Pathways of Regionally Coordinated Low-Carbon Development in China

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Abstract: *Carbon peak and carbon neutrality are both important goals in the Chinese government's plans for future economic development. With heterogeneous resource endowments, economic and technological levels, and industrial structures across China's many regions, regional differentiation can significantly affect the design of pathways toward achieving carbon peak and carbon neutrality. Regionally coordinated low-carbon development may be the only way for the Chinese government to mitigate supply and demand imbalances in the distribution of energy resources and green technologies. China's interregional energy industry and pollution abatement collaboration have also created conditions for regional collaboration in low-carbon development. Nevertheless, successful regional coordination for low-carbon development requires overcoming the institutional problems.*

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Carbon peak and carbon neutrality are major strategic objectives adopted by the Central Committee of the Communist Party of China (CPC), a stated commitments for taking part in global environmental and climate management (Liu, 2021). However, there is a great deal of regional heterogeneity in China's resource endowments, economic and technical conditions, industrial structure, and environmental capacity. While carbon peak and carbon neutrality programs are slated to be carried out across regions of various types in a state of unbalance, interregional coordination matters as well. In *Opinions on All-Round and Accurate Implementation of the New Development Concepts and Proper Implementation of Carbon Peak and Carbon Neutrality Work*, The CPC Central Committee and the State Council also called for "ensuring coordination and consistency for various regions and fields to achieve key targets, development directions, major policies, and major projects of carbon peak and carbon neutrality."

1. Regional Coordination in Low-Carbon Development

According to Climate Watch website (https://www.climatewatchdata.org), China faces a much shorter schedule for achieving carbon peak and carbon neutrality compared with developed countries. Additionally, China also faces unbalanced regional distribution of energy resources and low-carbon

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technologies, which calls for regionally coordinated low-carbon development. Regional coordination underpins the concept of creating a new paradigm for low-carbon development and implementing green and balanced development. The *Pre-2030 Carbon Peak Action Plan* issued by the State Council stresses that "various regions should advance local green and low-carbon development based on key regional strategies, promote coordinated regional development, create main functional zones, and pursue local green and low-carbon development in light of actual conditions." This requirement underscores the importance for various localities to consider local conditions and coordinate with other regions in formulating carbon peak action plans.

1.1 Supply and Demand Mismatch in the Regional Distribution of Energy Resources and Green Technologies

In China, there is a significant regional mismatch of supply and demand for energy resources. China's energy mix is dominated by coal, which is primarily distributed in western and northern regions, and oil and gas reserves are relatively small. Hydropower constitutes the bulk of China's renewable energy, but most hydropower resources are found in China's southwestern regions. In addition to coal and hydropower, China's western regions are home to 78% and 88.4% of the country's total available wind and photovoltaic energy resources, respectively (Wei, 2021). In contrast, China's major energy consumers are in the eastern coastal regions. Such a supply and demand mismatch has necessitated "massive and long-distance transportation of coal and oil from the north to the south and transmission of gas and electricity from western to eastern regions."[1]

Significant regional mismatch in the supply and demand remains for China's green technologies as well. A region's supply of green technology can be largely proxied by its amount and quality of green technology patents. According to the patent database of the China National Intellectual Property Administration (CNIPA), the level of green technologies has been increasing across China with a gradient decrease in green technological strength from the eastern to central and western regions; most green technologies are developed in more prosperous large cities, which are mostly located on the east coast (Sun and Zhang, 2022). China's western regions trail eastern regions in green energy technology application in high energy-consuming sectors such as nonferrous metals, electric power, steel smelting, and cement. Moreover, there has been no narrowing of the regional gaps in energy technologies, which means that the regional diffusion effect of energy technologies is insignificant (Wu, 2009). However, though technologically less advanced than their eastern counterparts, China's central and western regions still face the most urgent need to deploy high-tech solutions to decrease carbon emissions.

1.2 Regional Imbalances in Low-Carbon Development

After its reform and opening up policy was enacted in 1978, China prioritized the development of the eastern coastal regions with existing greater economic strengths in order to boost aggregate productivity. As a result, China's existing interregional development gaps widened. The eastern coastal regions have spearheaded nearly all technological advances, and in addition to strengths in human resources, economic fundamentals, public infrastructures, and geographic location, the eastern regions also benefited from national policy preferences for investment, taxation, foreign capital, trade, and finance. In the face of widening interregional economic and technological imbalances, in the late 1990s China adopted a strategy of beginning to develop its western regions, followed by similar programs to rejuvenate the northeast and promote the rise of the central region as well. Due to various constraints such as transportation and human resources, however, China's central, western, and northeastern regions still lag

[1] The State Council Information Office of the People's Republic of China: *China's Energy Status and Policies* (whitepaper), December 2007, Beijing, http://www.nea.gov.cn/2011-08/22/c_131065968.htm.

far behind the eastern regions in terms of GDP per capita reported by the National Bureau Statistics.

With more advanced technologies and industrial upgrades, the eastern coastal regions are also far more advanced than the interior regions in terms of low-carbon development. Although progress has been made in green and low-carbon technologies across all regions, the eastern regions of China are far more advanced than elsewhere. In recent years and especially after the 18th CPC National Congress, China's overall industrial structure has shifted towards low-carbon development, but the pace and effects of low-carbon transition are uneven across regions. While industrial restructuring in some provincial-level regions such as Beijing and Zhejiang is conducive to decarbonization, the carbon-reducing effects of industrial restructuring in other regions remain unclear (Zhang and Bai, 2021).

Given significant regional economic, technological, and industrial gaps, achieving carbon peak and carbon neutrality goals in a short period of time may be difficult, especially in regions that face barriers to economic development and lack industrial infrastructure for low-carbon development. This difficulty may be assuaged to some degree if more economically developed regions assist less-developed ones and low-carbon development leaders bring along the laggards to advance.

1.3 China's New Development Paradigm Can Benefit from Regional Coordination in Low-Carbon Development

China's current priority of creating a new development paradigm also seeks to integrate strategies for achieving high-quality development and carbon peak and carbon neutrality. In particular, carbon peak and carbon neutrality can be not only objectives of high-quality development but also part of a means to achieve the development as well, in line with the *14th Five-Year Plan and the 2035 Long-Range Goals*. In its new development paradigm, China is striving to create "domestic circulation" as the mainstay and domestic and international "dual circulation" reinforcing each other. As a key element of the new development paradigm, unimpeded economic circulation increases demand for coordinated regional development.

From the broader perspective of domestic circulation, regionally coordinated low-carbon development can indeed help integrate efforts to create a new development paradigm and achieve carbon peak and carbon neutrality goals. Such coordination also embodies the concept of green and balanced development. Under the framework of carbon peak and carbon neutrality, economic entities in various regions can cooperate with each other to help optimize the regionally differentiated layout of limited environmental and resource capacities, thus contributing to local economic development. While improving environmental quality, regional coordination for low-carbon development can encourage a wide range of green, healthy, and safe goods and services to be provided, such as organic food, innocuous detergents, energy-efficient and eco-friendly kitchen utensils, new-energy vehicles, and eco-tourism services, all contributing to increased domestic consumption in particular. In this sense, the promotion of regionally balanced low-carbon development can also be an important way to foster a new development paradigm.

From the perspective of domestic and international dual circulation reinforcing each other, regional coordination for low-carbon development can also be important way to support China's new development paradigm. With climate change receiving ever-greater attention from the international community, green and low-carbon development becomes key principles in international cooperation, according to the Paris Agreement. The new development paradigm calls for a higher degree of economic openness and better use of domestic and international markets and resources, and low-carbon development may play a key role in China's cooperation with the international community, may help to attract an inflow of more advanced foreign technology that can be used to support domestic circulation, and may improve trade.

2. The Historical Origins and Current State of Regional Coordination in Low-Carbon Development

China's regional coordination in low-carbon development has a long history. As mentioned before, China's unique regional layout of energy supply and demand has given rise to close energy-industry links across regions, and regional coordination in low-carbon development can be framed as an upgrade or higher requirement of interregional energy-industry links. Moreover, China's regional integration initiatives for pollution abatement provide a precedent for regionally coordinated low-carbon development.

2.1 Close Interregional Energy-Industry Linkages and Long-term Development

China's regional economic ties were strong during the planned economy and have been so in the era since 1978. First, there have been close energy linkages between regions. Given the prominent supply and demand imbalances in regional energy resources, China has implemented major national energy strategies, including the transmission of natural gas and electric power from western to eastern regions and the transportation of coal from western and northern to eastern and southern regions. It invested heavily in the construction of infrastructure such as the Three Gorges Dam Project, gas transmission pipelines, the power grid, and coal transportation systems. Massive energy transmission from energy-rich regions satisfies energy demand in eastern coastal regions. At the beginning 2021, over 100 billion cubic meters of natural gas were transmitted annually from western to eastern regions. By the end of December, 2021, over 700 billion cubic meters of natural gas were transmitted from western to eastern regions, covering over 3,000 large and medium-sized enterprises and 500 million people in more than 400 cities in China's western regions, the Yangtze River Delta, the Pearl River Delta, and central region.[2]

Second, close industrial correlation already exists between regions. Various regions have already formed their pillar industries with strong interregional economic complementarity. For these reasons, China has strong interregional industrial correlations and large interregional trade volumes. According to the input-output tables of Beijing in 2017 (Economic Accounting Department of the National Bureau of Statistics, 2020), 45% of intermediate inputs in the municipality were goods or services transferred from other regions, accounting for 29% of its total output value, while intermediate inputs transferred out from the municipality to other regions only accounted for 17% of its total output value. Moreover, Beijing fully relies on external supplies of coal, petroleum, and natural gas.

Third, close interregional industrial ties have given rise to large interregional carbon emission transfers. Since all goods and services consume energy and generate carbon emissions, when one region purchases goods or services from elsewhere, it transfers the associated carbon emissions to other regions. Given China's large interregional trade volume, such interregional transfer of carbon emissions cannot be overlooked. According to Zhang (2018), there is a significant difference in the carbon emission responsibilities under the producer principle and the consumer principle for emissions responsibility allocation. Due to massive carbon emissions transferred via interregional trade (embodied emissions in trade), Zhejiang, Shanghai and Beijing's consumer responsibilities for carbon emissions are 60% to 190% higher than their producer responsibilities (Zhang, 2018).

2.2 The Effects of Regional Coordination for Pollution Abatement

In recent years, China has worked relentlessly to enhance and modernize environmental management with a view to improving environmental quality. Among various initiatives, interregional coordination for air pollution abatement in particular has achieved some success (Huang, 2022) and may

[2] Source: http://finance.people.com.cn/n1/2021/1228/c1004-32319228.html.

serve as a reference for regionally coordinated low-carbon development.

First, the top-level design and top-down implementation of coordinated pollution abatement mechanisms across regions. In 2010, the State Council made decisions on air pollution abatement concerning key regions, major pollutants, and methods (for example, industrial restructuring, clean energy utilization, and the improvement of regional air quality monitoring) for pollution abatement, recognizing the importance of interregional coordination. Issued by the CPC Central Committee and the State Council on September 11, 2015, the *Master Plan for Institutional Reform for Ecological Civilization* called for establishing an interregional coordination mechanism for pollution abatement and improving coordination for air pollution abatement in key regions, including the Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta regions, and the *Outline of the People's Republic of China 14th Five-Year Plan for National Economic, Social Development, and Long-Range Objectives for 2035* reaffirmed the importance of pollution abatement at the source, integrated pollution abatement methods, and coordinated control of multiple pollution sources and regional coordination to curb pollution.

Second, China has proactively explored initiatives for coordinated measures for air pollution abatement. For instance, the six provinces and municipalities in North China reached the first cross-jurisdictional agreement on environmental cooperation for a "Green Olympics" in 2008. Regional, interprovincial, and cross-departmental coordination was then carried out to curb air pollution and ensure much better air quality in Beijing during the Olympic Games. During the APEC meetings in 2014, Beijing took draconian measures to restrict cars and suspend coal-fired power plants and industrial activities so that "Beijing blue" might reappear. In a series of major events such as the September 3 military parade in Beijing in 2015 and the G20 Summit in Hangzhou in 2016, relevant regions and departments explored the scope and methods of regional coordination, targeted control, and concentration curtailment, which have all since become valuable experience for curbing air pollution.

As mentioned in *A Review of 20 Years' Air Pollution Control in Beijing* released by the United Nations Environment Program (UNEP) on March 9, 2019, Beijing has achieved daunting air quality goals in a matter of five years with PM 2.5 annual average concentration down 35.6% in 2017 from 2013 levels. From 2015 to 2020, China's heavily polluted days more than halved, and heavily polluted days in the Beijing-Tianjin-Hebei region and neighboring areas fell by about 6% (Yan et al., 2018). Thanks to the joint efforts of neighboring regions, the "Beijing blue" that appeared during the APEC meetings in 2013 has now become the "new normal."

3. Feasible Pathways for Regionally Coordinated Low-Carbon Development

Low-carbon development can benefit from sustained transition to low carbon emissions and green and low-carbon technology innovations. The low-carbon transition of economic structure entails the transition of industrial structure as well as energy production. Hence, the pathway for regionally coordinated low-carbon development can be considered in three aspects: Industrial structure, energy production, and technology innovations.

3.1 The Regionally Coordinated Low-Carbon Transition of Industrial Structure

Under the carbon constraint, the competitive strengths of various regions can be brought into play in order to optimize a combination of factors on a broader spatial dimension: The geographic layout of industries. In both theory and practice, pathways for regionally coordinated industrial structure optimization include industrial relocation and integration with diverse modes of coordination. Regionally coordinated low-carbon transition of industrial structure may follow the above methods and in doing so may be able to strike a balance between carbon emissions reduction and economic development.

First, a more efficient allocation of resources may be to relocate energy-intensive industries essential

to national economic development to energy-rich regions. For instance, energy-intensive but less water-intensive industries may be relocated to energy-rich regions in the northwest (Pan et al., 2021) to avoid energy loss in long-distance transmission and allow energy-rich northwestern regions to thrive on their comparative advantages. With unique strengths in coal mining and dressing, China's southwestern province of Guizhou also is a desirable destination for industrial relocation for chemical processing, electric power generation, and heat production and supply as well (Zhang, 2020). In addition, methods of industrial relocation can be determined with flexibility, such as relocating entire enterprises, co-developing specialized industrial parks, creating the enclave economies, and relocating entire supply chains and related industries.

Second, regionally integrated industrial development may promote high-value industries for low-carbon industrial transition. One approach to such regional coordination is industrial agglomeration. In the Yangtze Economic Belt region with comparative advantages in advanced manufacturing, Shanghai may position itself as a global "sci-tech" innovation center while the neighboring provinces of Jiangsu and Zhejiang may develop supporting industries. In this manner, advanced manufacturing may cluster in the Yangtze River Delta, and industrial upgrade and low-carbon development can occur in the entire region. Moreover, with limited land available for development, the Yangtze River Delta region may relocate technology-intensive industries to the mid- and upper reaches of the Yangtze River in order to facilitate low-carbon transition.

Another approach to cross-regional industrial low-carbon transition is to develop high-end industrial chains with advanced technologies, high-value addition, and low-carbon emissions through interregional collaboration. For advanced manufacturing and other emerging industries, adjacent regions may rely on their comparative advantages and seek integrated development by fostering industrial chains through regional coordination to avoid redundant work and harsh competition. The Beijing-Tianjin-Hebei region, for instance, has made efforts to develop the hydrogen industry supply chain, where Beijing serves as the center for technological innovation, financial intermediation, and international exchange, and Tianjin and Hebei may specialize in developing and supplying special materials and equipment for hydrogen energy supply, storage, and transportation (Zhang and Bai, 2021).

3.2 Regional Coordination for Low-Carbon Transition

Regional coordination for low-carbon transition in China can be traced back far. Since the 2000s, the west-to-east natural gas transmission project has enabled the massive substitution of coal and other high-carbon-emission fuels with natural gas, re-optimizing the energy mix in regions along its route. By sending coal-fired power and hydropower to the eastern regions, the west-to-east electric power transmission project has reduced coal transportation costs and environmental pollution along the route while conserving thermal coal and re-optimizing the energy mix in the eastern regions as well.

However, the effects of those energy projects are merely regional, and further interregional coordination may be able to improve China's energy mix nationwide. The west-to-east gas and electric power transmission projects, though having effectively re-optimized the energy mix in the eastern region, did little to improve the energy mix in China's western regions and the energy mix nationwide. China's nationwide energy mix may benefit from further consideration being given to the improvement of the energy mix its western regions, and the development of new energy resources, most of which are located in China's western regions, to supplant coal-dominated energy production may indeed do just that. As the primary form of future interregional coordination for low-carbon transition, eastern regions can assist western regions with capital, technology, human resources, and training to tap into their huge reserves of new energy resources. By implementing the *Multi-Energy Complementary System Integration and Optimization Project* and the *Internet+ Smart Energy Project* according to local conditions, eastern regions may be able to increase the development of new energy resources such as

wind, photovoltaic, and biomass energies and create distributed energy systems to ease pressures on coal-fired power generation and improve the energy mix in the western regions.

By slashing the share of coal in its energy mix, the western regions may only be able to meet local energy demand at the expense of disruptions to social and economic development in the eastern regions, which are heavily dependent on energy and especially coal-fired power generation from the western regions. Hence, the question of how indeed to re-optimize the energy mix of western regions warrants attention.

3.3 Regional Coordination for Green and Low-Carbon Technology Innovations

China is far behind internationally advanced levels in many areas of green and low-carbon technologies, especially zero-carbon and negative carbon technologies like new energy technologies, and depends on foreign supplies of critical equipment and components (Zhang, 2021). Regional coordination for innovations in green and low-carbon technologies may therefore benefit from focusing on weak areas and bottlenecks and from enhancing collaboration in order to make breakthroughs. In particular, green and low-carbon technology innovations can be spearheaded by businesses in partnership with universities and research institutions in future regional coordination. For instance, the development of a CO_2 cycle power generation test unit has followed a cross-regional approach involving over 30 participants,[3] including leading Chinese universities, research and design institutes, manufacturers, and construction companies. This regional coordination approach also applies to the research, development, and application of supercritical CO_2 cycle power generation in areas like efficient photo-thermal technology, electric thermal energy storage systems (ETESs), advanced nuclear power, and flexible thermal power.

Second, advanced technologies can be employed for monitoring and managing carbon emissions from cross-regional industrial chains in order to increase efficiency. Local governments may develop low-carbon and energy-efficient smart management systems that cover major energy consumers and monitor key sectors within their jurisdictions, establish a complete early-warning mechanism for industrial and supply chain problems, enhance problem analysis, proactively respond to emergencies, and promptly defuse potential risks. For instance, the Chengdu-Chongqing region in China's southwest has envisioned the application of big data technology to curb industrial carbon emissions. The region may consider joining hands with the neighboring Guizhou Province, which is known for its big data capability, to pioneer monitoring and controlling carbon emissions of industrial chains in pilot zones.[4]

Third, interregional coordination may lead to a community of green innovations that underpin regionally coordinated low-carbon development. Various regions may create a community of green innovations following the "center-periphery" model (Krugman ,1991) based on their respective strengths. As the pioneer of green innovations in the Yangtze River Delta region, Shanghai has been committed to developing into a sci-tech center with global influence. In December 2017, the Green Technology Bank (GTB), together with the GTB Administrative Center, was unveiled in Shanghai with a 3.5 billion yuan green technology commercialization fund, which created financial incentives for technology innovation and commercialization (Zhou and Hu, 2020).

Finally, the three primary pathways for regionally coordinated low-carbon development are highly consistent and not independent from each other, and two or three pathways can be followed at the same time. For instance, Beijing consumes coal-fired electric power from Inner Mongolia but also engages in new and renewable energy technology cooperation with Inner Mongolia (Yang, 2009). The two localities collaborate not only for green and low-carbon technology innovations but for energy transition as well.

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[3] China's first CO_2 cycle power generation unit put into operation, http://www.cpnn.com.cn/news/kj/202112/t20211213_1465222.html.

[4] Chongqing Municipal Development and Reform Commission: "Joint Action Program for Carbon Peak and Carbon Neutrality in the Economic Circle of Chengdu and Chongqing (Consultation Draft)", http://fzggw.cq.gov.cn/hdjl/yjzq/202111/t20211119_9996222_wap.html.

4. Strengthening Institutional Development for Regional Coordination in Low-Carbon Development

Pathways for regionally coordinated low-carbon development can be designed with respect to industrial restructuring, energy transition, and green and low-carbon technology innovations. However, we now turn to certain institutional and policy barriers, including barriers to the formation of institutional mechanisms and the lack of incentives due to inadequate institutional mechanisms or policies. Solving these problems can help facilitate the formation of regionally balanced low-carbon development pathways as well as keep those pathways stable in the long run.

4.1 Institutional Problems and Countermeasures for Regional Coordination for Industrial Restructuring

Interest distribution presents a key institutional barrier to regional coordination for industrial restructuring, and one decisive interest distribution mechanism is the fiscal system. China's tax sharing reform of 1994, also known as fiscal decentralization, has incentivized local economic development at the expense of interregional coordination for optimizing industrial structure and reducing carbon emissions. Such adverse effects have been amplified by the government's GDP-centric performance evaluation system and the division of administrative powers related to fiscal decentralization. Some eastern regions have been reluctant to relocate energy-intensive enterprises to western regions for fear of losing tax revenue（China Center for International Economic Exchanges, 2014）. The GDP-centric government performance evaluation system has also led some regions to be reluctant to relocate relevant enterprises over local GDP concerns.

Another concern is employment. Local governments in the eastern regions lack incentives to relocate energy-intensive enterprises, which not only contribute to tax revenue and GDP but employment as well（Jiang, 2009）. Moreover, investment projects across regions tend to become homogeneous. Under the above institutional mechanisms, localities may be tempted to engage in short-term projects with immediate effects. The dash towards repetitive projects, local protectionism, and vicious competition has prevented local governments from making efforts to improve industrial structure and has impeded national economic restructuring and low-carbon transition, especially if those repetitive projects were carbon-intensive. However, these problems may be alleviated by enhanced coordination especially with neighboring regions in industrial planning under carbon constraints.

However, some enterprises are reluctant to relocate to energy-rich western regions with unfavorable market systems, government services, support for industrial conditions, transportation infrastructure, and distances to markets. Moreover, the tax collection system based on the place of company registration rather than the place of taxable event has also discouraged some central and western regions from welcoming nonlocal enterprises, which make use of government services without contributing to local tax revenues.

The following six steps may address the above institutional problems. First, the central government of China can enhance the evaluation of local government low-carbon development performance to internalize low-carbon development as a major decision-making constraint. In addition, it can tighten the energy consumption and intensity, carbon peak, and carbon neutrality quotas for the eastern regions and moderately relax quotas for the western regions in an effort to smooth out usage among regions. Second, the government can view the creation of a new development paradigm as an opportunity to break through local administrative barriers, promote market integration, and allow the market to fulfill its role of optimizing resource allocation on a broader spatial scale by deepening market economic reforms and thereby increasing the efficiency of resource consumption and carbon emissions control both regionally and nationwide.

Third, various regions and especially neighboring regions can enhance industrial planning

coordination under carbon constraints and seek alignment with major national strategies on regional development, including the integrated development of the Beijing-Tianjin-Hebei, the Yangtze River Economic Belt, the Guangdong-Hong Kong-Macao Greater Bay Area, the Yangtze River Delta, and the Yellow River Basin regions. Various regions can give focus on their own competitive strengths and facilitate regional industrial division of labor in an effort to enhance carbon reduction effects. Fourth, economic development zones or industrial parks in various regions can be encouraged to enhance industrial chain cooperation and division of labor, optimize cross-regional resource allocation, and improve cross-regional industrial chain competitiveness and carbon emission efficiency.

Fifth, proactive efforts can be made to develop cross-regional industry associations or similar cooperation institutions and platforms, to enhance dialogue between industrial chain enterprises, and to enhance dialogue between enterprises and local governments for industry-wide low-carbon development. Finally, energy-rich central and western regions can further improve their business climate and strengthen their infrastructure development to make more sufficient preparations for receiving energy-intensive industries with higher prospects for economic growth.

4.2 Institutional Difficulties and Countermeasures Facing Regional Coordination for Energy Transition

Institutional problems are the key barriers to both China's nationwide energy transition (Zhu, 2015), and its regional coordination for energy transition. The key to energy transition is new energy development, which faces impediments to market access and insufficient incentives, and the key institutional problem facing regional coordination for energy transition is the absence of a nationally unified electric power market.

The impediments in access to new energy market. Gaining access to power grid and administrative approval represent key challenges to new energy market access. Not only does it take a protracted review and approval process for new energies to access the power grid, but the construction of a secure power grid is costly as well (Qin, 2020). When power supply is abundant, some local governments in particular resort to administrative interventions to prioritize local coal-fired power generation and show little interest in absorbing new energy electricity from outside their jurisdictions（Li and Chen, 2018）. Administrative review and approval of new energy projects involve various departments in charge of land, forestry, electric power, and environmental protection with numerous administrative steps, overlapping review and approval rights, multiple administrative authorities, and repetitive administration (Zhu, 2015; Qin, 2020).

In addition, the incentives for new energy development are incomplete. New energy development in China is constrained by land, electricity tariffs, fiscal subsidies, and financial support limitations. With large chunks of land already occupied for economic development over the past few decades and ever-more stringent land space planning, China's land resources have become comparatively scarce, severely limiting new energy development. Regarding electricity tariffs, the problem has been that the cost of absorbing new energies cannot be effectively recognized in the electricity tariffs, thereby discouraging new energy absorption into the power grid, and the problem with fiscal subsidies is that it takes about two years for new energy enterprises to receive them. Regarding financial support, the new energy sector is a capital-intensive and high-risk sector faced with financing difficulties (Chen, 2011).

China's nationally unified power market has yet to be fully established, yet the electric power market is a key aspect of China's power system reform.[5] The first step toward fixing this may be to establish provincial electric power markets and cross-provincial regional power markets before improving cross-provincial and cross-regional electric power transaction mechanisms and establishing a nationally unified

[5] *Opinions on Further Deepening Power System Reforms* released by the CPC Central Committee and the State Council (Zhongfa [2015] No. 9).

power market. Currently, some progress has been made in developing provincial and cross-provincial regional electric power markets, but a nationally unified power market has yet to be fully established, the absence of which prevents surplus electric power in some regions from being allocated on a nationwide basis and impedes regional coordination for energy transition.

Based on the above problems, we put forth the following policy recommendations. First, proactive efforts should be made to develop an electric power market for new energies (Shi, 2018), and legal assurance should be enhanced for new energy market access in order to reduce administrative intervention that is unfavorable to new energy development. The new energy project review and approval system should be gradually replaced with a ratification system. Second, preference should be given to new energy projects regarding land resources in order for terminal electricity tariffs to reflect fully the cost of absorbing new energies into the power grid (Guo, 2021). The distribution of fiscal subsidies to new energy projects should be improved, and green finance should be developed vigorously to meet the massive cash demand from new energy development. New energy consumption should not be included into the scope of control on total energy consumption and energy intensity. Electric power enterprises may be granted carbon emission credits for absorbing new energies. Third, the government should implement the *Guiding Opinions on Expediting the Development of a Nationally Unified Electric Power Market System,*[6] race to establish a nationally unified electric power market system with multiple regional hierarchies, consistent transaction rules and technical standards, and strengthen the groundwork for regional coordination for energy transition.

4.3 Institutional Dilemmas and Countermeasures for Regional Coordination for Green and Low-Carbon Innovations

Green and low-carbon innovations are characterized by "dual externalities," i.e. propelling technological progress and improving environmental quality. Aside from institutional dilemmas facing other technological innovations, regional coordination for green and low-carbon technology innovations also face unique institutional problems for which we propose the following solutions.

First, create reliable financing mechanisms. As a high-risk commercial activity, innovation often struggles to garner financial support other than venture capital, which tends to be insufficient on its own to finance innovation. The shortage of funds is particularly striking for green and low-carbon technology innovations, which are intended to address environmental problems but cannot generate lucrative economic return if environmental regulation is lax. In promoting regional coordination for green and low-carbon technology innovation, local governments should establish regionally coordinated green innovation funds, relax bond market restrictions, encourage venture investment, intellectual property rights (IPRs), subsidized insurance, and in particular vigorously develop green finance.

Second, facilitate the cross-regional flow of talent. Currently, many problems including those on professional authentication, social security, and public services still pose barriers to regional coordination for green and low-carbon technology innovation. In response, the government should create a cross-regional talent database, adopt a unified and scientific talent evaluation system, and recognize cross-regional technical and vocational qualifications to award green and low-carbon professionals with social security and public service benefits.

Third, the government should create a sound cross-regional, market-based interest and risk sharing mechanism for collaborative innovation in green and low-carbon technologies. In the absence of such mechanism, various regions have learned from each other but have had little cooperation and have worked separately. An important reason for this is that companies have yet to become the backbone of green and low-carbon innovation, and the government-funded mode of innovation is unlikely to

[6] Deliberated and adopted at the 22nd meeting of the Central Comprehensively Deepening Reforms Commission on November 24, 2021.

form an interest and risk sharing mechanism on its own. In accordance with *Guiding Opinions on Creating a Market-Oriented Green Technology Innovation System* (Fa Gai Huan Zi (2019) No. 689), the government should enhance the status of enterprises as key players in green and low-carbon innovation and establish an interregional market-based interest and risk sharing mechanism that integrates industry, universities, research institutions, capital markets, and intermediary services.

Fourth, the government should expedite the development of a multi-tiered national green and low-carbon technology market. While the regional distribution of green and low-carbon technology innovations is uneven, the most innovative regions have a limited influence over other regions largely due to the absence of a national green and low-carbon technology transaction system to match the supply and demand of green and low-carbon innovations. Regional cooperation should be encouraged to establish cross-regional green and low-carbon technology transaction markets with standard operations, to foster intermediary service institutions and professional brokers, and to form a national green and low-carbon technology transaction market.

Finally, issues of legal assurance should be properly addressed. Despite overall improvements in China's intellectual property rights (IPRs) protection, some problems regarding green and low-carbon technology IPRs have yet to be addressed, including the sharing of profits from commercialization and the protection of relevant equity capital. Lax environmental law enforcement also discourages green and low-carbon innovations. Solving these problems requires improvements in relevant laws and regulations. In addition, regional coordination mechanisms should be established through work reporting, joint law enforcement, and regular meetings in order to enhance IPR protection.

5. Conclusion

Carbon peak and carbon neutrality have also become major constraints for China's development. As a basic principle for achieving its carbon peak and carbon neutrality goals, "national coordination" relies not only on differentiated policy-making according to actual conditions in various regions, but more importantly, coordinated policy-making between various regions as well. There is a prominent regional supply and demand mismatch in China's energy resources and green and low-carbon technologies. With intertwined interregional socio-economic relations and a policy vision for a new development paradigm, regional coordination for low-carbon development can become a feasible choice for China to make progress toward carbon peak and carbon neutrality. Judging by the key determinants on carbon emissions, we believe that regional coordination for low-carbon development should focus on industrial restructuring, energy transition, and green and low-carbon technology innovations and that related institutional mechanisms should be put into operation as soon as possible. This paper has made initial discussion on the pathways of regional coordination for low-carbon development, but further research is needed to address this policy issue at a deeper level. CE

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