-ECER policy and Germany's energy reform policy can provide a visual representation of the strengths and weaknesses of the policy, thus helping policymakers to make better-targeted adjustments in the next Five-Year Plan. At the enterprise level, analysis can identify areas of corporate strategy that are inconsistent with national policy or not ethically sustainable. The suggestions may help the management of the enterprise to make better decisions. At the grassroots level, findings can help people give feedback to their upstream and improve the communication between the three components. This research has important implications for environmental protection and the slowing of global warming in the region and worldwide.

2 Literature Review

In the order of the research chapters, the research will provide a complete description of the content of ECER policy in the order of the three core issues in the literature review chapter. Reasons for choosing Germany as a control. German content on energy reform for coal-fired power generation. Reasons for choosing A-GROUP to represent traditional boiler design and manufacturing enterprises in the region. Details of the long and short-term strategy of the A-GROUP. Description of farmers' specific role and organizational structure in the ECER policy.

2.1 ECER Policies, Targets, and Changes

2.1.1 Initial Establishment Phase

Although ECER policy was first proposed during the eleventh Five-Year Plan in 2006 by the government, the earliest energy policy was initiated two decades ago, beginning with the Report on Strengthening Energy Conservation in 1980. Initial energy policy was based on administrative measures, including establishing a comprehensive regulatory system based on energy conservation management, issuing energy conservation technology policies and reform measures, and promoting environmental protection legislation and pollution prevention.

The focus of the government at this phase was on energy conservation rather than reducing carbon emissions. The reason for emphasizing energy conservation was the conflict between energy development and economic development, [11]. This phenomenon was manifested in the high energy consumption per unit of GDP and the excessive focus of many enterprises on economic growth, leading to excess fuel consumption. At this phase, the country formally began work on supporting regulations and policies for energy conservation and environmental protection, setting energy conservation as a national strategy, [12]. The ECER system was dedicated to strengthening energy-saving technology transformation and controlling environmental pollution.

2.1.2 Development & Adjustment Phase

With the introduction of the eleventh Five-Year Plan and the ECER Comprehensive Work Programme, the ECER policy of reducing energy consumption per unit of GDP by around 20% and reducing total emissions of major pollutants by 10% has officially become a basic national policy, [13]. In addition to the continuation of the energy-saving strategy of the first phase, the reduction of pollutant emissions and the restructuring of energy sources policies were of equal importance. Within this phase, the country’s plan for Energy Conservation, promulgated in 1997, further improved China's legal system for energy conservation, [14]. Optimizing the industrial structure and energy consumption structure of energy-intensive industries, such as chemical and metallurgical industries, was proposed, and ECER was formally adopted as a national development strategy, [15]. In addition to industrial reform on the energy consumption side, the State Council's Outline for the Development of Renewable Energy Sources 1996-2010, promulgated in 1995, formally proposed structural reform on the energy production side for the first time and began to promote the development of renewable energy sources such as wind and solar energy. On this basis, the Medium- and Long-Term Development Plan for Energy (2004~2020) (Draft) proposed in 2004 included renewable energy as the focus of medium and long-term energy development for the first time.

In addition to restructuring capacity and energy consumption, the rule of law system relating to environmental protection and managing pollutant emissions has improved further. The Law o on the Prevention and Control of Environmental Pollution by Solid Waste has, for the first time, lowered management powers to county-level environmental protection departments, making implementing policies more effective. Several laws were promulgated to encourage enterprises to develop technologies to reduce pollutant emissions and to strengthen the supervision and management of emissions work.

2.1.3 Transformation Phase

In this transformation phase, low carbon emission is the new theme, emphasizing the importance of low carbon technologies in reducing pollutant emissions. In this phase, the government first summarises the achievement of specific ECER targets during the eleventh Five-Year Plan period. The ECER targets during the twelfth Five-Year Plan period were adjusted because there were differences in the completion within different provinces and cities, [16]. In addition, the government has further improved the ECER policy system by modifying the new Energy Conservation Law in 2008. Besides the provincial and municipal environmental protection bureaus, the regulatory powers of the government structure have been further improved regarding the obligations of the regulated. The responsibility of high energy-consuming enterprises under regulation has been clarified, avoiding the problem of no responsible party can be found, [17].

One of the most critical changes in the transformation phase was the attempt to marketize ECERs. To solve the problem of disparity in the degree of completion of ECER targets within and between provincial and municipal regions, established its first emissions trading center in 2007 in Jiaxing, Zhejiang Province, [18]. Under the premise that the total amount of pollutants emitted within a particular region does not exceed the permitted emissions, internal sources of pollution transfer their emissions to each other by using monetary exchange, thus achieving the objective of reducing emissions and protecting the environment, [19]. In essence, this is additional compensation for the environmental protection behavior of enterprises through market behavior. Besides this, the energy development strategy has been further adjusted. At the end of 2014, the State Council promulgated the Energy Development Strategy Action Plan 2014-2020, which for the first time, specifies the requirements for reducing coal-fired power generation and increasing the specific proportion of natural gas and renewable energy generation, [20].

2.1.4 Carbon Emissions Peak & Carbon Neutrality Phase

After the 2016 thirteenth Five-Year Plan, China continues to develop a market-based approach to carbon trading. While gradually opening carbon trading restrictions between provinces and municipalities, the region had expanded the number of industries participating in carbon trading to over twenty high energy-consuming initiatives. These industries account for more than 40% of the country’s total carbon emissions, and the total annual turnover of carbon trading exceeds RMB 9 billion, [18], [19]. Unlike carbon trading during the twelfth Five-Year Plan period, the government has increased its role in promoting the carbon trading market after the thirteenth Five-Year Plan. The market trading will accompany equal or reduced replacement advice for high energy-consuming industries. This advice includes stricter capacity restrictions for individual industries with new energy consumption exceeding 50,000 tonnes of standard coal to address overcapacity in low-end steel, for example, and to optimize the industrial structure while acting as a monitor outside the market, [21]. The government increased its support for low-carbon projects after the thirteenth Five-Year Plan by building a low-carbon-related investment and financing system for companies that meet energy consumption standards. The government has strengthened price-oriented incentives through tax incentives for low-carbon green projects and increased differential electricity prices, [22].

2.2 German ECER Policy, Indicators, Changes

2.2.1 Germany as a Comparison

Lack of production in the renewable energy sector due to COVID-19 and the sharp decline in Russia's oil and gas exports due to the sanctions imposed on Russia by European countries, both coal power generation and the share of coal power in the energy mix of European countries have rebounded significantly after hitting bottom. It has almost recovered from 15.7% in 2019 to 13.2% in 2020 and then rebounded to 15.2% in 2021. Germany accounts for 39.2% of all coal power in EU countries in 2021, followed by Poland with 28.9% and Turkey with 23.5%. In 2020, Germany contributed 44.4% of the EU's total incremental coal power, followed by Poland with 23.6% and the Netherlands with 11.5% [23], [24], [25]. This phenomenon shows that Germany highly relies on coal-fired power generation among European countries.

Analysis of Germany's installed energy capacity shows that although Germany achieved peak carbon before 1990, it has maintained a stable installed coal-fired power generation capacity of no less than 40GW over the past 30 years, [23], [24]. This is because coal power owns a special place in Germany's energy mix strategy. Considering that Germany's official carbon peak and carbon neutrality dates are 1990 and 2045, and China's planned carbon peak and carbon neutrality dates are 2030 and 2060, it is reasonable to assume that the gap between China and Germany's energy structure reform is around 30 years, [26]. A comparison of the electricity generation mixes in Germany around 1990 and China in 2020 shows a significant similarity. Furthermore, Germany's location in Europe means its renewable energy reserves are not exceptional. For these reasons, Germany has been chosen as a control for China's ECER policy in the coal power sector.

2.2.2 German Coal-Fired Power Generation

Germany is the eighth-largest coal producer and the ninth-largest coal consumer globally. Until Russia's restrictions on natural gas exports, Germany's coal-fired power generation and coal production industries have gradually stepped into the shutdown phase, [27]. Coal is an essential source of electricity in Germany. Still, in recent years the coal industry has undergone an overall policy change due to Germany's renewable energy-led "energy transition" strategy, [28]. Germany is gradually removing subsidies for hard coal mining and closing hard coal mines. In 2018, Germany's domestic complex coal production stopped, and coal-fired power plants shut down Programmatically, [29]. The phasing out of coal-fired power generation in Germany results from changes in the structure of primary energy consumption and the critical importance of coal-fired power.

The sharp reduction in the proportion of coal power in Germany comes from a determined coal industry and coal power sector policy. The German coal industry has gone through the whole life cycle from the initial simple mining to modern development, from the transformation of enterprises to the closure of coal mines. In 1997, the German federal government, coal companies, and mining energy associations agreed on hard coal subsidies. Under this new financial subsidy agreement, federal support for grant sales was reduced from €6.7 billion in 1996 to €2.7 billion in 2005. An agreement was reached in February 2007 between the Federal government, the governments of NRW and Saarland, the German complex Coal companies, and the Union of Mining, Chemical and Energy Industries (IG BCE). The agreement is that, under the Coal Industry Financing Act introduced at the end of December 2007, subsidies for hard coal should be phased out by the end of 2018. In 2007, EU competition regulations required Germany to end hard coal subsidies by 2018. In January 2008, the top two parties in power agreed to close all coal mines in Germany by 2018.

According to Germany's greenhouse gas emissions list, coal consumption accounts for 45% of Germany's CO2 emissions from all energy sectors (58% in 1990), with hard coal accounting for 21.3% and lignite for 23.7%. For several decades, Germany has been ineffective in reducing emissions in the coal sector, despite several emission reduction policies adopted at both EU and domestic levels. For Germany to meet its emissions reduction targets, the energy sector, and coal-fired power will have to make an above-average contribution. In June 2018, the German government created the Commission on Growth, Structural Change and Employment (also known as the "Coal Commission"), which submitted recommendations to the government in 2019 to phase out coal-based power generation projects by 2038 (possibly as early as 2035). In 2019, the Coal Commission recommended that the government phase out coal-based power generation projects by 2038 (2035 at the earliest), [30]. Based on the recommendations of the Coal Commission, the German Cabinet adopted the Coal Retirement Act in 2020, which sets out a policy to phase out coal-fired power generation by 2038.

2.2.3 Energy Transition Measures in Germany

Renewable Energy Law and Electricity Market

In Germany, the second Renewable Energy Law was promulgated in 2000. The Renewable Energy Law provides detailed and long-term regulations on investment protection, investment costs, and financial incentives. In contrast to the Chinese policy approach, Germany has identified the importance of economic instruments for implementing renewable energy policy from the beginning, [31]. Non-business customers who invest in renewable energy equipment can receive financial subsidies for the entire process of investment purchase, network installation, and long-term return on investment. Germany has also led the world in reforming its electricity market. Renewables can be traded more easily under the "prioritization principle" of the European Energy Exchange, with lower marginal offers. This beneficial treatment contrasts with the difficulty of getting renewable energy online in China. Regarding monopoly breaking and marketization, Germany started its electricity market reform in 1998 by adopting the Electricity Market Opening Regulation. The German government first broke up the companies that had monopolized the electricity market, creating conditions for new energy companies to enter the market and compete.

The development of renewable energy

Germany has one of the world's most aggressive and robust renewable energy strategies. On 7 July 2022, in the wake of the Russian gas supply disruption crisis, the German government introduced a new amendment to the Renewable Energy Act. The new law calls for an increase in the share of renewable energy in the electricity supply from 65% to 80% by 2030 and asks for the "carbon-neutral electricity" plan to be largely completed by 2035, [32]. In addition, the new bill's big step is also reflected in a significant increase in the installed capacity target, the degree of preferential policies, the reduction of financing costs, tax incentives, governmental simplification and standardization of the approval process, and other aspects, to increase the promotion of the energy transition. Germany's renewable energy generation currently accounts for more than 40% of the total power generation. Offshore and onshore wind power, photovoltaic, and biomass are Germany's most important sources of renewable energy power, [33]. Most of the provisions of the new bill, which will be implemented from 2023, specify specific installed capacity targets: onshore wind power capacity from 69 GW in 2024 to 160 GW in 2040; photovoltaic systems from 88 GW in 2024 to 400 GW in 2040; and cumulative onshore wind, solar and biomass capacity to reach 568.4 GW in 2040, [32].

The new bill stipulates that 2% of Germany's land will be used for wind power alone in the future, with each state having to allocate 2% of its land for installing wind power installations. Currently, the average share of such land is around 0.8%. Suppose the installed area does not meet the requirement. In that case, the minimum distance between wind power installations and buildings established by the Länder will lapse to reduce the impediment to wind power installation caused by land restrictions. This marks the first time in more than a decade that environmental regulations have been given a lower priority in Germany, as renewable energy construction can be given a higher priority than environmental regulations, [34].

2.3 A-Group Public Information Summary

2.3.1 A-Group for Analysis

A-Group is one of China's leading integrated energy solutions providers and is part of ABC Ltd, China. A-Group, named for its boilers, focuses on efficient energy use and holds core technology patents in supercritical, ultra-supercritical, secondary reheat, and other power generation technologies. The circulating fluidized bed technology, carbon dioxide boiler technology, low calorific value coal combustion technology, and other aspects of the leading position in scientific research.

A geographical division of responsibility characterizes China's energy companies. A company's R&D and regular service areas are relatively fixed. The southeast coastal region of China, where A-GROUP is located, is characterized by high energy consumption and low energy consumption per unit of GDP, which is caused by a combination of regional industrial adjustment and technological innovation in power generation. In addition, China's economic development and research investment centres are concentrated in the southeast coastal region. A-GROUP has a better R&D environment than other boiler companies in northwest China. These geographical advantages can be reflected in the company's technical indicators and the time of commercial use. In addition to the southeast coastal area, the ECER index requirements are more stringent, putting higher requirements for boiler design and manufacturing companies. Considering the need for emission and environmental protection, A-GROUP is also the first boiler company in China to propose the concept and service of an "environmental protection island." Based on the above reasons, A-GROUP was selected as the research object.

2.3.2 Main Technical Introduction and Advantages

A-GROUP's main advantages include ultra-supercritical power generation and circulating fluidized bed technology. Ultra-supercritical power generation technology can cope with the "energy saving" part of the national energy policy by reducing coal consumption per power generation unit and improving energy conversion efficiency. Circulating fluidized bed technologies can utilize biomass fuels generated in rural areas through hybrid combustion technologies and address the "lower emissions" part of energy policy by reducing the direct combustion of emitted biomass in rural areas.

Ultra-Supercritical Power Generation technology
Ultra-supercritical power generation technology refers to coal-fired power plants with water vapor pressure and temperature above the supercritical parameter to significantly improve unit thermal efficiency and reduce coal consumption and pollutant emission. The specific parameters are 25MPa and 580℃. Its power generation efficiency is 43.8% ~ 45.4%, much higher than the 37.5% of subcritical units, [35]. With the progress of materials related to power generation technology, ultra-supercritical power generation technology with higher parameters of 630℃ and 760℃ will become the primary choice of the next generation thermal power generation, and its power supply efficiency is expected to reach 47% ~ 53%. Compared with the current most advanced 600℃ ultra-supercritical power generation, the coal consumption can be reduced by 40 grams of standard coal/KWH. Up to 250 grams of typical coal/KWH below can significantly improve the power generation efficiency of units and reduce coal consumption and emissions of pollutants, CO2, and other greenhouse gases. The core advantage of advanced ultra-supercritical power generation technology lies in low carbon, high efficiency, and clean and technical inheritance.

Under the guidance of the Eleventh Five-Year Plan in 2006, Boiler design and manufacturing enterprises began to increase investment, research, and development of ultra-supercritical power generation technology. A-GROUP is responsible for Guodian Taizhou Phase II, Shenneng Pingshan Phase II, and other projects that have exceeded the 600℃ level, which is in the leading position of national installed units (A-GROUP). The Guodian Taizhou Phase II Project is the world's first secondary reheating megawatt ultra-supercritical coal-fired generating unit. The design parameters are 31MPa /600℃/610℃/610℃. The design power generation efficiency is 47.82%, and the design coal consumption is 256.82g/kWh (A-GROUP). The average annual coal consumption of other coal-fired units during the same period of operation is more than 310g/kWh, which is sufficient to demonstrate the advantages of A-GROUP technology, [36].

Circulating fluidized bed combustion technology
The country's total CFB coal-fired power capacity exceeds 100 million kW. It accounts for more than 10% of the whole coal-fired power generation and more than 50% of the thermoelectric heating market. A circulating fluidized bed boiler is a particular type of boiler that circulates fuel in a flowing state for combustion. The main structure includes two parts: a combustor and a circulating furnace. The power flow state refers to the phenomenon that when a gas or liquid flows upward through a solid particle at a certain speed, the solid particle layer behaves like a liquid state. Because the fuel needs the joint participation of gas and liquid to maintain the flow state, CFB is different from the traditional pulverized coal boiler, which has excellent tolerance for fuel. The country's coal resources contain a large proportion of high ash and high sulphur coal. A large amount of gangue is produced in the coal washing process, and the coal slime needs to be used. Fluidized bed combustion is the best way to use these fuels on a large scale.

A-GROUP can design and manufacture 660MW class ultra-supercritical circulating fluidized bed boilers. The boiler heating surface design of the product is accurate; The combustion chamber temperature design is consistent with the operation, which overcomes the problem of excessive emission of pollutants caused by the extreme error between the design and operating temperature of similar products in other countries. Nitrogen oxide and sulfuric oxide emissions were better than expected. The specific values are as follows: the average sulfuric dioxide emission concentration of 192.04mg/Nm3 is lower than the designed value of 380mg/Nm3, and the average nitrogen oxide emission concentration of 111.94mg/Nm3 is lower than the designed value of 160mg/Nm3. This marks A-GROUP's CFB development, manufacturing, and operation level to the world's highest level, [37].

2.3.3 Development and Transformation Strategy of A-GROUP
A-GROUP is one of the country's earliest boiler design and manufacturing enterprises to carry out industrial transformation. A-GROUP has partnered with the government on household waste disposal and direct biomass combustion projects. The utilization project of household garbage can provide solutions for different technical routes according to waste characteristics, processing scale, and user

needs. A-GROUP also provides equipment production, technical consultation, system integration, operation and maintenance, and other complete industry chain services simultaneously to establish a transparent modular system, [38].

A-GROUP also provides solutions for biomass direct combustion, gasification, and coal-fired power generation projects. The most advanced project is A-GROUP biomass gasification coupled with a coal-fired power generation plant, which uses fixed bed gas cooling technology. The heating value of gas is 5%-10% higher than that of conventional heat exchanger cooling, and the problem of contamination/corrosion of the heating surface caused by tar and alkali metal precipitation is avoided. We can provide the overall solution with a power of 10MW~50MW according to user demand.

3 Methodology

3.1 PESTEL Analysis and Comparative Analysis

Whether a country’s ECER policy is on the right path is the most macro problem for the logistic level of the three core issues in this study. The PESTEL analysis model is an effective tool for analyzing the macro environment. As for core question one, the research mainly focuses on formulating and adjusting energy policies at the national level, a complex issue involving many considerations. According to the analysis of the sequence from policy formulation to implementation, the government of the country making the policy should be considered first, which involves the governing characteristics of the government and the experience in policy formulation and other factors. When a policy is formulated and implemented, it is necessary to consider the economic means to promote implementation and the economic response after implementation. Then, it is essential to carry out legislative and judicial guarantees through legal means to ensure the smooth performance of the policy. Enterprises mainly accomplish the specific implementation of policies. To implement a policy, enterprises should consider whether there is sufficient technology accumulation and need to consider the relationship between the performance of the procedure and the society and the masses. The PSETEL analysis method can cover political, economic, social, technological, environmental, and legal factors. The components of PSETEL's analysis method coincide with the perspective that needs to be considered in macro policy analysis, so PESTEL analysis is an excellent approach to answer core question one.

The PESTEL analysis method also has obvious disadvantages. First, it involves too many variables, changing factors, and uncertain factors, which means that measuring the strengths and weaknesses of any one indicator alone cannot prove the extent of its scope. This study addresses this shortcoming by introducing the German energy policy system as a reference for analyzing a country’s energy policy. For example, discussing a country’s adjustment to the decline in energy consumption per unit of GDP is not an objective indication of the impact of this policy or adjustment on the overall ECER policy. However, the comparison with Germany's policy of reducing energy consumption per unit of GDP over the same period enhances the objectivity of the conclusions. Secondly, PESTEL analysis only considers macro market factors but does not consider specific market reaction measures. The way to deal with this shortcoming in this study is to strengthen the connection between macro analysis and exhaustive implementation means of enterprises in the analysis chapter. Secondly, in the discussion of core question two, this research plans to compare the conclusion between core questions one and two to prove the consistency of the findings.

3.2 CP/CI Analysis

CP/CI analysis is short for Competitive Position/Competitive Impact. Philip A. Roussel developed this theory in his 1991 book Third Generation R&D, [10]. This method needs to measure the extensive degree of specific technology applied in related industries and the advanced degree of technology. Then the technology is classified as Base, Key, step, and Emerging Technology. These categories can show how technology is making a Competitive Impact on companies. The method also measured how well the firm mastered the technology or how well it planned to invest in it. Then it classified the technologies as Clear Leader, Strong, Favourable, Tenable, and Weak. These categories can show how Competitive Position a company holds in technology.

Finally, Competitive Impact is taken as the vertical axis and Competitive Position as the horizontal axis. The position of coordinate points in the chart measures enterprises' mastery of specific technologies and development strategies. Suppose the CP/CI data of the same technology at different times can be obtained. In that case, the development and application strategy of the technology in the enterprise can be directly represented by the movement of arrows and coordinate points. This study only uses specific cases that have been published and put into commercial applications for CP/CI analysis, considering the legality of enterprise data acquisition. It can visually show the development degree of boiler-related technology owned by A-GROUP in 20 years, which reflects the enterprise's short-term and long-term goals.

CP/CI analysis also has its most significant disadvantages: it is subjective and inaccurate enough to measure specific technologies' CP/CI position. Different authors have different degrees of understanding and mastery of the same technology and its related knowledge background. This difference will lead to subjective differences in CP/CI location selection. This difference can also be seen between multiple technologies in the same CP/CI position range, resulting in a lack of accuracy. The approach of this study to address this shortcoming is firstly to select technologies for analysis with quantitative indicators to support them in preference. This was followed by a comparative analysis citing similar technologies and their quantitative indicators from competitor companies. Concerning the objectivity of the conclusions, technology positioning after comparison of indicators is more convincing than technology positioning through subjective judgment alone. For the analytical significance of the conclusions, the CP/CI analysis method was originally a tool for measuring the performance of a company's technology in the inter-competitive process. Using competitor data can assist CP/CI in the analysis of conclusions.

4 Analysis

4.1 Is Energy Efficiency Policy on the Right Track?

Summary and analysis of China's ECER policies
PESTEL analysis was conducted based on the analysis in Section 2.1.1 and the data summary in Table 1 (Appendix). From the political point of view, country’s ECER work is in the initial phase, and the government has no experience in energy policy decision-making. The policy thinking of this phase shows the characteristics that the government forces enterprises to implement by rough administrative orders. Specific measures include:

- Setting energy-saving requirements.
- Charging for excess energy consumption.
- Implementing a permit system for emissions.

Distinct from other phases, these measures are not tailored to specific regions and industries. Therefore, the political performance of the initial formation order of the country’s ECER policy is inefficient. In terms of law, since China has not had any relevant laws on ECER or environmental protection before, the judicial management and responsibility division are very confusing in this phase. The government is only partly responsible for the whole process, from formulating policies to implementing supervision. At the same time, enterprises and individuals do not have any responsibilities or clear obligations in this process. This makes it difficult to implement energy policies and is not conducive to cultivating environmental protection concepts among grassroots people. Therefore, the legal performance of the initial formation stage of ECER policy is poor.

In terms of social culture, environment, and science and technology, this phase in the country has no concept related to environmental protection from the government to enterprises and the public. The lack of relevant laws makes it difficult for relevant ideas to spread widely. There is also no incentive policy related to science and technology, and whether to develop energy-saving technology depends entirely on the consciousness of enterprises, so it cannot be evaluated.

Development and Adjustment Phase
PESTEL analysis was conducted based on the analysis in Section 2.1.2 and the data summary in Table 2 (Appendix). From the political point of view, the Chinese government began to upgrade the industrial structure while carrying out the ECER work. In this phase, the government has clarified the list of backward industries in energy consumption and strengthened the supervision of old enterprises and the qualification of new ones. In addition, the country’s government has determined six specific ECER indicators across the country so that enterprises can implement policies in a clear direction and carry out targeted R&D investments according to the indicators. The political performance of this phase's ECER policy in China began to show the trend of quantification and refinement of indicators. Still, the rough management mode of not subdividing different regions and different industries has not been improved.

In ***economic terms***, the government has begun to try to stimulate policy. Additional taxes will be collected from companies with high energy consumption and emissions. These funds are used to subsidize and reward research and development of

ECER-related technologies and the construction of related infrastructure. Companies can choose between shrinking capacity or maintaining capacity but developing better ECER technology. This is the first time the region's enterprises can obtain financial subsidies by actively developing ECER technology, which is of great significance. The problem is that the market regulation mechanism is still imperfect, and the lack of direct government funding supports the incentive policy.

From the ***legal perspective***, this phase makes up for the problems of the previous phase through legislative work. A target accountability system was introduced for the first time to break down ECER targets by region. While incorporating the reduction target for energy consumption per unit of GDP into the comprehensive evaluation system for local economic and social development, we will hold local people's governments at all levels accountable for their energy conservation work. The specific supervision and rectification work is responsible for the energy bureau under each province and city, and the overall ECER results of each province and city people's government are responsible. This measure significantly strengthened the government's awareness of energy conservation responsibility to local governments. It enhanced the efficiency of policy supervision, so the legal performance of this phase was very successful.

From the perspective of ***science and technology***, in addition to the initial establishment of the enterprise ECER R&D incentive system, the most critical thing in this phase is that China has included renewable energy technology R&D into the national key energy policy for the first time. Around the eleventh Five-Year Plan period, the country's energy consumption structure changed for the first time, with renewable energy and natural gas as the main growth points, increasing by 3%. However, the country's overall ECER and renewable energy technology are still very backward in this phase and lack low energy consumption and pollution production capacity. Therefore, the technological aspect of this phase's ECER policy in the country shows slow growth.

From the perspective of ***social culture and environment***, this phase's national special fund subsidy is still insufficient to make some enterprises switch from economic growth to energy conservation and environmental protection. ECER work remains one of the audit conditions for companies and individuals to complete average production and economic growth rather than a business development goal. ECER's awareness of environmental protection has been initially popularized but lacks deep understanding. Therefore, the socio-cultural and environmental performance of this phase is still poor, [39].

Transformation phase PESTEL analysis

PESTEL analysis was conducted based on the analysis in Section 2.1.3 and the data summary in Table 3 (Appendix).

From the political perspective, first, regarding the adjustment of ECER indicators, it is worth affirming that the government has objectively acknowledged the problems in some indicators during the eleventh Five-Year Plan period. Due to the significant differences in the completion of indicators reported by various provinces and cities and the low confidence of some provinces and cities, the government appropriately lowered some indicators. Unfortunately, Although the government is aware of the differences in completion between province and municipalities, the policies and tasks issued under the twelfth Five-Year Plan are still not fine-tuned according to the differences between provinces and municipalities. For the indicator setting itself, in addition to the indicators related to GDP, this adjustment adds the indicators related to industrial added value and further improves the emission management requirements. At the same time, the requirements for low-carbon industries and optimization of the energy structure have also been strengthened. Therefore, the policy performance of this phase is objective and practical but still not accurate enough.

The deepening reform phase of the country's ECER policy is very good at adjusting the economic perspective. As for the fiscal expenditure policy, the central government's allocation after the twelfth Five-Year plan period was significantly higher than that during the eleventh Five-Year plan period. For the first time, a government procurement mechanism has been introduced. The government will centrally purchase and provide price subsidies for products that meet low-carbon production standards. This strategy will ensure that these products have a higher competitive advantage in the market, encouraging companies to pursue ECER-compliant low-carbon production. As for tax policies, the government provides tax incentives to enterprises and products that meet low-carbon production standards. All business and value-added tax (VAT) are exempted for enterprises that meet the highest environmental protection standards. For enterprises that do not meet the standards of low-carbon production, in addition to punitive taxes, the export of products is strictly restricted, forcing enterprises to carry out industrial reform. As for the preferential price policy, the government has detailed the categories of high-energy consumption industries and set different punitive electricity prices. The government will subsidize the feed-in tariff for enterprises that use renewable energy to generate electricity to ensure a reasonable investment return cycle. In addition, the pilot work of emissions trading has started in some regions, which has improved the degree of market-oriented management. In general, the financial performance of this phase has many advantages, and the fiscal policy has brought a comprehensive incentive effect for the enterprise ECER.

From the perspective of technology and law, the motivation of enterprises to develop low-carbon technologies that meet the requirements of ECER has been comprehensively strengthened, so the related technologies of this phase accumulate rapidly. The perfection of legal work makes it possible to combine market adjustment and mandatory government adjustment. As for social, cultural, and environmental factors, objectively speaking, the country’s voice in global climate and environmental protection issues has been gradually strengthened, and the general public's awareness of environmental protection has been significantly enhanced. However, these social environments are not directly related to the excellent development of ECER work and the guidance of ECER policies for people and the social environment. The Chinese public still does not have the means to participate directly in the work of ECER, [40].

Summary of all phases with PESTEL analysis

The analysis in section 2.1.3 and Table 3 (Appendix) was used to conduct a PESTEL analysis in conjunction with the previous sections. From a political perspective, twenty years have passed since the Chinese government first made political demands related to energy efficiency. China has gained a great deal of experience in formulating energy policies, and there has been a dramatic shift in policy style.

In the fourth phase, policies on ECER targets were finally broken down by province and city region, with detailed requirements based on the core industrial layout of each province and city. The overall focus of the policy also changed from simply saving energy in the previous century to focusing on the transformation of the energy structure and industrial structure and the rapid development of related technologies. As ECER efforts matured, the policy implementation cycle was extended from the previous five-year period to a long-term plan for 2030 and 2060. In summary, the political performance of ECER policy is characterized by a refinement of management and comprehensive development that is gradually coming into line with the cutting-edge ideas of the international community.

From an economic perspective, the piloted emissions trading strategy gained importance during the Fourteenth Five-Year Plan. The new policy enables the trading of emission allowances and energy credits across provinces, cities, and sectors. This approach takes full advantage of the market's self-regulation and fills the international mandatory policy gap between provinces, municipalities, and industries. Strategies that have performed well in practice, such as government procurement, tax incentives, and financial subsidies, carried over from the Thirteenth Five-Year Plan period, have been further strengthened. In summary, the economic performance of ECER policies has been characterized by a combination of market economy and government coercive measures, with an increasing variety of economic incentives for ECER as shown in Table 4 (Appendix). Increased government guidance capacity helps to eliminate backward industries. Increased self-awareness of enterprises helps to achieve industrial upgrading. By motivating enterprises to use new energy sources, the government reduces the demand for carbon credits, thus achieving ECER.

Regarding science and technology, the 14th Five-Year Plan-related policies indicate that the focus has shifted from the traditional coal-fired power generation end technologies to renewable energy technologies. Along with this shift in policy focus, there are two potential problems. Firstly, for conventional energy sources, even if China reaches peak carbon emissions by 2030, it is foreseeable that coal, oil, and gas-based thermal power generation will still be a large part of the country’s energy mix. Whether the country has invested enough in ECER technologies for traditional energy sources is worth considering. Secondly, regarding renewable energy sources, the region has made significant technological achievements in wind power and PV generation and has already achieved grid parity in areas rich in renewable energy reserves, such as western China. However, these technologies have applied the centralized route. The country so far has no aggressive strategy to develop distributed energy technologies due to the lack of saturation of renewable energy deployment in the western region and the lack of related energy storage and sequestration technologies. In summary, the scientific and technological performance of ECER policy shows the beginning of a transition from traditional ECER technologies to renewable, low-carbon technologies, but there are still significant technical gaps.

To summarise the legal aspects of ECER policies, the establishment and revision of relevant laws can indeed guarantee a country's progressively more complex political, economic, and technological strategies. There is a trend toward an increasingly detailed division of responsibilities and management. There is a trend toward decentralization of supervision to local governments and units. To summarise the social and environmental performance of the country's ECER policies, there is an overall trend towards improvement but insufficient grassroots participation. As the target of ECER, enterprises play a role in linking the government with the masses. In previous analyses, it could be concluded that the enthusiasm of enterprises to participate in policy is determined by the government incentive system and the strength of penalties. However, the study did not collect data relating to the degree of familiarity of the public with ECER efforts or the degree of acceptance of the social climate for ECER efforts. Enterprises are organizations made up of grassroots people. There is a gap in research on how the public and social environment are optimistic about enterprises but with policies.

4.1.1 Comparison of German ECER Policies with Chinese Policies

The comparative analysis of this study for core question one consists of two main parts. For those parts of China's and Germany's policies that are inconsistent, the discussion focuses on what is missing in China's policies. This part of the analysis focuses on the reasons for the missing policies and whether China should supplement these policies. For those parts of the policy that are consistent between China and Germany, if there is data to support specific technical indicators, the data is used to compare the strength of China's ECER policies.

Policy differences in the coal industry

The most significant difference between Germany's overall approach to ECER and China's policy is the German government's direct regulation of the coal industry. Since achieving peak carbon emission in 1990, coal has slowly declined in Germany's primary energy consumption, and renewable energy consumption has increased over the same period. In 2019, Germany's total primary energy consumption was 436.0 Mtce, of which oil accounted for 35.3%, natural gas for 25.0%, coal for 17.7%, renewable for 14.8%, and nuclear energy for 6.4%. Compared to 1990, total primary energy consumption has fallen by 14.3%, with coal consumption falling by around 59% and renewable energy consumption rising by approximately 8.7 times, [41]. Germany's domestic energy production is dominated by coal and renewable energy, with oil and gas relying heavily on imports. Renewable energy production increased significantly from 1990 to 2019, from 6.8 Mtce in 1990 to 65.0 Mtce in 2019, an increase of about 8.6 times, while coal production fell by 77.3%. Germany is phasing out complex coal mining subsidies, closing hard coal mines, phasing out lignite power plants, and withdrawing from coal-fired power generation. 2018 saw the cessation of domestic hard coal production in Germany. The corresponding subsidies for hard coal sales were reduced from €6.7 billion in 1996 to €2.7 billion in 2005, with the hard coal subsidies ending in 2018, [42].

A comparative analysis shows that Germany's overall thinking on ECER is to limit the coal resource, which accounts for the largest share of primary energy consumption. Restrictions on coal are reflected in mandatory reductions in the proportion of primary energy consumption accounted for by coal, limiting the mining of domestic coal resources through reduced subsidies, and reducing coal imports. The advantage of such policies is that the effects are intuitive. A reduction in coal use corresponds directly to a decrease in carbon emissions. However, the disadvantage of such a policy is clear: the decline in coal's share of primary energy consumption will directly lead to a power shortfall. Managing the electricity gap requires other forms of energy generation to compensate and downstream energy-consuming industries to reduce production or improve energy efficiency. Coordinating the entire process of energy production and consumption requires complex management systems. This is difficult for the government, which has a much larger overall energy demand, a larger volume of coal-fired power generation, and a lack of experience with management systems.

However, the German approach to direct cuts in the coal sector is still worthy of study and experimentation by the government. The government has tried to reduce national coal consumption by one standard coal unit as early as the initial ECER stage. However, due to the government's management and legal system's backwardness, this policy was not effectively implemented. Directly reducing coal consumption is an inevitable choice after a certain level of energy restructuring has taken place. The country should start restructuring its coal industry by 2030 when it reaches its peak carbon emissions.

PV power generation policy differences

The most significant component of German PV is distributed PV. As of 2013, in countries such as Germany, Switzerland, and Austria, the installed capacity of rooftop distributed PV power generation accounts for nearly 80% of the total PV capacity, which is different from the characteristics of China, where large, centralized PV power plants are dominant.

Distributed PV brings the problem of unstable power generation and is difficult to reconcile with conventional energy sources. With the growth of renewable energy installations, Germany has seen a gradual increase in renewable energy electricity over-generation and abandonment in recent years, with negative tariffs becoming a major problem. In contrast, is the terrible weather, such as continuous rains. The overall grid faces a shortage of electricity supply. Solving this problem requires Germany to maintain the installed capacity of conventional means of power generation. This is why Germany still has a significant proportion of installed capacity despite its determination to abandon traditional power generation, such as coal-fired power generation.

The reasons that constrain the country's choice of the distributed route for PV power generation are energy layout constraints, inadequate supporting technologies, and insufficient social and environmental support. For energy layout, the western region has the world's richest solar resources. The Country's PV power generation has prioritized the centralized PV plant route to utilize these resources efficiently. The technology developed in conjunction with this is long-distance ultra-high voltage transmission technology. This development strategy has indeed boosted the economy of western China through feed-in tariffs, PV agriculture, etc. In 2021 country's cumulative grid-connected PV capacity reached 308GW, the world's largest in terms of both new and cumulative installed capacity. Annual PV power generation was 325.9 billion kWh, up 25.1% year-on-year, accounting for approximately 4.0% of the country's total annual power generation. While significant results have been achieved, distributed PV technologies, distributed energy storage technologies, and technologies related to distributed PV networking have not received sufficient attention. Although the installed capacity of distributed PV in the country is expected to reach 126.8GW by 2021, the proportion of connected PV is much lower than in European countries, the US, and Japan. The feed-in tariff in the country is only £0.0125/kWh for non-owner-occupied homes and £0.0375/kWh for residential homes (*the average price of domestic electricity in the country is £0.065-0.077/kWh for the same period*). The low feed-in tariff subsidy has led to a lack of enthusiasm among the grassroots to participate in distributed PV projects, which has led to a lack of social support for energy policy, [43].

Based on the above analysis, it can be concluded that the country still has the largest installed capacity of distributed PV in the world without primarily developing distributed PV. Therefore, there is no problem with the basis for the application of distributed PV among the people. The first problem that needs to be solved in the country is the lack of feed-in tariff subsidies for distributed PV. By increasing the feed-in tariff subsidies, the enthusiasm of the grassroots to apply distributed PV will increase, which in turn will promote the upstream R&D work of the industry towards distributed PV. The next issue the country needs to address is the energy storage and transmission technologies associated with distributed PV interconnection. Once it has addressed these two issues, the socio-cultural and environmental factors of the country's energy strategy will also improve.

Comparison of Policy Intensity and Effectiveness

By analyzing Figure 1, the curve of GD energy consumption per unit in the country decreased significantly around 1990, which marked the beginning of Phase I of energy reform. Germany's energy consumption per unit of GDP curve around 1990 showed a significant decline in the standard to reach the peak of carbon emissions, [44].

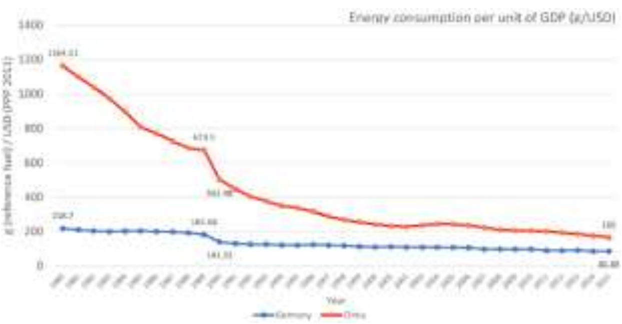

Fig. 1: China-Germany Comparison of Energy consumption per unit of GDP 1980-2015

The country's carbon emission is expected to peak by 2030, and its energy consumption per unit of GDP in recent years has been close to Germany's in 1990. In summary, the country's current overall energy strategy is effective from the results perspective, and the country's future energy plans are relatively credible. Figure 1 and Figure 2 show that renewable energy has sustained the overall energy consumption increase in Germany since 1990, while all other forms of energy generation have shown a decreasing trend in fluctuation. This finding is consistent with the conclusion that Germany had already reached its peak carbon emissions in 1990, [45].

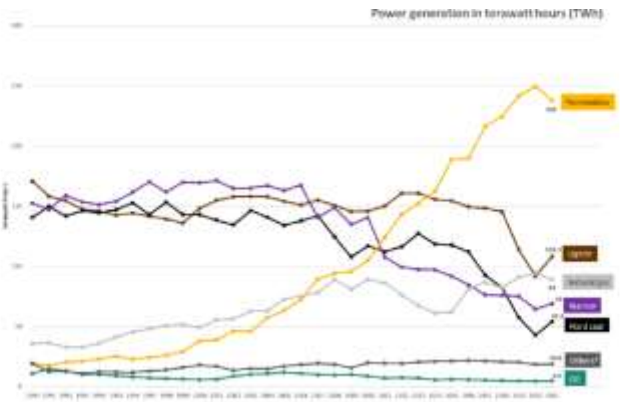

Fig. 2: German Power Generation (1990-2021 by energy type)

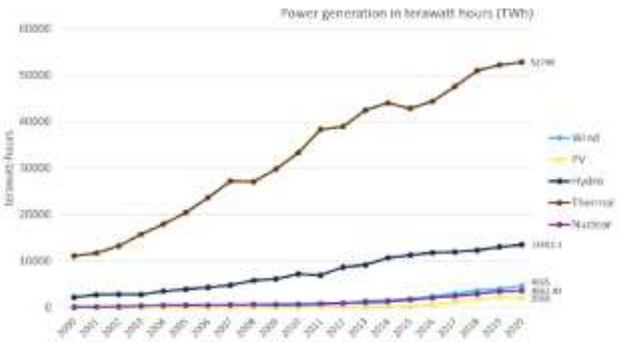

Fig. 3: China's Power Generation 2000-2020 by Energy Type

The growth in the country's overall energy consumption has been sustained by traditional thermal power generation, while the remaining forms of renewable energy generation have grown to varying degrees. This is consistent with the conclusion that the country has not yet reached peak carbon emissions. The growth rate in the country's total thermal power generation has declined since 2018 and is the lowest in almost 20 years (shown in Figure 3), which suggests that China has a chance of achieving peak carbon emissions in 2030, [46], [47].

Figure 4 and Figure 5 show that the country's installed renewable energy capacity has not risen as much as Germany's, simply in terms of the share of each type of installed renewable energy capacity in the country's overall installed power generation capacity. However, considering China's overall energy consumption is more than ten times that of Germany, the growth in installed renewable energy capacity of any type is far greater than that of Germany. And the country has maintained its rapid growth in installed renewable energy capacity during COVID-19. In conclusion, the country's overall strategy for renewable energy generation is effective and promising and is expected to continue to rise steadily in the future, [48].

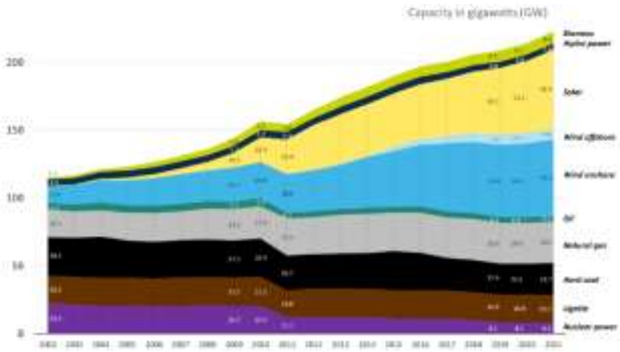

Fig. 4: Installed Power Generation Capacity in Germany 2002-2021 by types of Energy Source

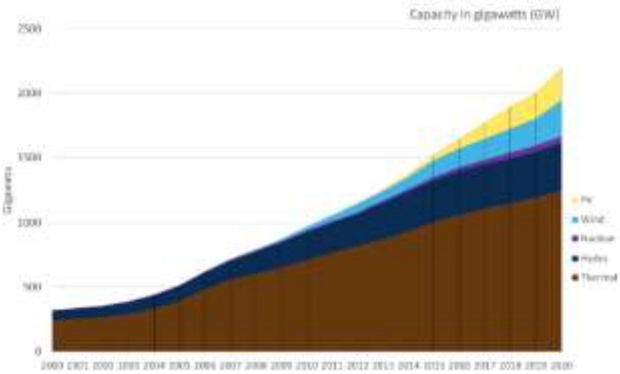

Fig. 5: Installed power generation capacity in China 2000-2020 by type of energy source

4.2 Development Strategies of A-GROUP in Response to the ECER Policy

4.2.1 Analysis of A-GROUP's Typical Projects

List of major A-GROUP projects

The Table 5 (Appendix) shows the 12 typical coal-fired power plant projects produced, constructed, and put into commercial operation by A-GROUP in China from 2010 to 2020. The data contains the project name, the installed capacity size, the commercial operation time (if a project has more than one unit, the time the last unit is used), and the technical route; they are listed in order of time.

Analysis of A-GROUP boiler parameters strategy

The coal-fired power station projects built by A-GROUP show a trend of gradually increasing water vapor parameters and installed capacity from 2010 to 2020, which is the most effective way to increase the thermal cycle efficiency. The most direct advantage of increasing the thermal cycle efficiency of boilers is that per unit of standard coal can produce more energy, which meets the ECER policy from the energy production source. Any boiler design and manufacturing company should treat it as one of the most important long-term goals to increase its products' water vapor parameters and unit capacity by R&D methods. A-GROUP meets this requirement, and therefore, A-GROUP's scientific and technological strategy in terms of water vapor parameters and installed capacity as a long-term strategy for the company is proactive, ethical, and sustainable.

Analysis of the A-GROUP boiler selection strategy

The Π-boiler and the tower boiler have their characteristics and are widely used worldwide for high-parameter and high-capacity boilers. The main advantage of the Π boiler is its relatively simple, compact structure, resulting in a low steel frame and low installation and maintenance costs. Π boilers have an exhaust port below the boiler, which facilitates the installation of air supply and dust removal equipment. The main disadvantages of the Π boiler are its large footprint and the fact that it has two 90° turns inside the boiler. These two turns lead to an uneven flue gas velocity, temperature, and density distribution within the boiler, further leading to localized wear on the heating surfaces. Π boilers have the problem of difficulties in arranging the coal economizer and air preheater on the tail heating surface due to the similar height of the combustion chamber and the tail flue, which is not conducive to the combustion of poor-quality coals, [49].

The main advantage of the tower boiler is that the convection heating surfaces are all arranged in the flue above the combustion chamber. This structure does not have a corner, so the flow rate, density, and temperature of the flue gas in the convection heating surface can be easily predicted by thermal calculations with little error in actual operation. The height of the combustion chamber and the height of the tail flue of the tower boiler are asymmetrical, making it the best choice for boilers burning lignite and lean coal. In addition, the boiler's flue has a self-ventilation function, and the resistance to flue gas transfer is low. The main disadvantage of the tower boiler is the significant height of the boiler itself and the high cost of installation and maintenance. The second is that the air preheater, coal economizer, and other equipment are installed at the top of the boiler, which is initially high. This type of installation places higher demands on the load-bearing capacity and stability of the overall structure. For boiler design and manufacturing units, load calculations are more complex, boiler steel requirements are higher, and the production and material costs of building the boiler are higher.

Considering the poor quality of China's indigenous coal and the need for mixed combustion of coal and biomass, which the Chinese government requires. Traditional coal-fired boilers in China need to ensure the efficiency of coal-fired power generation while balancing stability when burning poor-quality fuels. Once energy policies have been adjusted, boiler companies can retrofit existing boilers more quickly and easily. This is why Japan, the US, and the former Soviet Union chose Π boilers based on more stable coal quality. In contrast, some European countries with mixed combustion requirements chose tower boilers. A-GROUP's ability to anticipate policy is demonstrated by the fact that it started to transform its products at the beginning of the Twelfth Five-Year Plan to meet the requirements for mixed combustion of biomass and coal during the Thirteenth Five-Year Plan. From a corporate efficiency perspective, A-GROUP spontaneously changed its strategy to produce a less economical solution in the short term when other competitors opted for the lower cost Π boiler. This corporate strategy demonstrates that the management team has courage and policy foresight. In conclusion, as a long-term corporate strategy, A-GROUP's boiler selection strategy is positive, ethical, and sustainable.

Analysis of A-GROUP's boiler denitrification emission technology strategy

A-GROUP is gradually adding a compound air classification low NOx tangential combustion system with a tail thermoregulation baffle to the company's product. The compound air classification low NOx tangential combustion system is a particular type of boiler fuel combustion. The system splits the combustion zone of the boiler into several zones. Firstly, under superoxide conditions, 75% of the fuel is fully combusted in the main combustion zone. Afterward, the remaining fuel is fed into the upper part of the main combustion zone. After the remaining fuel is fed, the fuel/oxygen chemical equivalent ratio is less than one, creating a reducing atmosphere. The remaining fuel reacts with the NOx generated in the main combustion zone to produce N2, reducing NOx emissions. The technology requires boiler design and manufacturing companies with solid boiler modification calculation capabilities. Companies can achieve higher NOx emission standards at relatively low development costs and with as few modifications to existing products as possible. Therefore, A-GROUP's development of low NOx tangential combustion technology as a short-term strategy for the company is in line with proactive, ethical, and sustainable requirements.

Unfortunately, with the introduction of the Thirteenth and Fourteenth Five-Year Plans, NOx emission requirements have become more stringent, and A-GROUP's low NOx tangential combustion technology can no longer meet the policy requirements. The leading boiler flue gas denitrification technologies are selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR), [50]. SCR has high denitrification efficiency and low reaction temperatures, but more complex catalysts and increased R&D and equipment retrofit costs. The main denitrification strategy chosen by A-GROUP for its current boiler products is SNCR technology. This technology does meet the latest emission standards, but the higher flue gas temperatures lead to lower boiler thermal cycle efficiency. Instead of explaining the progress of our SCR technology development, A-GROUP has identified additional opportunities in SNCR technology. The higher temperature leads to a worse corrosion rate of the flue piping, which should have been replaced on a five-to-ten-year cycle, and now needs to be replaced on a two-to-three-year basis. A-GROUP has reacquired the flue piping line, which had been outsourced to a contractor, to generate a high profit for the company. Therefore, A-GROUP's developing SNCR technology as a short-term strategy for the company is extremely unethical, unsustainable, and not conducive to developing the country's ECER policy shown in Table 6.

4.2.2 A-GROUP Boiler Technology CP/CI Analysis

A side-by-side comparison of boiler parameters of other boiler design and manufacturing companies in Europe and Japan can more accurately determine the competitive position of A-GROUP's current technology for mastering ultra-supercritical coal-fired generating units.

A-GROUP's ultra-supercritical coal-fired unit technology reached global leadership by 2015 when A-GROUP began its research and development of this technology in around 2000 and 15 years before the Guodian Taizhou project went into operation. The current competitive position of A-GROUP's UCSG technology is therefore shown in Figure 6.

Table 6. Data of Major Ultra-Supercritical Units in Operation Worldwide

Project Name	Country	Capacity (MW)	Pressure (MPa)	Temperature (℃)	Operation Date
Sodegaura	Japan	1000	24.6	538/566	1979.08
Matsuura	Japan	1000	24.6	538/566	1990.06
East Ogishima	Japan	1000	24.6	538/566	1991.03
Matsuura	Japan	1000	24.6	593/593	1997.07
Misumi	Japan	1000	25.0	600/600	1998.06
Tachibana	Japan	1050	25.5	600/610	2000.12
Staudinger	Germany	500	25.0	540/560	1992
Lippendorf	Germany	933	26.7	554/583	1999
Niederaubem	Germany	965	26.9	580/600	2000
Hessler	Germany	700	30.0	580/600	2000
ALSTOM	France	1300	24.2	538/538	-
ALSTOM	France	1300	25.4	538/538	-
ALSTOM	France	930	26.0	550/580	-
Guodian Taizhou	China-SBW	1000	31	600/610	2015.09
Shenneng Pingshan II	China-SBW	1350	26.15~29.30	603/623	2020

Fig. 6: The competitive position of A-GROUP's ultra-supercritical technology

4.3 Farming Contribution to the Energy Sector

Biomass energy is another way to solve the global energy problem. The country is predominantly agricultural, with abundant biomass energy resources in rural areas. As early as 2001, to cooperate with the Pilot Program on Ethanol for Vehicle Gasoline issued by the State Planning Commission, the country carried out experiments using surplus grain stocks to simultaneously produce fuel ethanol in some pilot areas. The conversion efficiency of this method is low, and it cannot effectively recycle the straw and other wastes produced in grain production, [51]. In 2005, the Renewable Energy Law introduced the idea of "efficient development and utilization of biomass fuel, biomass fuel in line with national standards into the fuel sales system." This idea considers the requirement of direct biomass combustion and subsidizes farmers through marketizing biomass fuel. During the eleventh Five-Year Plan period, the government gradually refined the criteria for biomass fuel utilization, including the direct combustion of straw and forest matter for power generation and the incineration of waste for landfill power generation. Under the promotion of the government, biomass power generation installation increased rapidly. In 2021, the cumulative installed capacity of biomass power generation in the country was 37.98 million kW, an increase of 27.67 million kW compared with 2015, with a CAGR of 20.48%. Biomass generation increased from 52.7 billion KWH in 2015 to 163.7 billion KWH in 2021, reaching a CAGR of 17.58%. The share of biomass power generation in the total electricity generation increased from 0.92% in 2015 to 2.02% in 2021, an increase of 1.1 percentage points in seven years, [52].

The development of biomass energy requires the joint efforts of both biomass production end and biomass use end. For farmers at the production end and biomass recycling and processing enterprises, the government put forward a variety of financial subsidy policies during the fourteenth Five-Year Plan period, including biomass energy electricity price subsidy, investment, and construction cost subsidy, clean energy heating subsidy, straw total utilization subsidy, loan subsidy, and local policy extra subsidy. For using biomass energy, the government has gradually adjusted and tightened the requirements for biomass fuel combustion within ten years. During the twelfth Five-Year Plan period, the application of biomass fuel was mainly through the transformation of traditional coal-fired boilers into biomass fuel boilers or mixed combustion. During the thirteenth Five-Year Plan period, with the improvement of the biomass industry chain, the policy was adjusted to form large-scale biomass power generation in counties and rural areas to replace traditional coal-fired power generation. At the same time, investments in clean-burning biomass and clean-heating technologies have begun to increase, positioning biomass fuels for widespread use in municipal heating in the country. During the fourteenth five-year period, emission standards for biomass combustion were further regulated.

5 Findings and Conclusions

The political authorities of the country's ECER policy have evolved from being able to rely only on crude administrative orders to now having specific control targets for each province, city, and type of enterprise. It has gradually changed from the simple idea of energy saving to energy structure reform and industrial reform and has set carbon emission targets for decades.

The ***economic instruments*** of the country's ECER policy have gradually increased from the policy of fines at the beginning to a combination of financial incentives and cash penalties. In recent years it has gradually approached the advanced market-based thinking of the international community. The self-regulation of 40% of the country's energy-consuming enterprises has been achieved through multi-provincial and multi-industry energy and emissions trading and mandatory administrative measures. The ***legal protection*** of ECER policies has been adjusted from the initial state, where the central government was solely responsible for policy formulation, implementation, and supervision. Through legislative and judicial improvements, the power to supervise the implementation of policies has now been passed to county-level energy bureaus and people's governments. This has significantly improved the efficiency of policy transfer and the degree of completion of implementation. The ***R&D and technology*** for ECER policies have gone from a free rein for enterprises to conduct R&D based on emission targets in the beginning to a complete guidance and incentive system. The technological route has gradually shifted from energy conservation to low carbon, and the R&D and accumulation of renewable energy technologies have achieved remarkable results. The ***social and environmental aspects*** of ECER policies in the country have been relatively under-appreciated. Still, with the improvement in education and national quality, the grassroots have become more aware of and supportive of energy conservation and emission reduction efforts.

After 20 years of technology accumulation, A-GROUP's ultra-supercritical power generation technology and circulating fluidized bed technology have gained absolute technological superiority within boiler manufacturing companies worldwide. A-GROUP's boiler selection efforts demonstrated the management's excellent policy foresight and ability to implement policies regardless of short-term interests. However, A-GROUP has made mistakes in the choice of technology route between SCR and SNCR, resulting in a short-term strategy that is unethical and not sustainable for the company. Although the country's farmers play a singular role in ECER policies, the simple and repetitive nature of their work does have an impact on the country's route to energy reform in rural areas. The policy shifted from retrofitting boilers for coal-biomass combustion to the direct replacement of coal by biomass in biomass-producing areas within the decade of the 12th to 14th Five-Year Plan. The share of biomass in thermal power generation in rural areas has been increasing annually.

6 Recommendations and Limitations

The ECER policy should include an industrial upgrading effort for the coal industry. The country is approaching the carbon emission peak and should consider reducing the proportion of coal-fired power generation from the perspective of primary energy consumption. Specific strategies could include limiting the amount of domestic coal mining, reducing subsidies to the coal industry, and controlling coal imports. It should also increase financial investment in distributed renewable energy for individual customer subsidies and scientific research and development. Distributed renewable energy is a global trend in the energy route. It just reached the inflection point in 2020 when the growth rate of distributed renewables exceeded that of centralized renewables. The country should complete the technology shift before centralized renewable energy construction in the west nears saturation. For A-GROUP, companies should review the ethical and sustainability requirements of other low pollutant emission technology routes in their businesses while adapting SCR and SNCR technology routes. Companies can also take advantage of the rising trend of biomass fuel use in rural areas to continue their corporate transformation to provide circulating fluidized bed technology and services to rural areas and to act as an information bridge between farmers and the government. This study applies a significant amount of comparative analysis to overcome the inaccuracy of purely supervisory analysis. However, as coal-fired power generation and boiler-related technologies are no longer the focus of R&D in developed countries, all conclusions obtained from the study regarding the competitive position of technologies, the strength of technology targets, etc. are relative to developed countries being at their peak carbon emission stage in the last century. All readers of this study should be fully aware of the gap between the country's energy development and that of the developed world, rather than being optimistic about the positive conclusions drawn from the study.

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Conflict of Interest

The authors have no conflicts of interest to declare.

APPENDIX

Table 1. Major policies and indicators in the initial establishment phase of ECER track

Sector	Year	Policy Document	Summary of Priority Tasks
Energy Conservation	1980	Report on Strengthening Energy Conservation Efforts	Reduce oil consumption by compressing. unreasonable oil burning; conserve coal, fuel oil, and coke and save electricity; reduce self-use and losses in the energy production sector.
	1981	Implementation Measures of the Fuel Price Increase Charge for Excess Consumption	Supplement energy-saving costs by increasing charges for excess fuel consumption.
	1984	Outline of China's Energy Conservation Technology Policy	Vigorously carry out energy-saving technology renovation; strengthen energy management and improve the energy-saving management system; develop energy-saving services.
	1986	Interim Regulations on Energy Conservation Management	Improve energy-saving technology policies; adopt supportive policies for energy-saving technology transformation; speed up the development of energy-saving regulations, standards, and norms; gradually establish energy information systems.
Environmental Protection	1982	Provisional measures for the collection of sewage charges	Specify the standards and targets for sewage charges and fully implement sewage charges
	1989	Rules for the implementation of the Law of the Country on the Prevention and Control of Water Pollution	Carry out work on water environmental protection and adopt countermeasures and measures to prevent and control water pollution.
	1990	The decision of the State Council on Further Strengthening Environmental Protection	Take effective measures to prevent and control industrial pollution by the law; actively carry out comprehensive urban environmental improvement work; develop ecological protection science and technology.
	1991	Rules for the Implementation of Air Pollution Prevention and Control of the Country	Accelerate the Prevention and Control of Soot-Tyle pollution; put forward higher requirements and targets for the prevention and control of air pollution.
	1994	China Agenda 21 – White Paper on Country's Population, Environment and Development in the 21st Century	Rational use of resources and protection of the environment to reduce the hazards caused by environmental pollution.
Sector	**Year**	**Indicators**	**Implementation Measures**
Energy Conservation	1980-1982	Average annual energy savings of 40 million tonnes of standard coal.	Compression of industrial boilers and kilns burning oil, conservation of electricity, conservation of refined oil, protection of coal for industrial boilers, and development of rational energy use for coal washing and processing.
	1981	Penalty for excess fuel consumption.	A 50% markup fee is charged to enterprises whose fuel consumption exceeds a fixed amount as a supplement to the cost of energy-saving measures.
	1983	Energy saving technology loan subsidy.	The annual interest rate on investments in energy-saving infrastructure funded by the treasury was reduced from 5% to 2.4%.
Emission Reduction	1982	Penalty for excess emissions.	Emission charges for pollutants emitted over national standards.
	1989	Emission permits.	Enterprises and institutions that exceed the national or local standards for the discharge of pollutants are granted emission permits after a deadline for treatment.

Table 2. Major Policies and Indicators in the Development & Adjustment phase of ECER

Sector	Year	Policy Document	Summary of Priority Tasks
Energy Conservation Management	1997	Law of the People's Republic of China on Energy Conservation	Set energy conservation standards and energy consumption limits. Eliminate outdated and high energy consumption products; reduce energy consumption per unit of output value and unit of products; and improve energy development, processing, and supply.
	1999	Measures for the Administration of Energy Conservation in Key Energy-using Units	Strengthen the energy conservation management of critical energy-using units, improve energy use efficiency, and control total energy consumption.
	2006	The decision of the State Council on Strengthening Energy Conservation Work	Adhere to the development and conservation policy, prioritize protection, and vigorously promote ECER.
	2007	Notice of the State Council Approving the Implementation Plan and Measures for Statistical Monitoring and Assessment of ECER	Effectively carry out the work of ECER statistics, monitoring, and assessment.
Energy Planning	1995	Outline of the Development of New and Renewable Energy Sources for 1996-2010	Develop and promote clean energy by local conditions, strengthen scientific research and demonstration of new and renewable energy, and promote industrialization.
	2004	Draft Outline of Medium and Long-Term Energy Planning	Adjust and optimize the industrial structure; promote technological, institutional, and management innovation.
	2007	The Eleventh Five-Year Plan for Energy Development	Accelerate renewable energy development, promote resource conservation and environmental protection, and actively respond to global climate change.
Pollution Prevention and Control	2002	Law on the Promotion of Cleaner Production	Promote and implement cleaner production and encourage the development of cleaner production technologies.
	2003	Regulations on the Administration of the Collection and Use of Sewage Charges	Strengthen the supervision and management of sewage charge collection.
	2004	Law on the Prevention and Control of Environmental Pollution by Solid Waste (Newly Revised)	Preventing and controlling solid waste pollution and strengthening environmental enforcement means.
Sector	**Year**	**Indicators**	**Implementation Measures**
Energy Conservation	2006-2010	Reducing energy consumption per unit of GDP.	Decrease from 1.22 tonnes of standard coal in 2005 to less than 1 tonne of standard coal, a reduction of around 20%.
Emission Reduction	2006-2010	Reduce sulfuric dioxide emissions.	Sulfuric dioxide emissions were reduced from 25.49 million tonnes in 2005 to 22.95 million tonnes, around 10%.
		Reduce chemical oxygen demand.	Chemical oxygen demand (COD) reduced from 14.14 million tonnes to 12.73 million tonnes, around 10%.
		Increase the rate of urban sewage treatment.	No less than 70%.
		Increase the total utilization rate of industrial solid waste.	No less than 60%.

Table 3. Major policies and indicators in the Transformation phase of China's ECER track

Sector	Year	Policy Document	Summary of Priority Tasks
Policy Reform	2008	Law on Energy Conservation	Establish a market mechanism for ECER; improve implementation policies; and strengthen management and assessment.
	2014	Government Work Report	Increase ECER efforts; control total energy consumption; increase the proportion of non-fossil energy generation; develop clean production, green, low-carbon technologies, and a circular economy.
	2016	Comprehensive Work Plan for ECER in the 13th Five-Year Plan	Optimize industrial and energy structures, strengthen energy conservation in key areas, enhance emission reduction of major pollutants, and strengthen technical support and service system construction for ECER.
Energy Strategy	2008	Eleventh Five-Year Plan for the Development of Renewable Energy	Guide the development and use of renewable energy and direct the development of the renewable energy industry.
	2014	Strategic Action Plan for Energy Development 2014-2020	Promote the clean and efficient development and use of coal, strictly control the excessive energy consumption growth, and vigorously develop renewable energy.
Low Carbon Development	2007	Country's National Programme to Address Climate Change	Adhere to the principle of equal emphasis on mitigation and adaptation, control greenhouse gas emissions, and strengthen scientific research and technology development on climate change.
	2011	Work Plan for Controlling Greenhouse Gas Emissions in the 12th Five-Year Plan	Make extensive use of various means, such as optimizing energy structure and increasing carbon sinks. Carry out low-carbon pilot projects; strengthen the research and development and application of low-carbon technologies; accelerate the establishment of an industrial system characterized by low carbon; and improve the ability to cope with climate change.
Sector	**Year**	**Indicators**	**Implementation Measures**
Energy Conservation	2011-2015	Reducing energy consumption per unit of GDP	Adjusted from a reduction of around 20% in the 11th Five-Year Plan to a decrease of 17%.
		Reduce water consumption per unit of industrial value-added	Reduction of 30% (not adjusted).
		Reduce energy consumption per unit of industrial value-added	Reduction of 18% (new).
Emission Reduction	2011-2018	Reduce carbon emissions per unit of industrial increase	Reduction of more than 18% (new)
		Reduce chemical oxygen demand, carbon dioxide (old), ammonia nitrogen, and nitrogen oxide (new) emissions	Add two new categories with a total reduction of 8 to 10%.
		Increase the proportion of non-fossil energy in primary energy consumption.	Add two new categories with a total reduction of 8 to 10%.
		Increase the proportion of non-fossil energy in primary energy consumption.	Increase by 3.1 percentage points from 8.3% to 11.4% (new)
		Increase the comprehensive utilization rate of industrial solid waste	Adjusted from no less than 60% in the 11th Five-Year Plan to no less than about 76%.

Table 4. Major policies in the Carbon Emissions Peak & Neutrality phase of the Country's ECER track

Sector	Year	Policy Document	Summary of Priority Tasks
Energy Mix	2017	Energy Production and Consumption Revolutionary Gold Strategy (2016-2030)	Clarify the strategic objectives of the energy revolution and promote the clean-up of fossil energy and the energy consumption revolution.
	2021	Opinions on the Complete and Accurate Implementation of the New Development Concept for Carbon Neutrality	Clarify the targets and implementation plans for the "double carbon" initiative and promote energy conservation and recycling.
	2021	Action Plan for Carbon Peaking by 2030	Identify the critical tasks to achieve peak carbon and promote carbon compliance actions.
Carbon Trading and Green Finance	2016	Guiding Opinions on Building a Green Financial System	Support the green transformation of the country's economy by developing financial products and services, implementing relevant policy instruments, and building a better green financial investment environment.
	2017	National Carbon Emissions Trading Market Construction Programme (Power Generation Sector)	Accelerate the construction of a carbon trading market, expand the scope of market coverage, and enrich the variety and trading methods.
Low Carbon Tech	2020	Proposal of the Central Committee on the Formulation of the 14th Five-Year Plan for National Economic and Social Development and the Visionary Day Target for 2030	Adhere to green and low-carbon development principles and promote research and development of green and low-carbon technologies.

Table 5. A-GROUP Major Construction Projects 2010-2020

Project Name	Project Type & Capacity	Business Operation Time	Technology Route
Huadian Luohe	Two 330MW sub-critical coal boilers	29 May 2010	Π arrangement solution, tangential combustion system
Tianji II	Two 660MW ultra-supercritical п-type boilers	28 April 2014	Π arrangement, compound air classification low NOx tangential combustion system
Guodian Taizhou II	Two 1000MW secondary reheat ultra-supercritical tower boilers.	13 January 2016	Tower arrangement, combined air classification low NOx tangential combustion system, tail baffle temperature control.
Shenneng Pingshan I	Two 660MW ultra-supercritical tower boilers	30 March 2016	Tower arrangement, combined air classification low NOx tangential combustion system
Anuhui Banji	Two 1000MW ultra-supercritical DC п-type boilers	17 October 2016	Π arrangement, combined air classification low NOx tangential combustion system
Inner Mongolia Hangjin	Two 330MW subcritical circulating fluidized bed boilers	1 January 2017	Wide range of coal types, high reliability, high combustion efficiency, low NOx emissions, wide range of steam temperature regulation, uniform bed temperature, low wall temperature deviation, low plant electricity consumption, and easy maintenance.
Jiangsu Shazhou II	Two 1000MW ultra-supercritical tower boilers.	21 September 2017	Tower arrangement scheme, compound air classification low NOx tangential combustion system
Guoyue Shaoguan	Two 350MW ultra-supercritical circulating fluidized bed boilers	10 November 2017	Safe and reliable hydrodynamics, high boiler efficiency, low cost to achieve ultra-low emissions, uniform wall, and bed temperature, no deformation and wear of the furnace screen, no slag leakage from the air cap, and large proportion of poor-quality fuels such as coal slurry and gangue can be blended.
Guoxin Zhundong	Two 660MW supercritical pressure unit tower boilers	27 January 2018	Tower arrangement, compound air classification, low NOx tangential combustion system
Guangdong Yangxi II	Two 1240MW ultra-supercritical tower boilers	1 February 2018	Tower arrangement, compound air classification low NOx tangential combustion system, tail baffle temperature control
Guodian Suqian	Two 660MW ultra-supercritical secondary reheat tower boilers.	March 2019	Tower arrangement, combined air-graded low-NOx tangential combustion system, flue gas recirculation with tail baffle.
Shenneng Pingshan II	One 1350MW secondary reheat ultra-supercritical tower boiler.	August 2020	Tower arrangement, combined air classification, low NOx tangential combustion system, tail baffle.