China Council for International Cooperation on Environment and Development (CCICED)

Low-carbon Transition of Traditional Energy Regions in China

——A Case Study of the Coal Triangle Area

CCICED Scoping Study Report

CCICED

October 2024

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Executive Summary

1. **The transition to move away from fossil fuels has become a shared responsibility of governments and the international community. The regional differences in energy distribution are significant factors influencing the realization of energy transition.** The use of fossil fuels is one of the main reasons for the intensification of global climate change, and achieving the long-term temperature control goal of 1.5° C set out in the Paris Agreement requires sustained efforts to reduce emissions. The 28th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP28) explicitly stated that countries must "transition away from fossil fuels in a just, orderly, and fair manner within the energy system," and proposed that global renewable energy installed capacity be tripled by 2030 compared to 2022, accelerating the shift from fossil fuels to renewable energy. At the same time, COP28 pointed out that regional differences in energy distribution are important factors affecting the realization of energy transition.

2. **This project first proposes the concept of China's Coal Triangle Area. Studying the low-carbon transformation of this region is of great significance for promoting the energy transition of China and even the world.**The Coal Triangle Area encompasses four provinces: Inner Mongolia, Ningxia, Shaanxi, and Shanxi. It is an important energy and coal base in China, rich in coal resources. In 2023, the coal production in these four provinces reached 1.21 billion tons, 100 million tons, 760 million tons, and 1.38 billion tons respectively, accounting for 74% of the national raw coal output. The Coal Triangle Area is a typical, and perhaps the only large-scale coal energy cluster in China. It has long been developing an economic development and industrial model that is overly dependent on coal resources. The total carbon dioxide emissions, per capita carbon emissions, and carbon intensity of the four provinces of Inner Mongolia, Ningxia, Shaanxi, and Shanxi are all among the top in the country. Under China's strategy for peaking carbon emissions and achieving carbon neutrality, the Coal Triangle Area faces enormous challenges but also a rare strategic opportunity. Conducting research on energy transition and industrial upgrading in the Coal Triangle Area can provide extremely valuable experience for traditional energy regions both nationally and globally.

3. **Research on the energy transition in the Coal Triangle Area plays a significant role in changing the regional development in a sustainable and coordinated way and promoting a just transition.** The Coal Triangle Area has long been over-exploiting and relying on coal resources, facing environmental pollution and resource depletion issues. During the transition process, the fairness issue has not been given enough attention. Therefore, this project studies the energy transformation in the coal triangle area, and formulats relevant strategic plans, supporting policies so as to facilitate the energy and industrial transition, regional economic and social development in the Coal Triangle Area, and provide a viable path to achieve regional equity, ecological equity, and employment equity in the area.

4. **Based on the China's medium- and long-term emission pathway model (CAEP-CP 2.0), a "black energy—blue energy—green energy" energy transition path has been established for the Coal Triangle Area.** Utilizing the medium- and long-term emission pathway model

(CAEP-CP 2.0) developed by the project team, and taking into account data such as resource endowment, energy production, energy consumption, inter-provincial power exchange, and power grid planning within the triangle area, the potential of renewable energy in the Coal Triangle Area is scientifically assessed. A pathway for energy transition in the Coal Triangle Area is established under the constraint of carbon dioxide emission targets, promoting the transition of the Coal Triangle Area from "black energy (current status)—blue energy (by 2035)—green energy (by 2060)."

5. **Propose the industrial transition direction for the Coal Triangle Area under the withdrawal of traditional coal industry and the integrated development of new energy.** Under the constraints of the "dual carbon" goal, based on the current industrial status, international and domestic experiences, and the latest research progress, analyze the green and low-carbon transition of coal-related industries and the integrated development transition direction of new energy industries in the Coal Triangle Area. Explore the integrated development model of industrial energy, and rely on regional advantageous resources such as new energy resources and manufacturing elements to comprehensively analyze dimensions including new energy equipment manufacturing, new energy power consumption, hydrogen energy-storage, CCUS, etc. Propose the upstream and downstream industrial system of the "wind and solar plus" industrial chain within the area to provide technical guidance for the energy transition of the Coal Triangle Area.

6. **Identify new opportunities for coordinated development of regional equity, employment equity, and ecological equity in the energy transition path of the Coal Triangle Area.** The study is based on the concept of achieving regional economic and regional coordinated development, analyze the opportunities for regional economic development brought about by the energy transition and the industrial transition of the Coal Triangle Area. It combines the relationship between energy transition and industrial transition with rural revitalization, identifies new opportunities for development from the perspective of equitable transition, including regional equity, employment equity, and ecological equity, and proposes policy recommendations to ensure equitable transition.

7. **Establish a national-level coordination mechanism for the low-carbon transition in the Coal Triangle Area, paving the way for the low-carbon transition of China's fossil fuel gathering areas within the grand scheme of a unified national strategy, and establishing systems and regulations.** It suggests to set up a leading group for the low-carbon transition of the Coal Triangle Area and establish an integrated transition collaboration mechanism for the Coal Triangle Area. Rationally determining the functional positioning of the Coal Triangle Area in the national strategy for peaking carbon emissions in stages, fully considering national energy security and demand, clarifying the national demand for coal and coal-fired power transmission from the Coal Triangle Area, establishing a coal production reserve system, and introducing preferential policies to encourage new energy power generation and green channels for grid acceptance, incentivizing non-fossil fuel power generation. Optimize the timetable, roadmap, and assessment methods for peaking carbon emissions in the Coal Triangle Area. At the same time, fully consider the impact and effects of the low-carbon transition of traditional energy on vulnerable groups, employment, and ecology, and explore the establishment of a just transition mechanism. Encourage the Coal Triangle Area to establish communication channels with

international coal areas, leading the global low-carbon transition of coal areas.

8. **By leveraging the collective strength of the entire Coal Triangle Area, establish a "Zero-Carbon Power Industry and Trade Special Zone" to provide "Zero-Carbon Power" certification for export-oriented enterprises, using the spillover effects of the special zone to drive a breakthrough transition of the Coal Triangle Area's industries.** It recommends that the Coal Triangle Area fully establish a "Zero-Carbon Power Industry Trade Special Zone" (referred to as the "Zero-Carbon Special Zone") mechanism, utilizing its vast land, large-scale new energy capacity, and the flexible complementary potential advantages with fossil fuels. Exploit the new business model of regional microgrids to ensure a long-term continuous supply of zero-carbon power for the special zone, and provide preferential import/export tax policies to attract export-oriented enterprises to settle in the "Zero-Carbon Special Zone". The internal construction of the "Zero-Carbon Special Zone" includes a zero-carbon digital certification system that provides full life cycle carbon footprint certification for products, endowing products within the park with traceable, internationally standard-compliant "Zero-Carbon Certification" labels. Establishing a "Zero-Carbon Power Industry and Trade Special Zone" is expected to break through the dilemmas of new energy absorption and industrial transition in the Coal Triangle Area, and will help China explore effective ways to address international trade carbon regulations.

9. **Establish a Low-Carbon Transition Fund for the Coal Triangle Area to leverage regional low-carbon transition technology upgrades and ensure fairness and justice.** It is suggested to adopt a mixed financing model of "government-guided fund + venture capital/equity investment institutions + corporate investors", providing capital at favourable prices through public and international development capital to drive private capital that offers funds at market prices. The catalytic capital consists of state-owned capital holding groups from the provinces of the Coal Triangle Area and various green industry funds, while the public capital is composed of coal taxes and government public budget investments, attracting private capital. A financial holding group at the provincial level of the Coal Triangle Area could jointly establish a fund management company responsible for the professional management of the transition fund.

Key words：Coal Triangle Area; China; Low-carbon transition; New energy; Carbon peak and carbon neutrality

Nomenclature

Abbreviation	Annotate
CCUS	Carbon Capture Utilization and Storage
CGE	Computable General Equilibrium
COP28	28th Conference of the Parties to the United Nations Framework Convention on Climate Change
ETS	Emissions Trading System
EGD	European Green Deal
ESR	Effort Sharing Regulation
GIS	Geographic Information System
IEA	International Energy Agency
GDP	Gross Domestic Product
IPCC	Intergovernmental Panel on Climate Change
JTF	Just Transition Fund
LMDI	Logarithmic Mean Divisia Index
UNFCCC	United Nations Framework Convention on Climate Change
SCF	Social Climate Fund

contents

1. Introduction

The China Council for International Cooperation on Environment and Development has established a special policy research project on "Research Project on Low-carbon Transition of Traditional Energy Regions of China" with the Chinese Academy of Environmental Planning and the Environmental Defense Fund serving as the leading units for the project. This project focuses on the green and low-carbon transition in the Coal Triangle Area, while also considering issues of fairness, justice, and energy security during the transition process. It aims to develop strategies tailored to local conditions, formulate comprehensive plans for industrial transition and upgrading, and provide integrated solutions for climate change to support the early and rapid realization of China's dual carbon goals.

2. Research Background and Significance

2.1. Research background

2.1.1. The 28th United Nations Climate Change Conference (COP28) explicitly stated that countries around the world should gradually phase out the use of fossil fuels, and a series of initiatives and alliances on coal phase-out have been reached internationally.

The "United Arab Emirates Consensus" reached at COP28, held from November 30 to December 12, 2023, at the Expo City in Dubai, United Arab Emirates, is widely regarded as a historic milestone. For the first time, this agreement explicitly set a critical goal: countries must transition away from fossil fuels in an equitable, orderly, and fair manner within the energy system. In addition to setting the goal of phasing out fossil energy, the "United Arab Emirates Consensus" also specified the concrete objective of tripling the global installed capacity of renewable energy by 2030. There has been extensive international research on coal phase-out and decarbonization. The United Nations Climate Change Conference (COP28) has become an important platform aimed at assessing and discussing global climate change issues, as well as the actions taken by countries to reduce greenhouse gas emissions, adapt to the impacts of climate change, and provide financial support and technology transfer.

2.1.2. The Party Central Committee attaches great importance to the comprehensive green and low-carbon transition of the economy under the dual-carbon goals, but faces the risk of high-carbon lock-in in traditional industries.

On August 11, 2024, the "Opinions of the CPC Central Committee and the State Council on Accelerating the Green Transition of Economic and Social Development" emphasized that promoting the greening and decarbonization of economic and social development is a key link in achieving high-quality development and a fundamental strategy for addressing China's resource, environmental, and ecological issues. On July 30, 2024, the General Office of the State Council issued the "Work Plan for Accelerating the Construction of a Dual-Control System for Carbon Emissions," signaling the implementation phase of the dual-control system for carbon emissions. China faces a tight timeline and heavy tasks to achieve carbon peak and carbon neutrality, being the country with the shortest time from peak to neutrality, the largest scale of carbon reduction, and the fastest rate of reduction in the world. According to relevant research by the project team, in 2020, China's key industries (including power, steel, cement, and petrochemical industries) had carbon locked in at 196 billion tons, the highest among all countries globally, accounting for 65% of China's carbon budget, posing a significant challenge to the dual-carbon goals. Urgently manage energy infrastructure in advance to avoid high-carbon lock-in, reduce losses from stranded assets, and gradually transition away from coal dependency.

2.1.3. The Chinese Coal Triangle Area (comprising the provinces of Inner Mongolia, Ningxia, Shaanxi, and Shanxi) is the world's largest coal energy concentration area and faces severe transition challenges.

There are significant differences in the geographical distribution of fossil and non-fossil energy resources in China. The Coal Triangle Area, which includes the provinces of Inner Mongolia, Ningxia, Shaanxi, and Shanxi, is rich in coal and new energy resources. In 2023, the coal production in these four provinces reached 1.21 billion tons, 100 million tons, 760 million tons, and 1.38 billion tons respectively, accounting for 74.4% of the country's raw coal production. At the same time, the land area of this region accounts for only about 16.8% of the national total, yet it hosts 28% of the installed wind power capacity and 15% of the installed solar power capacity, indicating a rich potential for wind and solar resources. Faced with severe transition challenges, it is necessary to adopt effective measures to reduce the over-exploitation of coal resources, promote the development of clean energy, reduce greenhouse gas emissions, and enhance the overall level of regional development. Achieving goals such as the clean utilization of fossil energy, the large-scale development of clean energy, the comprehensive utilization of various energy sources, the electrification of end-use energy, and the integration of industrial energy is essential for the sustainable development of energy production.

2.2. Overview of the study area

The Coal Triangle Area occupies 16.8% of the national land area, accounts for 7.48% of the national population (as of 2023) and generated 7.1% of the national GDP (in 2023). In 2023, the national per capita GDP was 89,000 yuan, while the per capita GDP in the Coal Triangle region, except for Inner Mongolia where it was higher than the national average, was 74,000 yuan in Shanxi, 73,000 yuan in Ningxia, and 85,000 yuan in Shaanxi, all of which were below the national average. Therefore, in relative terms, the per capita GDP in Shanxi and Ningxia was 18% lower than the national average.

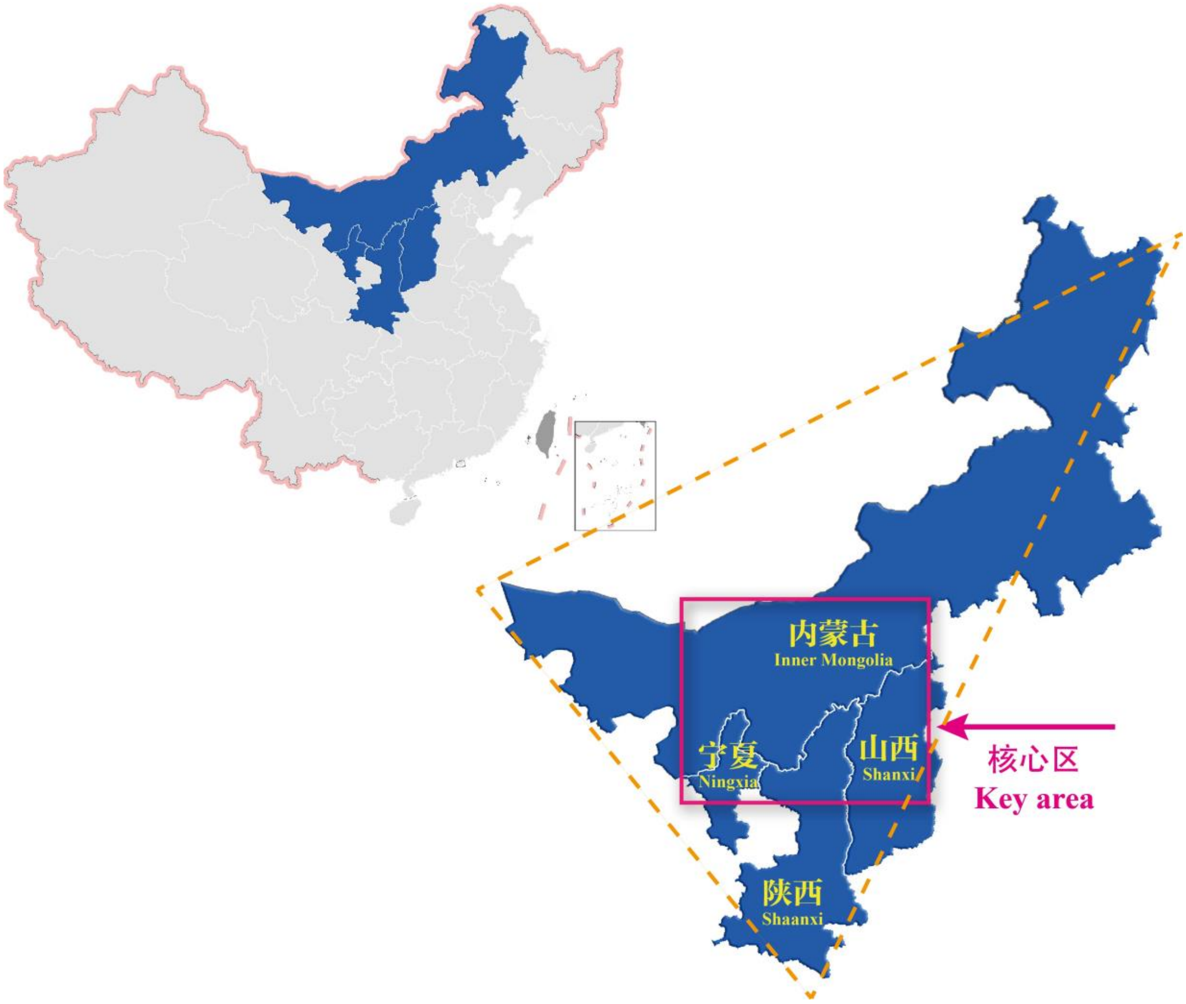

Figure 2-1 Geographical Location Map of the Coal Triangle Area

3. International and Domestic Experiences and Insights on Energy Transition

China is the world's largest producer and consumer of coal, and thus has the highest greenhouse gas emissions related to coal. Coal production is still growing and is expected to peak in 2027. At the same time, China is a world leader in renewable energy production and electric mobility, such as clean energy investment. All this means that the green transition in the country has been a win-win game so far, both as regards its economic and employment effects. The dynamic developments in the green economy came on top of the still growing coal (or in broader sense fossil fuel) driven economy. China was not yet confronted with any potentially negative employment or social effect of the energy transition. This is a major difference when compared to Europe and this is why experiences and practices from Europe – both positive and negative – can be helpful for the upcoming new phase of the energy transition in China.

3.1. Case analysis of international energy transition

The EU has the most comprehensive regulatory framework for the green transition, under the umbrella of the European Green Deal and the related legal implementation packages. This framework combines market mechanisms (like the European Emissions Trading System), regulations, standards, incentives, subsidies and taxes. All this needs to be translated into national legislation by the 27 member states. There is also a lot of policy co-ordination taking place between the EU and the national level. The performance of the EU in terms of greenhouse gas emission reductions is convincing, it has achieved an absolute decoupling of emissions from GDP growth.

Column 3-1 EU Energy Transition

Question:

Fiscal policy: The EU needs to speed up green investment not only to meet its own climate objectives but also to face the challenge of increased international competition for green manufacturing. In 2021, the Commission calculated that, to achieve the EGD objectives, additional investment of 520 billion euros per year would be needed. The average yearly investment need is at least 813 billion euros (5.1 percent of EU GDP) if the 2030 EU climate targets are to be met. Given the current level of investment, the yearly European climate investment deficit is thus estimated at 406 billion euros.

Slow progress in expanding renewable energy generation: The relatively slow progress in renewables development in the EU is also shown by IEA data on renewables capacity additions and energy composition. After stagnation in 2020, renewables generation capacity improved by 20% in 2021. The share of renewable energy in the EU grew from 22% in 2020 to 23% in 2022. The IEA notes that 2020 was an extraordinary year, during which consumption of non-renewables dropped considerably because of lower energy demand during the Covid-19 pandemic, thus pushing up the renewable energy sources (RES) share. In 2021, however, consumption of non-renewables experienced a rapid rebound, although the growth of renewables remained constant.

Fragmentation, complex governance mechanism between the EU and national level: Being a political union, the EU is also a particular construct, not a nation state, not having a federal structure and EU level policies and objectives are implemented through complicated co-ordination mechanisms. Climate and energy policy governance is complex and not always transparent. There is a significant diversity among member states.

Solution:

The EU considers itself as a leader in climate policy, a role model for the rest of the world and a region (continent) with the highest climate ambition. It is also stated in the European Green Deal (EGD) launched in 2019 that the EU is committed to become the first world region to become climate neutral by 2050. This objective is also anchored in the European Climate Law, a part of the EGD. While the EU does not officially acknowledge its responsibility as largest contributor to cumulative global emissions not willing to offer ground for retrospective legal loss and damage claims, in the background, this is one motive for adopting a high ambition decarbonisation strategy.

The EU is the only world region that has a comprehensive and very detailed legislative framework for its decarbonisation agenda. The EGD not only sets targets but has a very detailed and in parts binding implementation framework, known as the 'Fit for 55' legislative package. Europe' climate ambition is anchored in a strong commitment to the UNFCCC Paris targets and in the legislative packages of the European Green Deal. The decarbonisation agenda is not a foggy vision of a climate enthusiast elite, it is a political and economic reality. This policy-driven process is fundamentally reshaping economic activity (production, consumption, mobility, trade and investment). Policy instruments include a delicate balance between market mechanism, regulation, standard setting, incentives, taxes, levies and tariffs.

According to the European Green Deal and the ‘Fit for 55’ legislative package, by 2030 greenhouse gas emissions across the EU27 should be reduced by 55% from 1990 levels: this would enable climate neutrality to be achieved by 2050, as laid down in the European Climate Law. There are no uniform GHG reduction targets for Member States, but the Effort Sharing Regulation (ESR) sets binding targets on each Member State to cut greenhouse gas emissions in sectors not covered by the Emissions Trading System (ETS), such as transport, agriculture, buildings and waste – which together are responsible for 60% of the EU’s greenhouse gas emissions.

Effect:

Based on Eurostat data, tracking how individual member states have reduced their GHG emissions by 2021, taking into account total GHG emissions in UNFCCC reporting format, including LULUCEF.[1] Across the EU27, 2021 net emissions had fallen by 30.4% from 1990 levels. However, the data reveal significant variation among Member States. The three best performers are Sweden, Romania and Lithuania with GHG reductions of 76%, 71% and 67% respectively.

Among main world regions, the EU has managed to cut GHG emissions most and delivered also in absolute decoupling of emissions from GDP growth. Greenhouse gas emissions and GDP trends in the 27 EU countries illustrates that it is possible to decouple trends in GHG emissions from GDP. EU27 GDP grew by 50% over this 26-year period, while GHG emissions fell by 23.6%. When considering the various drivers of this reduction, it is important to note that fuel combustion made up 75.4% of total

[1] LULUCEF stands for ‘land use, land-use change and forestry’: this encompasses the management of cropland, grassland, wetlands, forests and settlements and includes land-use change such as afforestation (planting trees). Currently, the EU land-use sector absorbs more greenhouse gases than it emits, but the difference between GHG reductions with or without LULUCEF is not significant at EU27 level. LULUCEF has played a major role in emissions reductions in a number of Member States, such as Sweden, Lithuania and Latvia.

EU27 emissions in 2021. Eurostat points to two main factors behind emissions reductions: energy efficiency improvements and changes in the energy mix.

Phasing out coal in EU member states. The phase-out of coal in energy generation is gaining momentum throughout Europe. The majority in EU Member States have set up a plan with a deadline by which they are to become coal-free. Phasing out coal in energy generation is an explicit policy target for most Member States. All EU Member States in western Europe other than Germany are planning to phase out coal by 2030 at the latest, with Germany announcing a later deadline of 2038. These 'phase-out countries' have been responsible for almost all the fall in hard coal generation in the last decade. While western Europe is thus on course to phase out coal, for the new Member States in central and eastern Europe the picture is more mixed. Slovakia planned coal exit by 2023 but completes it in 2024 and Hungary is to phase out coal by 2025. Poland took an important first step in September 2020 with an agreement to phase out coal mining by 2049, however a phase-out of coal in energy generation is not currently on the agenda. Meanwhile, Bulgaria (2040), Czechia, Croatia and Slovenia set a date for 2033, while Romania for 2032.

3.2. Case analysis of international just transition

Where EU experiences could be most useful for China is how the EU tries to manage the green transition from a social and labour perspective. When China enters the phase of the transition where to coal based economy will start to shrink and where economic restructuring of regions and companies becomes a great challenge, Europe' practices with 'just transition' can be helpful. Not even the green transition (that serves the common good of humanity) can be forced through against the will of the people. Just transition policies are an integral part of the EU Green Deal. The declared aim is that 'no one should be left behind'. Detailed policies equipped with available resources (although not properly, but this is a part of an internal debate), such as the Just Transition Fund and the Social Climate Fund are mobilized to support and facilitate employment transitions, contribute to the economic diversification of carbon-intensive regions and to address distributional effects of climate policies. The EU also puts great emphasis on the participatory dimension of the green transition. People, stakeholders, trade unions and workers need to be involved in the policy making process, in its implementation and in its monitoring. The EU has also bitterly learned that having a just transition approach is also key to the success of the entire transition.

Column 3-2 International Just Transition
Question: Decarbonisation will have a profound effect on the world of work. In the coming decades, related restructuring processes will be a determining factor, with massive employment and social effects. Another strength of the EU climate policy approach is the recognition that this epochal transition of the entire economy needs to take account of the employment and distribution effects of the process, in other words that this transition needs to be just. From a functional point of view, just transition is interpreted in two main dimensions: ‘outcome’ and ‘process’. The outcome should be an inclusive society in a zero-carbon world with low inequality and quality jobs, whereby the UN Sustainable Development Goals provide guidance. From the ‘process’ perspective, just transition has two main pillars: one that deals with the distributional effects of climate policies and one that deals with the management of employment transitions. The EU approach of just transition has a focus on addressing the effects of decarbonisation related labour market change, including job losses, employment transitions and skills development. A second focus is in dealing with the distributional effects of climate policies including energy and transport poverty, but trying also to make low carbon technologies accessible and affordable to all. The EU also acknowledges the necessity of a strong participatory dimension of the green transformation, the involvement of social partners and the civil society in shaping, implementing and monitoring the transition process at all levels. **Solution:** The European Commission originally designed the Just Transition Fund (JTF) to

provide social support for workers dismissed when mines or related fossil-fuel-based power plants closed, but it was then extended to meet industrial and regional policy objectives. Given the smaller size of the fund approved by the European Council (down from its originally proposed 40 billion euros to 17.5 billion euros), the JTF is clearly no longer a satisfactory means of addressing the restructuring challenges faced by carbon-intensive regions. For comparison, the German government has allocated 40 billion euros to just transition support measures for its coal regions. It is also clear that just transition assistance is needed not only for carbon-intensive regions (mostly producing coal and peat) but also for a much broader range of economic sectors affected by the green transition (e.g. automotive and other manufacturing sectors). The SCF was set up with modest resources, aiming to fend off social effects by the second iteration of the Emissions Trading System (ETS2) for road transport and buildings, and will be operational from 2026. Lately, it has come to be regarded as a general tool for tackling the adverse social effects of runaway energy prices. The 2022 energy and cost-of-living crisis also demonstrated the shortcomings of existing resource allocations, leading the EU to repurpose its most innovative instrument, the Recovery and Resilience Facility, as part of the Next Generation EU plan to support Member States in dealing with its impacts. In the face of a new geopolitical configuration, the EU has also ramped up its industrial policy efforts, launching the Green Deal Industrial Plan and the Net-Zero Industry Act.

In addition, taking Germany (the number one coal burner in Europe) as a case, a cautious, gradual, and consensual way of phasing out coal has been chosen. Germany's coal phase-out applies three main elements of a just transition approach: slow and gradual transition with a high level of social dialogue; active labour transition management; and engagement in industrial and regional development. The Ruhr region in Western Germany used to be one of the most important industrial regions of Europe. The iconic industrial landscape has also become a major example of de-industrialisation and economic diversification throughout the decades and while having kept an industrial backbone, the region's main strength became a knowledge-based services economy. The Ruhr experience also delivers a lesson from point of view of 'just transition'. The economic diversification of the once mining dependent Ruhr region had been actively managed by the federal and regional governments, restructuring processes were embedded in an industrial relations culture marked by the strong role of workers participation. In addition, in 2018, the federal government established the Commission on Growth, Structural Change and Employment to provide recommendations on a gradual reduction of the capacities of existing coal-fired power plants in Germany.

Effect:

The areas where the JTF will be implemented are defined in 'territorial just transition plans', which are agreed during talks with the European Commission. A total of 67 plans covering 93 areas have been approved. Each plan includes an analysis of the anticipated economic and social impacts of the green transition, such as job losses, and of how pollution from production processes will be reduced. To be eligible for the funding allocated under the Just Transition Mechanism, EU Member States were required to negotiate territorial just transition plans for regions identified as likely to suffer negative socio-economic impacts from the transition to a carbon-neutral economy. Apart from Germany, the main beneficiaries are mostly CEE Member States that have relatively low GDP per capita levels, higher carbon intensity and a higher concentration of affected regions.

As a general conclusion, the Ruhr restructuring experience also showed that a complex process of restructuring from a resource intensive industrial base towards a green resource-material and energy efficient economy needs a comprehensive policy framework. Structural and regional policies not only included industrial policy, regional development, urban recreation policies, but education, labour market policies were equally important. Also, The forward-looking element of coal transition policies are the regional and industrial policy initiatives to revitalise coal regions after coal phase-out;

these make up the main strength of the German case.

4. Analysis of the Current Situation of the Coal Triangle Area and the Path to Peak Carbon Emissions

4.1. Current situation analysis

4.1.1. Carbon dioxide emissions

Energy activities account for 93% of total carbon dioxide emissions, with industrial processes contributing 7%. Within energy activities, the power industry has the largest contribution, accounting for 58%, followed by industrial processes at 30%. Breaking down by industrial sectors, steel, petrochemicals, coking, and heating industries also have significant emission contributions. In addition, the transportation and construction sectors contribute 3% and 2% respectively to the carbon emissions from energy activities. Overall, emissions from the industrial sector account for 30% of the total, while emissions from other sectors such as transportation and construction also constitute a considerable portion.

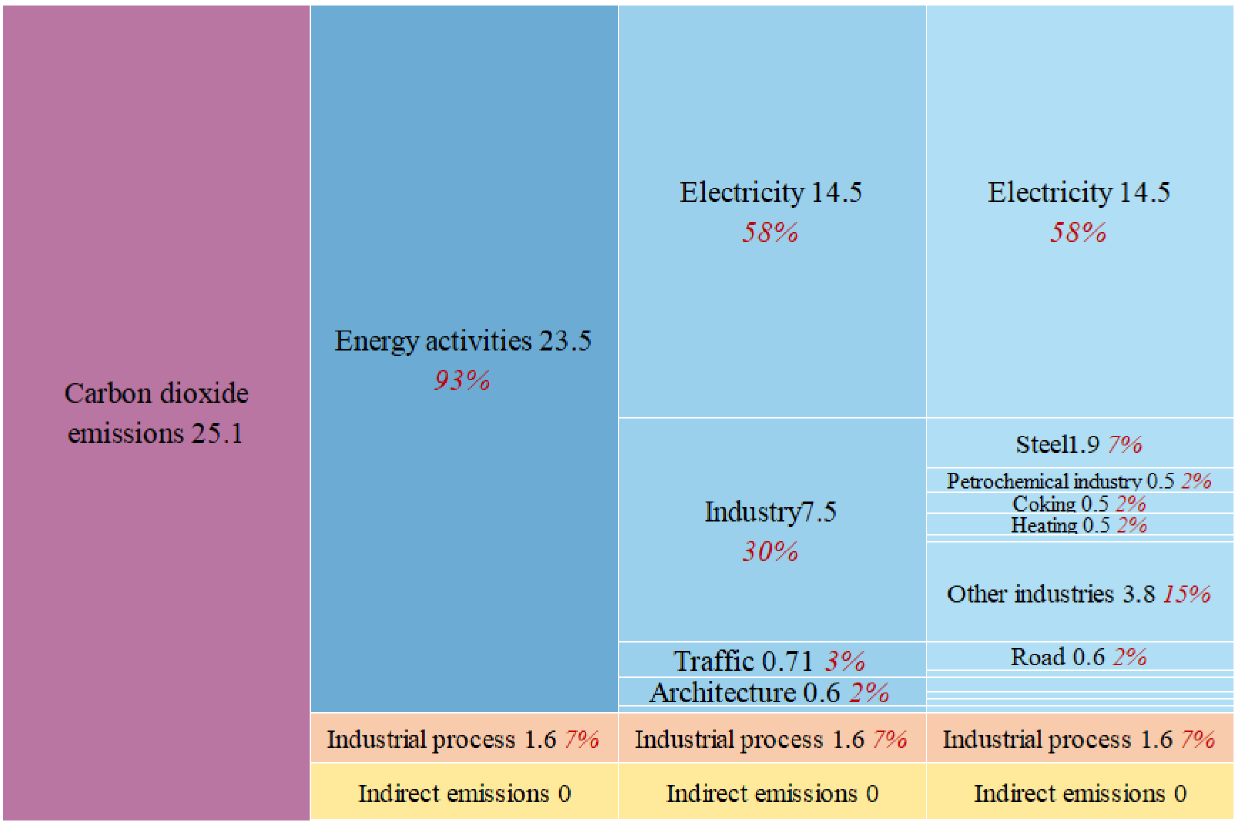

Figure 4-1 2023 Carbon Dioxide Emissions Inventory for the Coal Triangle

4.1.2. Coal production

From 2010 to 2023, coal production in the Coal Triangle Area has generally shown an upward trend. By 2023, the production in the Coal Triangle Area had reached 3.45 billion tons, with Inner Mongolia, Shanxi, and Shaanxi producing 1.21 billion tons, 1.378 billion tons, and 761 million tons respectively. The production from Inner Mongolia and Shanxi accounted for 26% and 29% of the national coal production, while Shaanxi's production accounted for 16% of the national total. Coal production from Ningxia accounted for 2% of the national total. Together, they made up 74% of the national coal production, highlighting the significant importance of the Coal Triangle Area as a national energy supply base.

4.1.3. New energy development

In 2023, the national solar power installed capacity was 610 million kilowatts, and the solar power installed capacity in the Coal Triangle Area was 90 million kilowatts; the national solar power generation in 2023 was 294 billion kilowatt-hours, and the solar power generation in the Coal Triangle Area was 82.3 billion kilowatt-hours. In 2023, the national wind power installed capacity was 440 million kilowatts, and the wind power installed capacity in the Coal Triangle Area was 120 million kilowatts; the national wind power generation in 2023 was 809 billion kilowatt-hours, and the wind power generation in the Coal Triangle Area was 219.8 billion kilowatt-hours. The total national power generation in 2023 was 9,456.4 billion kilowatt-hours, and the total power generation in the Coal Triangle Area was 1,701.9 billion kilowatt-hours.

Therefore, in relative terms, the coal triangle generated 27% of the wind and solar electricity used in China in this year.

Table 4-1 Solar Power Capacity and Generation in the Coal Triangle Area in 2023

Province	Installation volume （ten thousand kW）	Electricity generation （a hundred million kWh）	Total power generation （a hundred million kWh）	Total electricity consumption by society （a hundred million kWh）
Shanxi	2491	275	4376	2885
Inner Mongolia	2296	205	7451	4823

Shaanxi	2292	111	2946	2450
Ningxia	2137	232	2246	1387
Coal Triangle Area	9216	823	17019	11545
Nationwide	60949	2940	94564	92241

Table 4-2 Wind Power Installation and Generation Capacity in the Coal Triangle Area in 2023

Province	**Installation volume （ten thousand kW）**	**Electricity generation （a hundred million kWh）**	**Total power generation （a hundred million kWh）**	**Total electricity consumption by society （a hundred million kWh）**
Shanxi	2500	477	4376	2885
Inner Mongolia	6961	1271	7451	4823
Shaanxi	1285	171	2946	2450
Ningxia	1464	279	2246	1387
Coal Triangle Area	12210	2198	17019	11545
Nationwide	44134	8090	94564	92241

Note: Data sources include the National Energy Administration, National Bureau of Statistics, China Electricity Council, State Grid Corporation of China, and Wind database. Total power generation is the sum of the power generation from fossil fuels and non-fossil fuel sources in the province .

4.1.4. Energy flow chart

According to the data, in 2023, the coal production in the Coal Triangle Area amounted to 2.43 billion tons of standard coal. Out of this production, 1.68 billion tons of standard coal were allocated for distribution, with a distribution ratio reaching as high as 69%.

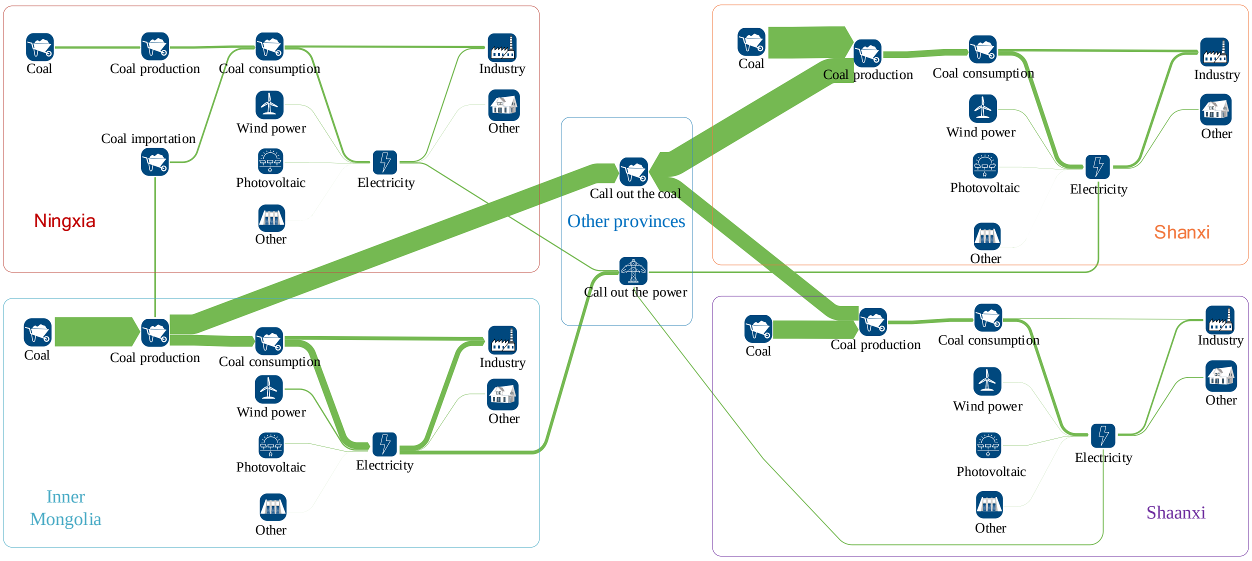

Figure 4-2 Coal and New Energy Production and Circulation Diagram of the Coal Triangle Area in 2023

4.1.5. Emission drive analysis

We used the Logarithmic Mean Divisia Index (LMDI) method to quantitatively decompose the changes in carbon emissions from the Coal Triangle Area as a whole and from the provinces of Inner Mongolia, Ningxia, Shaanxi, and Shanxi from 2010 to 2023. The specific results are shown in the table below, where the orange-yellow represents a positive effect, green represents a negative effect, and the deeper the color, the greater the effect.

Table 4-3 LMDI Decomposition Results of Carbon Emission Drivers in the Coal Triangle Area and Four Provinces from 2010 to 2023

LMDI decompose	Coal Triangle Area	Shanxi	Shaanxi	Inner Mongolia	Ningxia
Carbon emissions	12.64	4.20	2.27	5.16	1.01
Population	0.21	-0.16	0.16	-0.23	0.25
Per capita GDP	14.83	4.25	2.58	6.47	1.39
Industrial structure	-0.60	-0.59	-0.14	0.79	0.01
Energy intensity	-3.55	-1.25	-1.16	-1.59	0.13
Energy structure	-0.17	-0.09	-0.03	-0.05	0.02
	Factors contributing to the increase in carbon emissions				Factors inhibiting the growth of carbon emissions

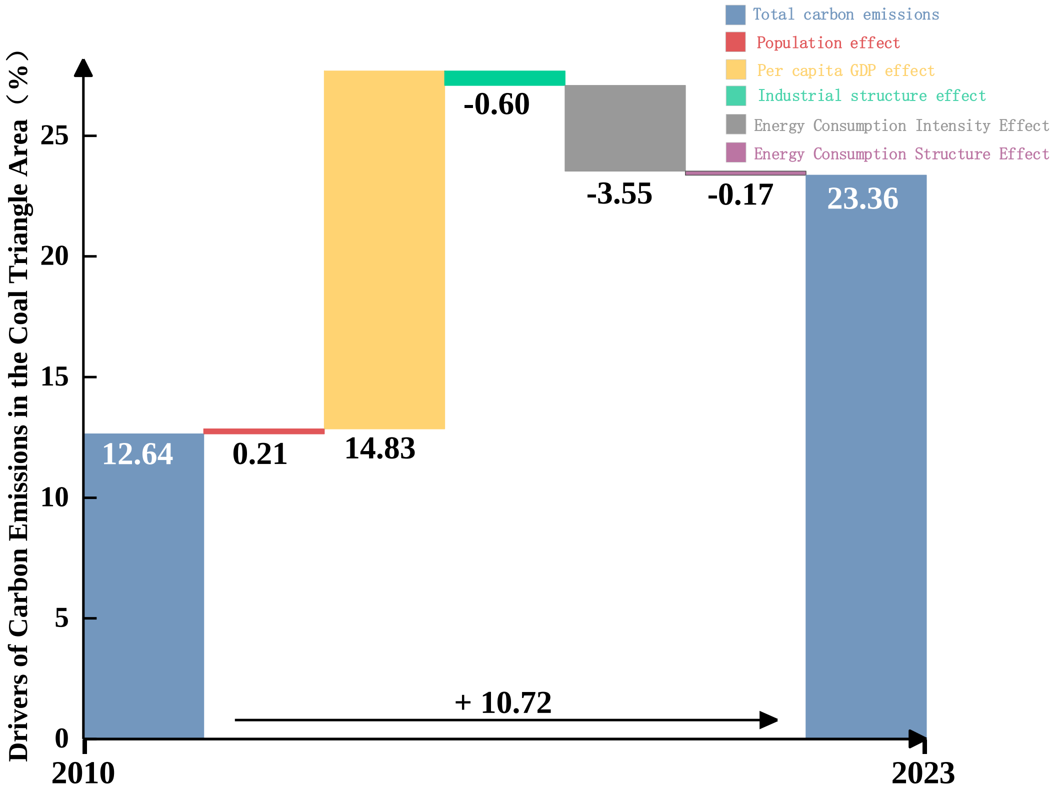

Figure 4-4 Decomposition of driving factors of carbon emissions in the Coal Triangle Area from 2010 to 2023

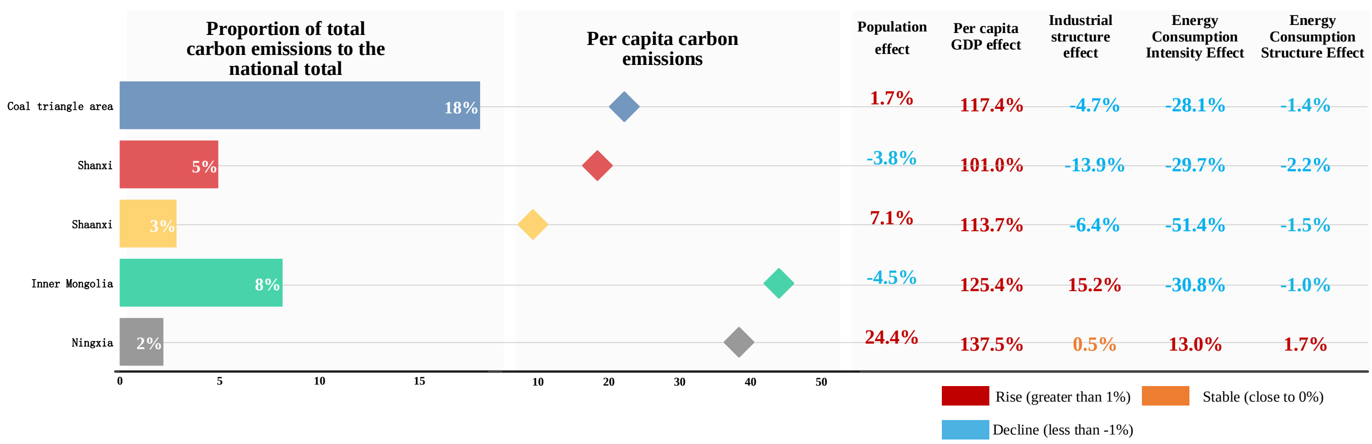

Figure 4-5 Characteristics of carbon emissions and driving factors in the Coal Triangle Area from 2010 to 2023

An analysis of the driving factors behind the changes in carbon emissions from 2010 to 2023 in the Coal Triangle Area, which includes Inner Mongolia, Ningxia, Shaanxi, and Shanxi provinces, reveals that economic development is the decisive factor for the growth in carbon emissions across the region and the four provinces, while the intensity of energy consumption is the primary factor for the reduction in carbon emissions. The effect of industrial structure adjustment is secondary, and the impact of population and energy consumption structure is relatively small.

(1) Economic development is the decisive factor for the increase in carbon emissions. The effect of per capita GDP in the Coal Triangle Area has driven an increase of 1.483 billion tons of carbon emissions. Between 2010 and 2023, the GDP of the Coal Triangle Area increased from 2.8521 trillion yuan to 6.8324 trillion yuan (at 2010 constant prices). The population size remained relatively stable, growing from 104 million to 105 million people, while per capita GDP increased from 27,400 yuan/person in 2010 to 64,800 yuan/person. Specifically, over the 14-year period from 2010 to 2023, for every 1% increase in GDP, emissions increased by 2.69 million tons. Due to the relatively stable population, the population effect contribution was relatively small, accounting for 2%.

(2) Energy consumption intensity is the most significant factor in reducing carbon emissions in the Coal Triangle Area, contributing to a total reduction of 355 million tons. During the period from 2010 to 2023, the energy consumption intensity in the Coal Triangle Area continuously decreased. Moreover, for the changes in carbon emissions caused by changes in energy consumption intensity, except for Ningxia, the effect of changes in the other provinces was negative.

(3) Adjustments in industrial structure have significantly reduced carbon emissions, with the industrial structure effect contributing a total of 60 million tons of emission reductions. From 2010 to 2023, the proportion of the tertiary industry in the industrial structure of the Coal Triangle Area gradually increased, while the proportion of the secondary industry, such as electricity and industry, decreased. The combined effect of industrial structure changes from 2010 to 2023 led to a 4.7% reduction in carbon emissions across the Coal Triangle Area.

(4) Optimization of energy consumption structure has a clear effect on reducing carbon emissions, but the actual reduction in carbon emissions due to adjustments in energy structure is relatively low. Overall, the Coal Triangle Area has achieved a reduction of 17.18 million tons.

This is mainly because the improvement in energy structure, especially in Ningxia, is not yet significant. Therefore, in the future, it is necessary to further adjust the proportion of energy use and optimize the energy structure to reduce per capita carbon emissions in the Coal Triangle Area.

4.2. Historical transition effect assessment of the Coal Triangle Area 2010-2023

From 2010 to 2023, the annual average growth rates of thermal power capacity and non-fossil energy capacity in the Coal Triangle Area were both higher than the national average. However, the proportion of non-fossil energy consumption to total primary energy consumption and the proportion of non-fossil energy generation to total electricity generation in the Coal Triangle region were both lower than the national average, although the annual average growth rate of non-fossil energy consumption was higher than the national average. The annual average growth rate of thermal power capacity in the Coal Triangle region from 2010 to 2023 was 5.8%, higher than the national average growth rate of thermal power capacity at 5.3%. The annual average growth rate of non-fossil energy capacity from 2010 to 2023 was 22.4%, which is 1.5 times the national average growth rate. The proportion of non-fossil energy consumption to total primary energy consumption in the Coal Triangle region increased from 3.0% in 2010 to 12.5% in 2023, but this proportion is still much lower than the national level. The annual average growth rate of non-fossil energy consumption in the Coal Triangle region was 11.6%, which is 2.3 times the national average. The proportion of non-fossil energy generation to total electricity generation in the Coal Triangle Area is also increasing, reaching 18.2% in 2023, but it is still lower than the national level of 30.0%.

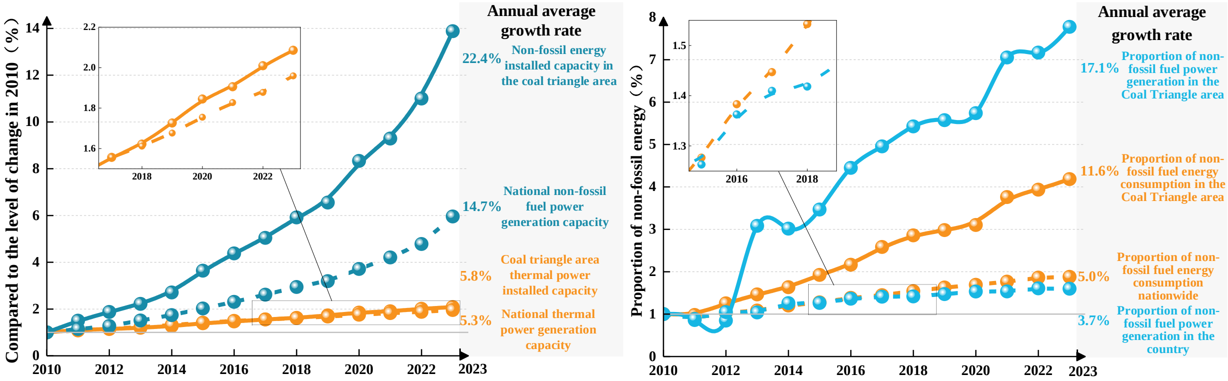

Figure4-6 2010-2023 Coal Triangle Area and National Energy Structure Changes

From 2010 to 2023, the carbon emission volume, per capita carbon emissions, and the annual average growth rate of coal production in the Coal Triangle Area were all higher than the national average, while the annual average rate of decline in carbon emission intensity was lower than the national average. The annual average growth rate of carbon emissions in the Coal Triangle Area from 2010 to 2023 was 4.7%, which is 1.6 times the national level, and the annual average growth rate of per capita carbon emissions was 4.6%, which is 1.7 times the national level. The annual average growth rate of coal production was 4.4%, which is 1.8 times the national level. However, the annual average rate of decline in carbon emission intensity was 2.1%, which is lower than the national level of 3.3% and is 0.6 times the national average decline rate of carbon emission intensity.

From 2010 to 2023, the GDP growth rate in the Coal Triangle Area showed the same trend as the national GDP growth rate, and the proportion of coal-related industries in GDP showed a downward trend but was still much higher than the national level. From 2010 to 2023, the overall GDP trend in the Coal Triangle Area was basically consistent with the national GDP trend. However, looking at the proportion of coal-related industries in GDP, although the proportion of coal-related industries in the Coal Triangle Area showed an overall downward trend, it was higher than the national level. In 2010, the proportion of coal-related industries in GDP in the Coal Triangle Area was 36.78%, which was 1.3 times the national level, and in 2023, it was 25.02%, which was 1.4 times the national level. The average annual rate of decline was 0.6%, which was much lower than the national level of 3.7%, and was only 0.16 times the national rate.

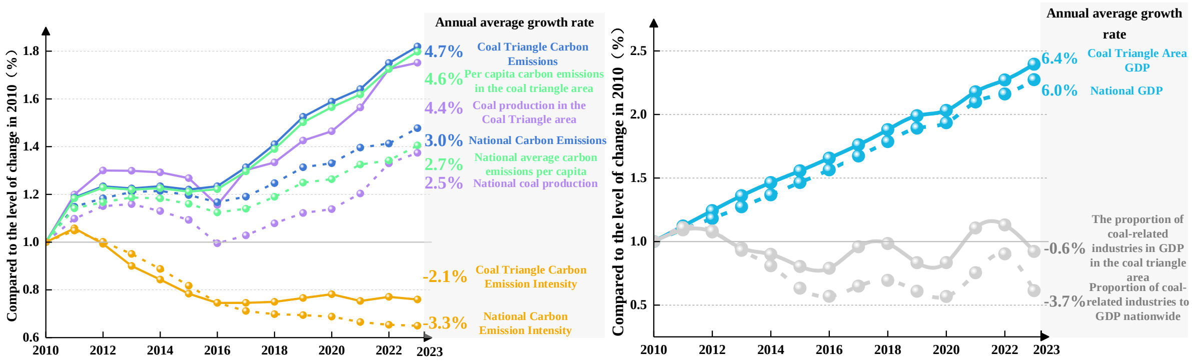

Figure4-7: Coal Triangle Area and national carbon emissions (left) and the proportion of coal-related industries in GDP in the Coal Triangle Area and nationwide (right) from 2010 to 2023.

Note: This project comprehensively applies the M3C-CGE module in CAEP-CP 2.0 to calculate the proportion of value-added of coal-related industries in the national and the Coal Triangle Area to GDP for different years. The coal-related industries specifically include the production and supply of electricity and heat, the processing of petroleum, coking products, and nuclear fuel, as well as the manufacturing of chemical products, among other sectors.

5. Challenges and Issues Faced in the Transition of the Coal Triangle Area

5.1. The coal triangle has been lacking in momentum over the past 15 years of energy transition and has failed to achieve significant overall results.

From 2010 to 2023, the installed capacity of thermal power in the Coal Triangle Area increased by 140 million kilowatts, and the output of thermal power increased by 739 billion kilowatt-hours. The average annual growth rates were 1.1 times and 1.3 times the national level, respectively. From 2010 to 2023, the coal production in the Coal Triangle Area increased by 1.47 billion tons, with an average annual growth rate of 4.4%, which was 1.8 times the national average annual growth rate of coal production, and the average annual growth rate was much higher than the national level. The per capita carbon emissions and the average annual growth rate of carbon emissions in the Coal Triangle Area were 1.7 times and 1.6 times the national level, respectively, which were much higher than the national level. Although the carbon emission intensity in the Coal Triangle Area has decreased, the reduction rate of 2.1% is lower than the national level of 3.3%. Therefore, the main reasons for the insignificant results of the energy transition in the Coal Triangle Area are the single energy structure, dependence on coal and thermal power, high and fast-growing carbon emissions, and insufficient efforts to reduce emissions. Currently, with the proposal of carbon peak and carbon neutrality goals, the energy transition path for the Coal Triangle Area has become clearer and more definite. This goal constraint provides important guidance for its energy transition and upgrading and industrial structure optimization.

5.2. The Coal Triangle Area is over-dependent on coal-related industries and has formed a path dependence, facing the risk of carbon lock-in in the future.

Coal resource-based areas have vigorously developed resource-based industries due to their abundant coal resources, which has led to a significant degree of economic development relying on coal. This has gradually formed an advantageous industry based on coal mining and processing, thereby influencing the development of the entire regional economy. Once a stable technology system based on carbon is formed, the system will maintain stability and resist changes. Therefore, energy systems based on carbon that benefit from long-term increasing returns may produce a "lock-in effect," hindering the innovation of low-carbon and renewable energy technologies. At the same time, participants benefiting from the existing system will attempt to maintain that system, further strengthening the lock-in of the existing technological system. Currently, the carbon-based energy and transportation systems of industrialized countries have formed a locked-in technology-institutional complex, which is also carbon lock-in.

5.3. Breakthroughs in the transition of key areas have given rise to a batch of emerging industries.

As an important area for China's economic transformation, the Coal Triangle Area has achieved significant breakthroughs in the transition of key areas in recent years. According to research by the research group, the Coal Triangle Area has gradually explored local resource endowments and natural characteristics, and has carried out innovative demonstration projects in accordance with local conditions, with the dawn of transition becoming visible. The energy transition in the Coal Triangle Area continuously explores new industrial models, for example, the Ordos Zero-Carbon Industrial Park has enhanced the low-carbon competitiveness of its products by supplying green electricity to park enterprises, and has also attracted a large number of high-tech enterprises to settle, stimulating economic development to some extent. Another example is the combination of energy transition and ecological environment governance, with benchmark projects including the Ordos Kubuqi Solar Photovoltaic Desertification Control Project and the Ningxia Tengger Desert's New Energy Base Project. While developing photovoltaics, these projects have achieved local desert environment governance. Furthermore, the combination of energy transition and rural revitalization has benchmark projects such as the Shaanxi Kefang Village Photovoltaic Agriculture Project and the Linfen, Fushan County "Sunshine Action" 16MW Distributed Photovoltaic Pilot Project, achieving a win-win situation for "enterprise-village collective-zero-carbon energy." The successful implementation of zero-carbon industrial parks, solar photovoltaic desertification control projects, and photovoltaic agriculture projects not only promotes the green development of the local economy but also provides useful references for the energy transition and sustainable development of the whole country and even the world.

6. Transition Path Analysis

This study, under the constraints of enhanced CO_2 emission pathways in the Coal Triangle Area, fully considers data on resource endowment, energy production, energy consumption, inter-provincial power exchange, and power grid planning across four provinces. It combines various methods such as literature analysis, expert discussions, and field research. Based on the China's medium- and long-term emission pathway model (CAEP-CP 2.0), including modules such as M3C-CGE and assessment of new energy potential, it establishes an energy transition path for the Coal Triangle Area. The goal is to promote the transition of the Coal Triangle Area from black energy scenario (status quo) to blue energy scenario (by 2035) to green energy scenario (by 2060). The development objectives of the energy transition path for the triangle area are shown in the table below.

Table6-1 Energy Transition Path Development Goals for the Coal Triangle Area

	Black energy	Blue energy	Green energy

Energy production	Fossil Non-fossil	4% 96%	20% 80%	20% 80%
	Hydrogen energy	A small test	Grey hydrogen: Green hydrogen 1.2： 1	Green hydrogen
Energy consumption	Fossil： Non-fossil	8% 92%	40% 60%	90% 10%
	Hydrogen	Minority gray hydrogen	Hydrogen energy accounts for a proportion of energy consumption 12%	Green hydrogen
Carbon removal	Remove quantity	<One million tons	>10 Million tons	500-800 million tons
Industry	The contribution of the coal industry to GDP	45%	32%	5%
	The contribution of the new energy industry to GDP	0.50%	2.00%	5.00%
	The contribution of the coal industry to employment	29%	21%	3%
	The contribution of the new energy industry to	0.10%	0.20%	0.60%

	employment

6.1. The Coal Triangle Area emission pathways

Social and economic development parameters are the foundation for model simulation. The project team integrated research findings from important domestic institutions and the latest authoritative international reports, and had extensive communication with Development and Reform Commissions, Departments of Ecological Environment, Environmental Science Research Institutes, Environmental Planning Research Institutes, Energy Research Institutes, and university scientific research institutions in four provinces including Inner Mongolia, Ningxia, Shaanxi, and Shanxi. They also fully consulted with relevant experts and combined field research, government discussions, and other forms, forming the basic parameters for the social and economic development of the Coal Triangle Area through repeated iterative optimization and comprehensive judgment.

Table 6-2 Socio-economic Development Parameters of the Coal Triangle Area

	GDP/Billion yuan	GDP Growth rate			Population / Ten thousand people			
	2020 year	2020-2025	2025-2030	2030-2035	2020 year	2025 year	2030 year	2035 year
Shanxi	17836	5.5% (5.2%,5.8%)	4.0% (3.5%,4.5%)	3.2% (2.7%,3.7%)	3490	3452 (3383,3521)	3420 (3317,3523)	3394 (3224,3564)
Inner Mongolia	17360	5.0% (4.7%,5.3%)	4.0% (3.5%,4.5%)	3.3% (2.8%,3.8%)	2403	2432 (2383,2481)	2424 (2351,2497)	2392 (2272,2512)
Shaanxi	26014	6.0% (5.7%,6.3%)	4.5% (4.0%,5.0%)	4.1% (3.6%,4.6%)	3955	4002 (3922,4082)	3977 (3858,3096)	3910 (3715,4106)
Ningxia	3956	6.0% (5.7%,6.3%)	4.5% (4.0%,5.0%)	4.4% (3.9%,4.9%)	721	756 (741,771)	781 (758,804)	798 (758,838)

Based on the emission scenarios (policy scenarios and strengthening scenarios[2]) of China's

2 Policy scenario: Taking into account the goals of peaking carbon emissions and achieving carbon neutrality, the national self-contribution targets (a 65% reduction in carbon intensity by 2030 compared to 2005), and the implementation plans for peaking carbon emissions in various provinces, combined with the latest

Carbon Peak and Carbon neutral Strategy and Path Research (2021) and Research on Some Major Issues of China's Carbon Peak and Neutrality (2024), the policy scenarios and strengthening scenarios of carbon dioxide emissions in the Coal Triangle Area was established.

In the CO_2 emission policy scenario for the Coal Triangle Area, the CO2 emissions from coal reached 2.3 billion tons in 2023, reflecting the current state of carbon emissions. From 2023 to 2030, the trend of carbon emissions are on the rise, with CO_2 emissions from the Coal Triangle peaking at 2.6 billion tons in 2030. After reaching this peak, from 2030 to 2035, the emissions followed a path of gradual decline, with CO_2 emissions from coal expected to reach 2.49 billion tons in 2035, a 5% decrease from the 2030 level.

In the enhanced CO_2 emission scenario for the Coal Triangle Area, the peak emissions occurred in 2027 at 2.6 billion tons, which was three years earlier than in the 2030 scenario. From 2023 to 2027, the emissions followed a path of moderate growth. After reaching the peak, the emissions decreased rapidly from 2027 to 2035, with CO_2 emissions from coal expected to reach 2 billion tons in 2035, a 23% decrease from the peak in 2027.

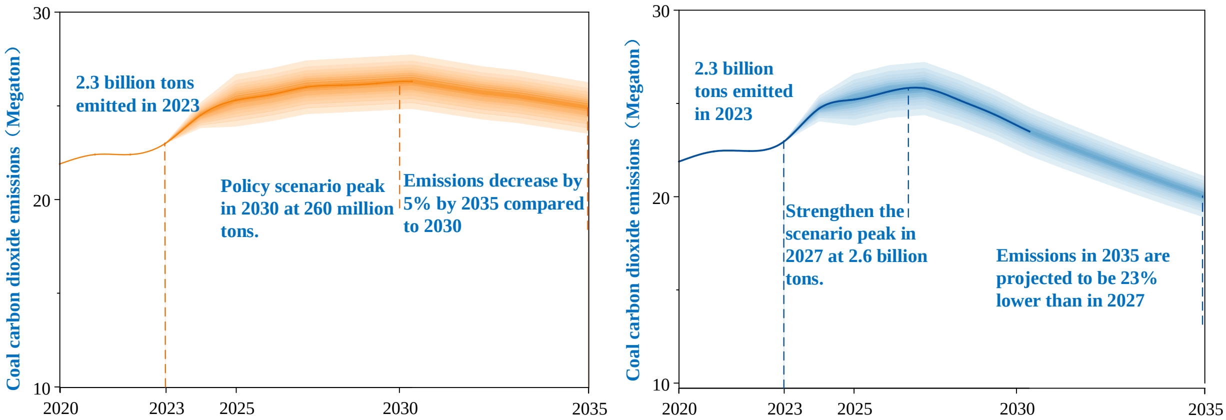

Figure6-1: Policy scenario (left) and enhanced scenario (right) for CO2 emissions in the Coal Triangle Area.

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assessments of provincial emission situations, a policy scenario under the national carbon peaking target is formed; Enhanced scenario: On the basis of the policy scenario, considering the national and regional requirements for high-quality peaking and strong promotion of energy conservation and emission reduction, as well as the rapid growth of new energy in regions, an emission scenario is constructed to achieve high-quality carbon peaking goals.

6.2. Energy transition pathways

6.2.1. Energy transition

In 2023, the energy production in the Coal Triangle Area mainly relied on fossil fuels, with the ratio of fossil fuels to non-fossil fuels being 96:4, and energy consumption was also predominantly fossil fuels, with the ratio being 92:8. A very small portion of energy consumption was gray hydrogen, and the amount of carbon removal was less than 1 million tons.

Based on the China's medium and long-term emission pathway model (CAEP-CP 2.0), it is expected that by 2035, the total energy production will be 2.2 billion tons, of which fossil fuels will account for 77%, non-fossil fuels 18%, and hydrogen energy 5%, with the ratio of gray hydrogen to green hydrogen in hydrogen production being 1.2:1. By 2035, the coal production in the Coal Triangle Area will see a significant decrease compared to 2023. Specifically, the coal production in the Coal Triangle Area will be equivalent to 1.72 billion tons of standard coal.

By 2035, the proportion of fossil fuels in energy consumption in the Coal Triangle Area will decrease to 40%, with hydrogen energy accounting for 12%, and the amount of carbon removal exceeding 10 million tons. By 2060, the transition to green energy will be achieved, with non-fossil fuels accounting for 80% and 90% of energy production and consumption, respectively, and all hydrogen energy production and consumption being green hydrogen, with the amount of carbon removal being approximately 500-800 million tons. In terms of coal dispatching, the Coal Triangle Area also shows distinct characteristics. It is expected that by 2035, the area will dispatch out 1.11 billion tons of standard coal, with a dispatching ratio of 65%. In addition to coal dispatching, in terms of electricity dispatching, the Inner Mongolia Autonomous Region leads the provinces in the Coal Triangle Area with an electricity dispatching amount of 13 million tons of standard coal.

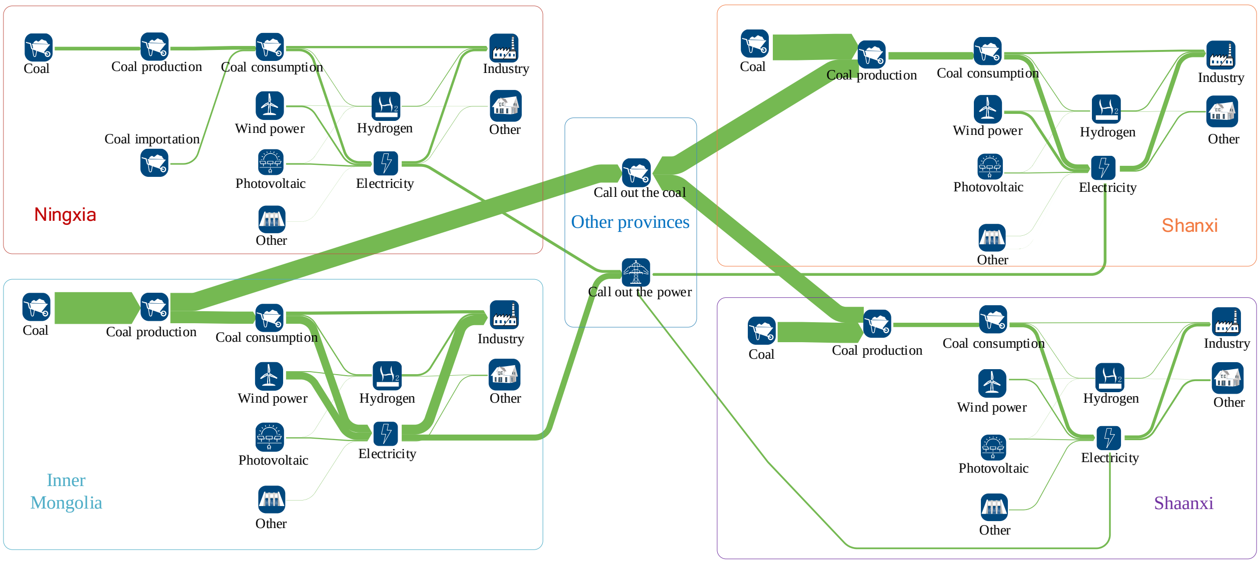

Figure 6-2 Coal and New Energy Production and Circulation Diagram for the Coal Triangle Area in 2035

6.2.2. Assessment of new energy development potential

The Coal Triangle Area is one of the fastest-growing areas for wind and solar power generation in China and is also one of the regions with the greatest potential for future development. According to the research report "Assessment of Wind and Solar Power Potential in China (2024)," it is expected that by 2025, the installed capacity of solar power in the Coal Triangle Area will reach 110 million kilowatts, and by 2030, it will reach 180 million kilowatts. According to the same research report, it is expected that by 2025, the installed capacity of wind power in the Coal Triangle Area will reach 150 million kilowatts, and by 2030, it will reach 230 million kilowatts.

6.2.3. New energy consumption and power grid construction

The energy transition in the Coal Triangle Area relies on the vigorous development and absorption of new energy sources, with the key being the absorption of new energy to ensure a gradual shift in regional energy consumption towards predominantly new energy sources. Specifically, this includes: (1) Scientifically determining the new energy absorption targets for the Coal Triangle Area. Regularly conduct analyses of the new energy absorption capacity of the Coal Triangle Area's power grid, maintaining new energy utilization at a reasonable level, and proposing the scale of new energy that can be connected and absorbed; (2) Promoting the broader optimization of new energy allocation. Fully implement the national major strategic deployments, build ultra-high voltage DC transmission projects to ensure the outward transmission of new energy from the Coal Triangle Area, fully form a DC power transmission pattern to North China, East China, and Central China, further expand the development and outward transmission scale of new energy in the Coal Triangle Area, promote the broader optimization of new energy absorption, and accelerate the transition of energy resource advantages into economic advantages; (3) Continuously enhancing the regulation capacity of the power supply side. Utilize advanced technologies such as big data and artificial intelligence to improve the prediction accuracy of wind conditions and sunlight, enhancing the accuracy of power output predictions; promote applications such as electric heating, electric vehicles, and hydrogen production from electricity, expanding the space for new energy absorption in the Coal Triangle Area. Strengthen demand-side management and the construction of the response system, cultivating emerging market entities such as demand-side response aggregation service providers.

6.3. Technological transition pathways.

The energy transition in the Coal Triangle Area, while ensuring safe production and stable energy supply, requires continuous strengthening of scientific and technological innovation. It is essential to promote the transition and upgrading of the coal industry and achieve efficient and clean utilization. The key to the transition of the coal industry is the ajustment from fuel coal to raw material coal, and from coal-fired power generation to new energy power generation. It is crucial to break through key technologies such as hydrogen production through water electrolysis, advanced and efficient coal-fired power generation technology, hydrogen energy storage technology, and CCUS (Carbon Capture Utilization and Storage) support technology. Ultimately, by connecting the technological chain of new energy, new modern coal chemical industry, and CCUS support technology in the Coal Triangle Area, it is expected that green hydrogen proportion will be over 50% by 2030 and achieve near-zero emissions in near-zero emissions.

Specific technological transition paths include: (1) High-quality intelligent coal mining technology, which deeply integrates modern information technologies such as big data, artificial intelligence, blockchain, and the Internet of Things with the coal industry, driving the coal sector towards digitalization and intelligent transformation. This should be done while remaining mindful of the risk that even the most efficient coal assets might become stranded by advances in other energy technologies; (2) Advanced and efficient coal-fired power generation technology, promoting the development of coal-fired power generation towards high-parameter, large-capacity, and intelligent systems, advancing ultra-high parameter coal-fired power generation, new power cycle systems, highly flexible and intelligent coal-fired power generation, efficient and low-cost multi-pollutant joint control of coal-fired power, and the independent industrialization of complete sets of technologies and equipment for resource utilization, facilitating the technological upgrade and structural transition of power equipment; (3) By optimizing the combination of coal, oil, and gas resources, breaking the traditional single processing mode of coal chemical and petrochemical industries, effectively solving the problems of "too much carbon and too little hydrogen" in coal-to-methanol and "too much hydrogen and too little carbon" in natural gas-to-methanol, achieving "carbon-hydrogen complementarity," and creating a new model for green, low-carbon, and circular development in the energy and chemical industry; (4) Green electricity to green hydrogen technology, coupling new modern coal chemical low-carbon and clean development; (5) Hydrogen energy storage technology, promoting a comprehensive transition from coal-fired power generation to new energy power generation; (6) CCUS technology (Carbon Capture Utilization and Storage) can separate CO_2 from emission sources related to power generation and industrial processes and convert it into useful products or permanently store it, serving as the foundational technology for carbon reduction during the transition of the coal industry in the Coal Triangle Area; (7) The state and local governments jointly fund the establishment of the "Coal Triangle Area Energy Transition Innovation Technology Research Center".

6.4. Industrial transition path.

During the industrial transition process in the Coal Triangle Area, the decline in coal production leads to a decrease in the contribution to GDP growth and employment by the relevant departments. Taking the coal mining and processing sector as an example, the contribution of coal mining and processing to GDP growth was 12.81% in 2023, which decreased to 9.11% in 2035.

With the continuous advancement of the industrial transition in the Coal Triangle Area, the contribution of coal mining and processing to GDP growth will only be 1.42% by 2060. The contribution of the coal mining and processing sector to employment decreased from 15.66% in 2023 to 1.62% in 2060, with a decline rate of 89%. On the other hand, the development of the new energy industry will bring certain promotion to the overall economic growth and employment in the Coal Triangle Area. The overall economic improvement brought by the new energy industry can increase the output of most industries, affecting the output value of industries. The industries that benefit the most include construction, manufacturing, and engineering industries related to the manufacturing and installation of renewable energy equipment. In 2023, the contribution of construction, manufacturing, and engineering industries to GDP growth was 7.04%, which increased to 8.36% in 2035 and 8.80% in 2060. In 2023, the contribution of construction, manufacturing, and engineering industries to employment was 3.52%, which increased to 5.72% by 2060.

The traditional coal industry is facing enormous pressure to transform. The decline in coal production will lead to a decrease in the added value of traditional industries such as coal-fired power, coal coking, and steel, worsening the overall production and operational conditions of the industry and having a negative impact on economic development. It will also directly affect employment in coal-related industries. Under the constraints of the carbon emission strengthening path in the Coal Triangle Area and driven by energy transition, integrating industry with energy production, distribution, and consumption to form an efficient, interactive, and sustainable system is crucial. The industry-energy integration model aims to maximize energy efficiency and minimize environmental impact through the deep integration of industry and energy systems. The Coal Triangle Area should leverage its regional advantages, such as wind and solar resources and manufacturing elements, to improve the upstream and downstream industrial chain of the regional "wind and solar plus" industry. It should also create a low-carbon industrial symbiosis system within the region, including "wind and solar plus agriculture plus food processing," "wind and solar plus energy storage plus manufacturing," "wind and solar plus hydrogen plus traditional industries," "wind and solar plus new energy vehicles," and "wind and solar plus equipment and component recycling" industrial chains.

7. Fair Transition

During the transition process of the Coal Triangle Area, an important energy base, regional equity issues have become increasingly prominent, posing a significant challenge in the transition process. Energy transition involves not only the substitution and updating of energy sources but also a complex socio-economic process. It often comes with substantial capital investment, redistribution of resources, and adjustments to the industrial structure. Firstly, in the process of transformation, new energy projects, technological research and development, and infrastructure construction all require substantial capital investment. However, these resources are often difficult to evenly distribute among different regions. Secondly, the development gap between regions may give rise to a series of social equity issues. On one hand, the widening economic gap may lead to increased population mobility, causing some areas to experience depopulation, while other areas may face resource shortages, increased environmental pressures, and other issues due to excessive population concentration. On the other hand, uneven development between regions can also affect social stability and ethnic unity.

The energy transition in the Coal Triangle Area has had a profound impact on the job market. With the decline of the traditional coal industry, a large number of workers are facing the risk of unemployment, especially those with specialized skills who find it difficult to adapt to the requirements of new industries. This change in employment structure may lead to the solidification of social classes, making it difficult for workers who previously depended on the coal industry to find new employment opportunities, thereby exacerbating social inequality. Moreover, although the rise of new energy industries has created new job opportunities, these positions often require higher skill levels, and the threshold for transition is high for workers from the original coal industry, further exacerbating employment equity issues.

The issue of ecological equity during the energy transition process is also not to be overlooked. The ecological restoration of traditional energy extraction involves environmental, economic, and social aspects. For residents and communities affected by coal mining, a fair compensation mechanism needs to be established to ensure that they receive reasonable compensation for any losses incurred due to ecological restoration. The development of new energy projects, such as wind and solar power, may also impact the local ecological environment during the siting, construction, and operation process. For example, the construction of wind farms may impact the habitats of birds, and the construction of photovoltaic power facilities may change the ecological structure of the land surface. These impacts are often borne by local communities, while the economic benefits may be obtained by project investors, leading to a mismatch between benefits and costs that may cause ecological equity issues. In addition, the environmental impact assessment and regulation of new energy projects need to fairly consider all stakeholders to ensure that ecological protection measures are effectively implemented and to avoid unfair damage to the ecological environment.

8. Policy Recommendations

8.1. Establish a national-level coordination mechanism for the low-carbon transition of the Coal Triangle Area.

It is recommended to establish a low-carbon transition leadership group for the Coal Triangle Area, and to build an integrated transition collaboration mechanism for the Coal Triangle Area. Rationally determine the functional positioning of the Coal Triangle Area in the national strategy for phased peak carbon emissions, fully considering national energy security and energy demand, clarify the national demand for coal and coal-fired power transmission from the Coal Triangle Area, establish a coal production capacity reserve system, and introduce preferential policies to encourage new energy power generation and a green channel for grid absorption, to incentivize non-fossil fuel power generation. Optimize the timetable, roadmap, and assessment methods for the Coal Triangle Area to reach peak carbon emissions. At the same time, fully consider the impact and effects of the low-carbon transition of traditional energy on vulnerable groups, employment, ecology, etc., and explore the establishment of a fair transition mechanism. Encourage the Coal Triangle Area to establish communication channels with international coal areas, leading the global coal areas in low-carbon transition.

8.2. Establish a "Zero-Carbon Power Industry and Trade Special Zone".

It is suggested that the Coal Triangle Area, leveraging its resource endowment, comprehensively establish a "Zero-Carbon Electricity Industry Trade Zone" (referred to as "Zero-Carbon Zone") mechanism. This would capitalize on the advantages of vast land, large-scale new energy capacity, and the potential for flexible complementarity with fossil fuels. By utilizing new microgrid business models in the region, the Zero-Carbon Zone would ensure a long-term, continuous supply of zero-carbon electricity for the entire area's power system. Additionally, it would offer preferential import and export tax policies to attract export-oriented enterprises to settle in the "Zero-Carbon Zone." Within the zone, a zero-carbon digital certification system would be built to provide full lifecycle carbon footprint certification for products, granting them traceable, internationally standard-compliant "Zero-Carbon Certification" labels. Establishing a "Zero-Carbon Electricity Industry and Trade Zone" is expected to break through the dilemmas of new energy absorption and industrial transition in the Coal Triangle Area, and will help China explore effective ways to address international trade carbon regulations.

8.3. Establish a low-carbon transition fund for the Coal Triangle Area

It is recommended to adopt a mixed financing model of "government-guided funds + venture capital/equity investment institutions + corporate investors," where public capital and international development capital provide capital at preferential prices to drive private capital that provides funds at market prices. Among these, catalytic capital is composed of state-owned capital holding groups from the Coal Triangle Area and various green industry funds, while public capital comes from coal taxes and government’s public budget investments, attracting private capital. A financial holding group from the provincial level of the Coal Triangle Area could jointly establish a fund management company responsible for the professional management of the transition fund. The financing model adopts a mixed financing approach, with the fund manager investing as a general partner at 1%. The transition fund is mainly used to support key technological breakthroughs during the transition of the Coal Triangle Area, such as green hydrogen and energy storage technologies, new modern coal chemical technologies, CCUS technologies, etc., as well as ecological restoration and various compensation mechanisms in the transition process.

References

[1] Agora Energiewende (2020) The European power sector in 2019 The European power sector in 2019 (agora-energiewende.org)

[2] Akgüç M., Arabadjieva K. and Galgóczi B. (2022) Why the EU's patchy 'just transition' framework is not up to meeting its climate ambitions, Policy Brief 2022.06, ETUI. https://www.etui.org/publications/why-eus-patchy-just-transition-framework-not-meeting-its-climate-ambitions

[3] Ang B W, 2015. LMDI decomposition approach: A guide for implementation[J]. Energy Policy, 86: 233-238.

[4] Betts K, 2010. Can the US phase out coal's greenhouse gas emissions by 2030?[J]. Environmental Science & Technology, 44(11): 4035-4036.

[5] Chen L, Xie J, Zhang X, et al., 2023. Mining 5.0: Concept and framework for intelligent mining systems in CPSS[J]. IEEE Transactions on Intelligent Vehicles, 8(6): 3533-3536.

[6] Chen Q, Kang C, Ming H, et al., 2014. Assessing the low-carbon effects of inter-regional energy delivery in China's electricity sector[J]. Renewable and Sustainable Energy Reviews, 32: 671-683.

[7] Chen W, Wu F, Geng W, et al., 2017. Carbon emissions in China's industrial sectors[J]. Resources, Conservation and Recycling, 117: 264-273.

[8] Conley S, Konisky D M, Mullin M, 2023. Delivering on environmental justice? US state implementation of the Justice40 initiative[J]. Publius-the Journal of Federalism, 53(3): 349-377.

[9] Dou L, Sun L, Lyu W, et al., 2023. Trend of global carbon dioxide capture, utilization and storage industry and challenges and countermeasures in China[J]. Petroleum Exploration and Development, 50(5): 1246-1260.

[10] Du Z, Lin B, 2018. Analysis of carbon emissions reduction of China's metallurgical industry[J]. Journal of Cleaner Production, 176: 1177-1184.

[11] European Commission (2022) REPowerEU: Affordable, secure and sustainable energy. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

[12] Feng K, Song K, Viteri A, et al., 2023. National and local labor impacts of coal phase-out scenarios in chile[J]. Journal of Cleaner Production, 414: 137399.

[13] Galgóczi B. (2018) Just transition towards environmentally sustainable economies and societies for all, ILO Actrav policy brief, 2018, The International Labour Office. https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---actrav/documents/publication/wcms_647648.pdf.

[14] Galgóczi B. (2020) The path to 'zero carbon' in a post-Covid-19 world, in ETUC/ETUI (2020) Benchmarking Working Europe 2020, ETUI, 75-94. The path to zero carbon in a post-Covid-19 world_2020.pdf (etui.org)

[15] Gong J W, Li Y P, Lv J, et al., 2022. Development of an integrated bi-level model for China's multi-regional energy system planning under uncertainty[J]. Applied Energy, 308: 118299.

[16] Graf K, 2021. EU-climate package "fit for 55"[J]. WOCHENBLATT FUR PAPIERFABRIKATION, 149(7): 371-371.

[17] He B, Shao Y, Wang S, et al., 2019. Product environmental footprints assessment for product life

cycle[J]. Journal of Cleaner Production, 233: 446-460.
[18] Hill C A, Such M C, Chen D, et al., 2012. Battery energy storage for enabling integration of distributed solar power generation[J]. IEEE Transactions on Smart Grid, 3(2): 850-857.
[19] Calipel C, Antoine B, Thomas P C.(2024) European climate investment deficit report, An investment pathway for Europe’s future, 2024.02, I4CE.
[20] ILO (2015) Guidelines for a just transition towards environmentally sustainable economies and societies for all, ILO. https://www.ilo.org/wcmsp5/groups/public/---ed_emp/---emp_ent/documents/publication/wcms_432859.pdf
[21] Jia Z, Liu Y, Lin B, 2024. The impossible triangle of carbon mitigation policy[J]. Energy Policy, 189: 114107.
[22] Johansson N, 2021. Does the EU’s action plan for a circular economy challenge the linear economy?[J]. Environmental Science & Technology, 55(22): 15001-15003.
[23] Keles D, Yilmaz H U, 2020. Decarbonisation through coal phase-out in germany and europe - impact on emissions, electricity prices and power production[J]. Energy Policy, 141: 111472.
[24] Li H, Wu L, 2014. Analysis of hubei province industry’s carbon emissions based on the LMDI[C]//Zhang L. Environmental Technology And Resource Utilization II: Vols. 675-677. Durnten-Zurich: Trans Tech Publications Ltd: 1865-,.
[25] Liu B, Ding C J, Hu J, et al., 2023. Carbon trading and regional carbon productivity[J]. Journal of Cleaner Production, 420: 138395.
[26] Liu F, Lv T, 2019. Assessment of geographical distribution of photovoltaic generation in China for a low carbon electricity transition[J]. Journal of Cleaner Production, 212: 655-665.
[27] Ning, S Z, , Cao, D Y. Coal resources in shanxi, shaanxi and western inner mongolia region and its exploration and exploitation strategy-all databases[EB/OL]. (2010-01-01) [2024-08-09]. https://webofscience.clarivate.cn/wos/alldb/full-record/WOS:000392561100026.
[28] Oei P Y, Hermann H, Herpich P, et al., 2020. Coal phase-out in germany - implications and policies for affected regions[J]. Energy, 196: 117004.
[29] Ren K, Zhang T, Bai Y, et al., 2022. Environmental and economical assessment of high-value utilization routes for coke oven gas in China[J]. Journal of Cleaner Production, 353: 131668.
[30] Rinscheid A, Wustenhagen R, 2019. ENERGY POLICY german voters would prefer a more ambitious timeline to phase out coal[J]. Nature Energy, 4(12): 1016-1017.
[31] Sanderson K, 2023. COP28 climate summit signals the end of fossil fuels - but is it enough?[J]. NATURE, 624(7992): 484-485.
[32] Schulz F. (2020) Germany begins allocating 40 billion Euros to coal regions to start phase-out, Euractiv, 31.08.2020. https://www.euractiv.com/section/energy/news/germany-begins-allocating-e40-billion-to-coal-regions-to-start-phase-out/
[33] Singh G K, 2013. Solar power generation by PV (photovoltaic) technology: A review[J]. Energy, 53: 1-13.
[34] Song M, Wang J, Zhao J, 2018. Coal endowment, resource curse, and high coal-consuming industries location: Analysis based on large-scale data[J]. Resources, Conservation and Recycling, 129: 333-344.
[35] Sun X, Li J, Qiao H, et al., 2017. Energy implications of China’s regional development: New insights from multi-regional input-output analysis[J]. Applied Energy, 196: 118-131.
[36] Sun Z, Liu Y, Yu Y, 2019. China’s carbon emission peak pre-2030: Exploring multi-scenario optimal

low-carbon behaviors for China's regions[J]. Journal of Cleaner Production, 231: 963-979.
[37] Tian JY, Yao W. Research on the Ecological Restoration of Coal Mining Subsidence Area in Shanxi Province. Advanced Materials Research, 2013;827:384-8. https://doi.org/10.4028/www.scientific.net/amr.827.384.
[38] Unruh G C, Carrillo-Hermosilla J, 2006. Globalizing carbon lock-in[J]. Energy Policy, 34(10): 1185-1197.
[39] Wang G, Xu Y, Ren H, 2019. Intelligent and ecological coal mining as well as clean utilization technology in China: Review and prospects[J]. International Journal of Mining Science and Technology, 29(2): 161-169.
[40] Wang J, Huang Z, 2017. The recent technological development of intelligent mining in China[J]. Engineering, 3(4): 439-444.
[41] Wang W, Liu X, Zhang M, et al., 2014. Using a new generalized LMDI (logarithmic mean divisia index) method to analyze china's energy consumption[J]. Energy, 67: 617-622.
[42] WRI (2024) World's top emitters World's Top Emitters Interactive Chart I World Resources Institute (wri.org)
[43] Xiao K, Yu B, Cheng L, et al., 2022. The effects of CCUS combined with renewable energy penetration under the carbon peak by an SD-CGE model: Evidence from China[J]. Applied Energy, 321: 119396.
[44] Xie Z, Wu R, Wang S, 2021. How technological progress affects the carbon emission efficiency? Evidence from national panel quantile regression[J]. Journal of Cleaner Production, 307: 127133.
[45] Xu B, Lin B, 2016. Assessing CO2 emissions in China's iron and steel industry: A dynamic vector autoregression model[J]. Applied Energy, 161: 375-386.
[46] Xu B, Lin B, 2024. How can green finance effectively promote low-carbon cities? Evidence from 237 cities in China[J]. Journal of Environmental Management, 365: 121641.
[47] Yan Q, Wang Y, Balezentis T, et al., 2019. Analysis of China's regional thermal electricity generation and CO2 emissions: Decomposition based on the generalized divisia index[J]. Science of the Total Environment, 682: 737-755.
[48] Yan Y, Borhani T N, Subraveti S G, et al., 2021. Harnessing the power of machine learning for carbon capture, utilisation, and storage (CCUS) - a state-of-the-art review[J]. Energy & Environmental Science, 14(12): 6122-6157.
[49] Yang L, Lin B, 2016. Carbon dioxide-emission in China's power industry: Evidence and policy implications[J]. Renewable and Sustainable Energy Reviews, 60: 258-267.
[50] Yuan J, Na C, Lei Q, et al., 2018. Coal use for power generation in China[J]. Resources, Conservation and Recycling, 129: 443-453.
[51] Zhang H, Shen L, Zhong S, et al., 2020. Economic structure transformation and low-carbon development in energy-rich cities: The case of the contiguous area of shanxi and shaanxi provinces, and inner mongolia autonomous region of China[J]. Sustainability, 12(5): 1875.
[52] Zhang J, Liu L, Xie Y, et al., 2022. An integrated optimization and multi-scale input-output model for interaction mechanism analysis of energy-economic-environmental policy in a typical fossil-energy-dependent region[J]. Energy Strategy Reviews, 44: 100947.
[53] Zhao C, Dong K, Lee C C, 2024. Carbon lock-in endgame: Can energy trilemma eradication contribute to decarbonization?[J]. Energy, 293: 130662.

[54] Zhao C, Ma X, Che S, et al., 2024. Does climate aid alleviate carbon lock-in? A global perspective[J]. Journal of Cleaner Production, 449: 141782.
[55] Zhou S, Tong Q, Yu S, et al., 2012. Role of non-fossil energy in meeting China’s energy and climate target for 2020[J]. Energy Policy, 51: 14-19.
[56] Zitek V, Klimova V, 2023. Just transformation as a way to sustainable development of regions[C]//Klimova V, Zitek V. 26th International Colloquium On Regional Sciences. Brno: Masarykova Univ: 84-92.
[57] Huang W J, Si F Y, Zhang N, et al., 2023. Extraction and Optimization of Urban Energy System Security Rules for Resilience[J]. Automation of Electric Power Systems, 47(12): 1-8.
[58] Jia J, Tian S M, Jiang E H, et al., 2023. Research on Carbon Emission Status in the Yellow River Basin and the Path to Achieve the "Dual Carbon" Goals[J]. Yellow River, 45(12): 8-13.
[59] Liu J Y, Zhang B Y, Zhu R B, 2023. Just Transition: Concepts, Practices, and Insights[J]. Hainan Finance(5): 53-65.
[60] Liu Litao, Shen Lei, Gao Tianming, et al., 2012. Evaluation of China's Energy Security and Temporal and Spatial Evolution Characteristics[J]. Acta Geographica Sinica, 67(12): 1634-1644.
[61] Niu H L, 2023. Research on Measurement and Temporal and Spatial Evolution Characteristics of Carbon Lock-in in China's Manufacturing Industry[J]. Statistics and Decision Making, 39(8): 153-157.
[62] Qi H, 2023. Research on High-Quality Economic Development of Resource-Based Cities - Based on the Sample Study of Erdos Zero-Carbon Industrial Park[J]. Inner Mongolia Statistics(3): 67-69.
[63] Wang F, 2024. Why can Ordos build a zero-carbon industrial park? [J]. Wind Energy (1): 14-17.
[64] National Energy Administration: Notice on Printing and Distributing the 2018 Provincial (District, City) Coal Power Ultra-low Emission and Energy-saving Transformation Target Tasks [EB/OL]. (2018-08-27) [2024-08-10]. https://www.gov.cn/xinwen/2018-08/28/content_5317088.htm.
[65] Yang B W, 2024. The gradual logic, transformation deployment, and institutional orientation of implementing carbon emission "dual control" in China [J]. Contemporary Economic Research (7): 105-116.
[66] China 21st Century Agenda Management Center. China Carbon Dioxide Capture, Utilization, and Storage (CCUS) Annual Report (2023) [EB/OL]. (2023-12-29) [2024-08-09]. http://m.tsjinquan.com/apollo/dongshow-450619.html.
[67] Ministry of Ecology and Environment of China, Academy of Environmental Planning. China Wind Power and Solar Power Generation Potential Assessment Report (2024) released [EB/OL]. (2024-6-14) [2024-08-09]. http://www.caep.org.cn/sy/tdftzhyjzx/zxdt/202406/t20240614_1075803.shtml.
[68] Yuan J H, Wang Y, Yang X W, et al., 2023. Employment impact and vulnerability assessment of provincial coal power phase-out under the "dual carbon" goal [J]. China Population, Resources and Environment, 33(7): 67-80.
[69] Zhang S X, Song Q, Cheng H Z, et al., 2024. Key technologies and challenges of port integrated energy system planning considering energy flow-logistics coupling [J]. Proceedings of the Chinese Society for Electrical Engineering: 1-20.
[70] Zhang W H, Song Y R, 2024. New thoughts on energy justice and fair energy transition under the background of Chinese modernization [J]. Jianghan Tribune (3): 36-43.
[71] Zhang W R, Yuan J H, 2021. Research on stranded assets of China's coal power under global 2°C

warming carbon constraints [J]. Climate Change Research Progress, 17(1): 36-44.
[72] Zhang Y, Ji X R, Wang M, 2021. Issues of Just Transition in International Climate Governance: Conceptual Analysis and Governance Progress [J]. Climate Change Research Progress, 17(2): 245-254.
[73] Zhao J Y, Zhu Y, Ma J C, et al., 2022. Research on Carbon Emission Inventory and Influencing Factors of Energy Consumption in Shanxi Province [J]. Journal of Taiyuan University of Technology, 53(6): 989-996.
[74] Zhu J Z, Dong H J, Li S L, et al., 2024. A Review of Optimal Scheduling of Micro-energy Grids Based on Distributed New Energy Clusters [J]. Proceedings of the CSEE: 1-22.

Appendix A Research Methods and Technical Approach

1. Research technical approach

The research methods include literature and field research, expert consultation, and government discussions, specifically:

Literature Research: Systematically review the latest international and domestic studies and typical cases of green and low-carbon transition in traditional industries, summarizing international and domestic experiences in the green and low-carbon transition of traditional industries;

Field Research: Conduct field research in the Coal Triangle Area, organize authoritative experts and project research teams in the international and domestic energy field to conduct in-depth field research, systematically evaluate the energy consumption and production base of the Coal Triangle Area, and accurately understand the current situation of coal development and renewable energy development;

Expert Consultation: Hold a series of expert consultation meetings on issues such as the future industrial development direction of the Coal Triangle Area and the construction path of new energy integrated industry support, proposing development suggestions and strategic paths;

Government Discussions: Fully carry out government functional agency and research institute discussions in the provinces of Inner Mongolia, Ningxia, Shaanxi, and Shanxi in the Coal Triangle Area, including the Development and Reform Commission and the Department of Ecology and Environment, to deeply explore the energy transition pathway of the Coal Triangle Area and its significant impact on regional economic development and rural revitalization, providing scientific policy recommendations for future transformation.

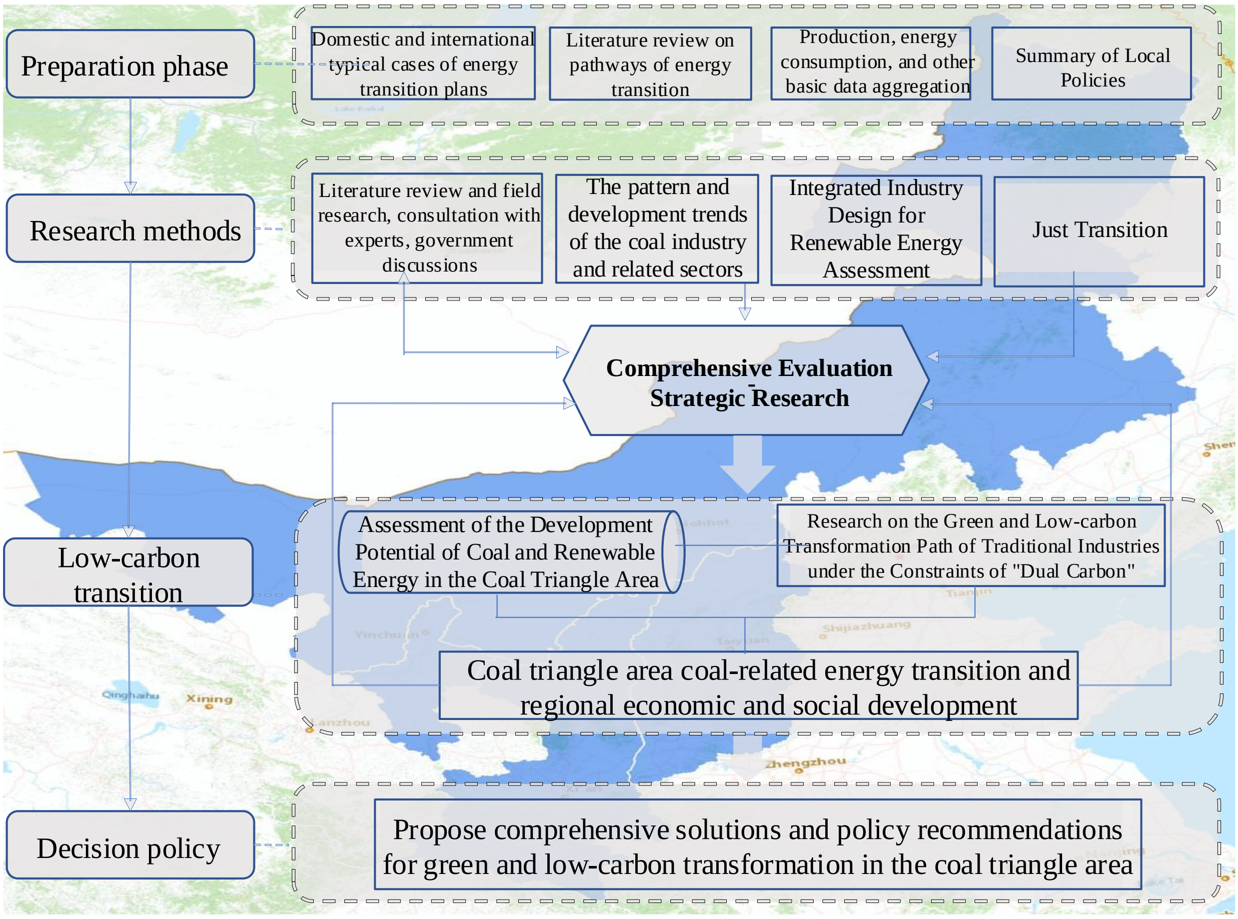

Figure A-1 Research Technology Roadmap

2. China's medium- and long-term emission pathway model CAEP-CP 2.0

The China's medium- and long-term emission pathway model CAEP-CP 2.0 is an integrated emission pathway model established by Academician Wang Jinnan from the Chinese Academy of Environmental Planning under the Ministry of Ecology and Environment. The CAEP-CP 2.0 model is based on a top-down macroeconomic model and a bottom-up evolutionary model, and mainly includes modules such as high spatial resolution emission gridding, medium- and long-term energy module, M3C-CGE model, spatialized new energy potential assessment module, emission reduction technology assessment module, carbon removal module, and key industry forecasting module. Among these, the top-down macroeconomic model fully considers social and economic development, China's goals of reaching peak carbon emissions before 2030 and achieving carbon neutrality before 2060, while also taking into account technological accessibility and the feasibility of measures. Through iterative optimization, it forms emission pathways based on industries/sectors. The bottom-up approach is at the spatial emission grid level, on an annual basis, evolving emission patterns at different stages through specific rules and constraints.

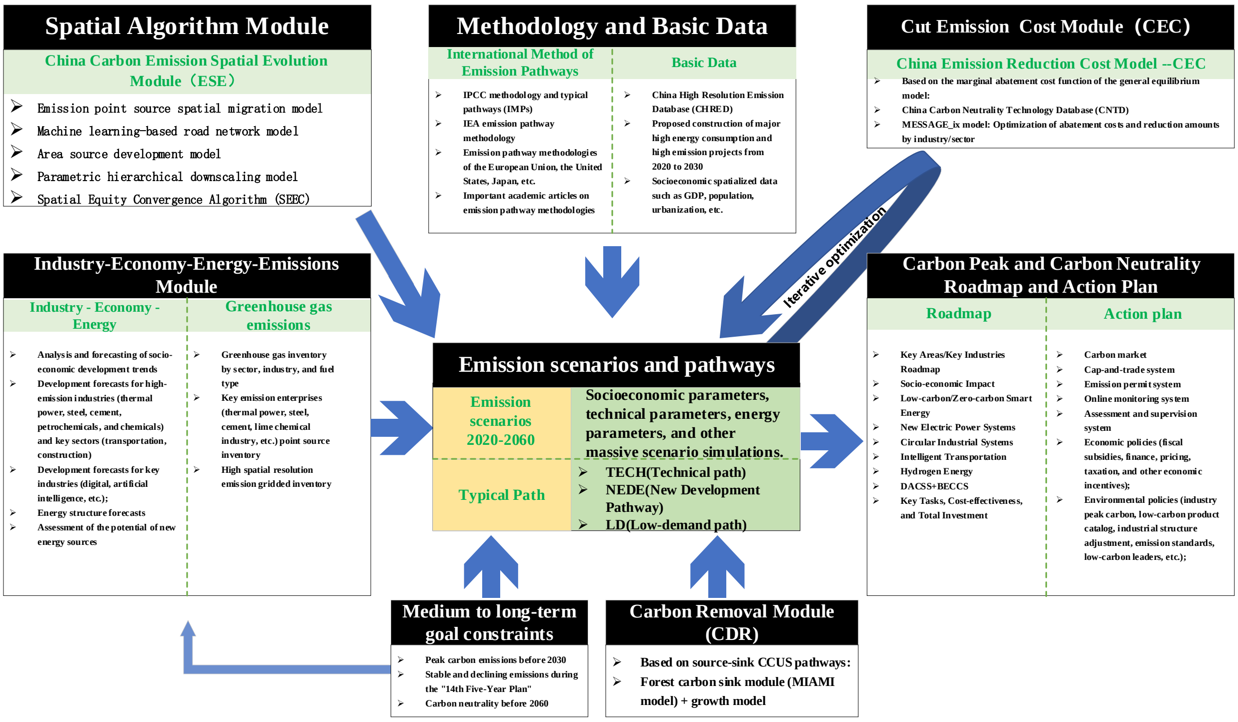

Figure A-2 CAEP-CP 2.0 Model

The results of the CAEP-CP 2.0 model have been reported multiple times at important meetings such as the 29th collective study session of the Political Bureau of the CPC Central Committee, high-level meetings of the Chinese Academy of Engineering, and high-level meetings of the Ministry of Ecology and Environment. Currently, the model serves as the comprehensive model for the major consulting project of the Chinese Academy of Engineering titled "Research on China's Carbon Peak and Carbon Neutrality Strategy and Pathways," integrating the basic data and research findings of over 40 academicians and more than 300 experts, continuously improving and upgrading iteratively.

The CAEP-CP 2.0 model has been fully applied in the analysis of China's greenhouse gas emission scenarios and the pathways to carbon peak and carbon neutrality, providing technical support for the formulation of various national policies. Moreover, the model has played a significant role in the research on the pathways to carbon peak and carbon neutrality in provinces such as Ningxia, Jiangxi, Fujian, and Shanxi, as well as in cities like Yantai, Nanping, and Wuyishan, effectively supporting the introduction of local carbon peak plans.

2.1 M3C-CGE Module: Macro-Micro Multi-Dimensional Carbon Neutrality-CGE

The M3C-CGE module is an important component of the CAEP-CP 2.0 model that addresses the interrelated impacts of regional energy, industry, and economy. The M3C-CGE module is built upon the CGE model, which is a multi-sector, multi-region dynamic model that considers the connections between different economic entities and markets. The CGE model employs a large number of mathematical equations to depict the behaviors of various economic agents (such as enterprises, residents, governments, investors, importers, and exporters) including production, consumption, investment, and import/export activities. Under the conditions of maximizing resident utility, maximizing corporate profits, minimizing costs, and adhering to resource and budget constraints, the model determines the supply and demand for production factors or other commodities at market equilibrium, thereby obtaining equilibrium prices. The Institute of Environmental Planning at the Ministry of Ecology and Environment, in collaboration with the Center for Forecasting Science at the Chinese Academy of Sciences and the School of Economics and Management at the University of Chinese Academy of Sciences, has developed the M3C-CGE module based on the CGE model. This module comprehensively considers the interconnections between environmental, economic, and social systems, incorporating environmental and energy accounts to analyze the interactions and feedbacks between different economic entities across various regions. As a result, it assesses the impacts of various emission reduction scenarios on the economy, society, and environment under the constraints of "dual carbon" goals.

Using the provincial input-output table for the year 2020 as the socio-economic foundational data, combined with the provincial energy balance table, provincial statistical yearbooks, and provincial carbon emission data for the year 2020, the baseline data was established. The model encompasses 40 sectors, including production modules, domestic and international trade market modules, government and household income and expenditure modules, and a carbon emission module. With a step size of one year, it dynamically simulates the provincial industrial economic trends, changes in industrial structure, energy consumption, and variations in carbon emissions under different carbon emission constraint scenarios from 2020 to 2060.

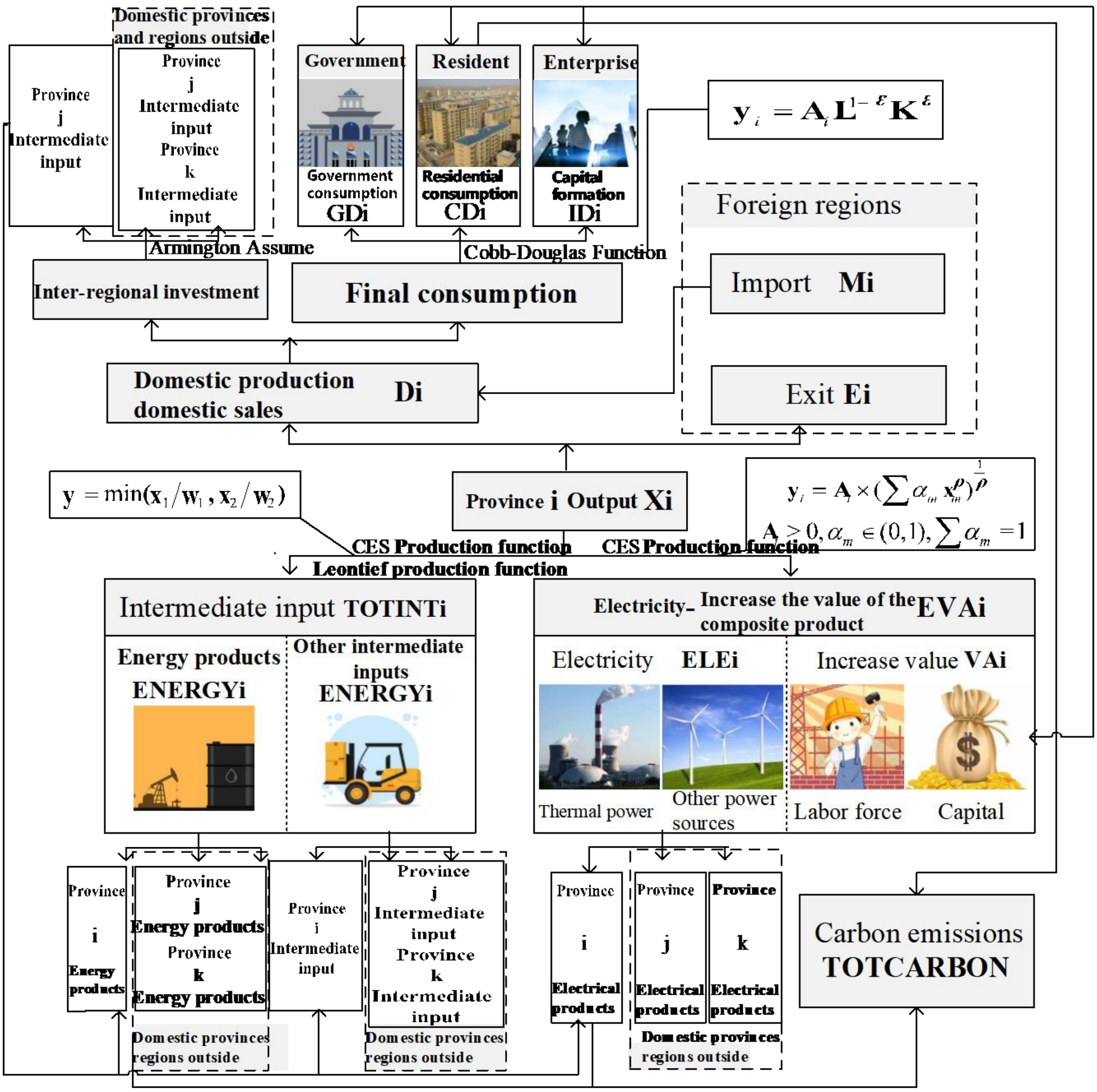

Figure A-3 Carbon Regulation Economic Model (CARBON-CGE) Module

2.2 New energy potential assessment module

Based on the GIS spatial analysis platform, this module utilizes high-resolution wind and solar resource maps (wind resource map at 100 meters height, global horizontal irradiance, equivalent hourly data for photovoltaic power generation potential, etc.), in conjunction with a database of limiting factors (ecological red lines, water bodies, residential areas, airport runways, etc.), a terrain parameter library (elevation data SRTM, slope, aspect), landforms, equipment databases, regional characteristic parameters, etc. By employing GIS spatial analysis, optimal equipment selection, and operational power generation assessment algorithms, it evaluates the developable areas for wind and solar power within a region. It also selects suitable equipment based on the local terrain and resource characteristics, ultimately determining the theoretical developable capacity and power generation hours for wind and solar power within the region. The optimal power generation equipment is matched according to the resource characteristics of the potential area available for renewable resource development. Specifically, for wind power development, the wind turbine rotor swept area, generator power, and tower height determine the wind energy conversion efficiency. Combining the wind resource endowment at heights of 80-140 meters aims to achieve the lowest cost per kilowatt-hour. Wind resource data comes from high-resolution wind resource maps corrected with long-term historical actual wind measurement data from the wind power industry. Information on wind turbines comes from databases of technical parameters of mainstream industry models and projections for future technological advancements.

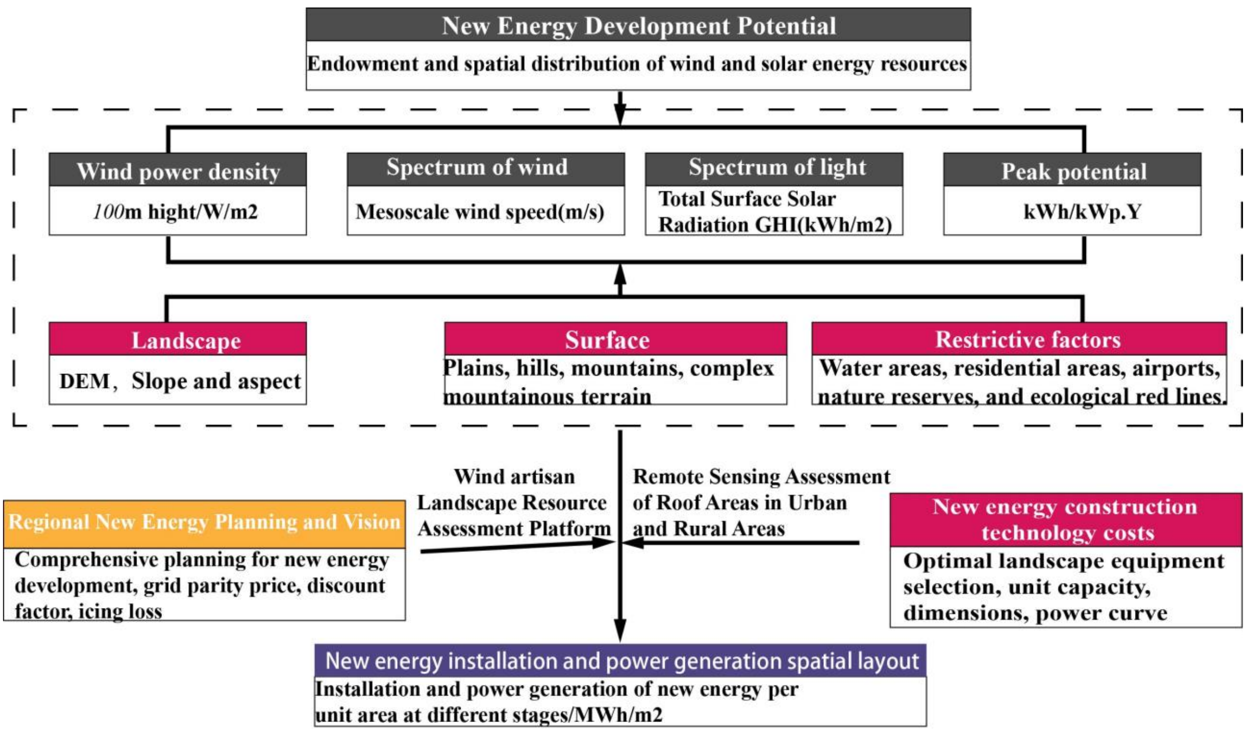

Figure A-4 New Energy Potential Assessment Module

3. Conduct field research and hold symposiums

After constructing the transition path for the Coal Triangle Area based on CAEP-CP 2.0, the research team conducted extensive field research and symposiums during the research process to ensure full communication with provincial administrative departments and research institutions, and to receive timely feedback, thereby dynamically adjusting the research results of the transition path.

On one hand, our research group conducted in-depth field investigations and interviews in Ordos, Inner Mongolia, and Tongchuan, Shaanxi, aiming to explore the innovative practices and strategic planning in the development of new energy in the Coal Triangle Area, as well as the difficulties and issues encountered during the transition process. The Tianjiao Green Energy Photovoltaic Power Generation Demonstration Project in Ejin Horo Banner, Ordos, effectively utilized the land resources of the coal mining subsidence area and, through photovoltaic technology, provided clean energy to the region, achieving the dual goals of ecological restoration and energy production. The China Shenhua Coal-to-Liquids Project represents the cutting-edge technology in the deep processing of coal resources, converting coal into clean oil products, and providing a new solution for the efficient utilization of coal resources and ensuring national energy security. The Vision Zero Carbon Industrial Park Project demonstrates the potential of energy transition in promoting green industrial transformation. The Kubuqi Photovoltaic Desertification Control Project combines photovoltaic power generation with desert management, effectively curbing the desertification process and providing new momentum for regional economic development. The Photovoltaic Agriculture Support Project in Kefang Village, Tongchuan, reflects the positive role of new energy technology in promoting rural revitalization and expanding the village's collective economy. This research has given us a deeper understanding of the new energy development model and the layout of low-carbon industries in the Coal Triangle Area. The practices in these areas show that developing new energy in combination with local natural resources can effectively promote the sustainable economic development of the area.

On the other hand, since the project's initiation in January 2024, the initiative has organized two online seminars and two offline meetings. The offline meeting in May 2024 was held in Ordos, bringing together numerous experts and scholars in the field, as well as heads of local relevant departments, including Liu Shijin, Huang Qingxue, Bela Galgoczi, Pete Harrison, Guo Jing, Huang Shaozhong, Hu Xiulian, among others. They provided profound insights and suggestions from various perspectives, such as market economy solutions for resource-based areas, the role of technological innovation in energy transition, the difficulties and challenges of reaching peak carbon and carbon neutrality in the Coal Triangle Area, and the construction of a new energy system. Local participating units, including the Bureau of Ecology and Environment, the Bureau of Energy, and the Bureau of Industry and Information Technology, engaged in in-depth discussions on issues such as carbon emission quotas for resource and energy exporting areas, new energy pilot projects, energy export line capacity, and hydrogen energy policy support, and proposed corresponding policy recommendations.

The symposium in May 2024 was held in Xi'an, Shaanxi, focusing on the energy transition paths of the Coal Triangle Area. The project leaders showcased the current achievements, followed by presentations on the energy transition status of their respective provinces by experts from Inner Mongolia, Ningxia, Shaanxi, and Shanxi experts such as Jiang Kejun, Béla Galgóczi, Han Wenke, Huang Shaozhong, Xu Dakang, and Gao Lijuan engaged in in-depth discussions on issues such as electricity costs, industrial chain security, techno-economic feasibility, legal frameworks, and fair mechanisms for international trade. They proposed specific directions for modifications and implementation strategies. Local departments including the Development and Reform Commission, Provincial Department of Ecology and Environment, and Provincial Academy of Social Sciences discussed policy recommendations and research content, particularly the fiscal contributions of wind and solar projects, the impact of land and environmental policies on the development of new energy, and the delayed introduction of CCUS policies. Both symposiums further explored the technological and market logic of new energy development, providing not only theoretical support and policy recommendations for local energy transitions but also indicating the direction for the optimization of China's energy structure and the development of green and low-carbon initiatives.

Figure A-5 The research group conducting field research (left) and the research group holding a seminar (right)