

Problems and Countermeasures of Low Carbon Transformation in Manufacturing Supply Chain under the "Double Carbon" Target

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Abstract: *Manufacturing companies and their supply chains are the most important contributors to carbon emissions, and their low-carbon transformation is imperative. At present, the low-carbon transformation of China's manufacturing supply chain is facing many problems and challenges, including unbalanced industrial structure, insufficient independent innovation capacity, and insufficient diffusion effect of technological innovation. To overcome these problems, the government needs to lead manufacturing supply chain enterprises and low-carbon technology enterprises to jointly establish a regional collaborative innovation system, promote the low-carbon transformation of the manufacturing supply chain, and help China achieve the goal of double talk as soon as possible.*

Keywords: *Manufacturing; Supply Chain; Low Carbon Transition*

1. Introduction

The rapid development of industrialization has brought unprecedented prosperity and progress to human society, but it has also triggered a series of environmental problems, such as global warming caused by large-scale greenhouse gas emissions, severe impact on human society due to frequent extreme weather events, over-exploitation of water resources has led to a decline in groundwater levels, serious pollution of lakes and rivers, and biodiversity loss poses a threat to the stability of the Earth's ecosystem. These problems seriously restrict the sustainable development of human society. Scientists around the world have reached a consensus on the root cause of environmental problems: unrestrained human behavior[1]. According to a report by the humanitarian organization Dara, if effective measures are not taken in a timely manner to address climate change, more than 100 million people worldwide will be lost by 2030, and economic growth will be reduced by 3.2%. Therefore, environmental problems have become a major obstacle to the development of human society. If effective measures are not taken to address them, they will pose a serious threat to the sustainable development of human society[2].

Building a green and low-carbon supply chain is the general trend [3]. Since the 19th National Congress of the Communist Party of China, China's economy has achieved fruitful results, maintained a reasonable growth rate, ranked among the top in the world, and has a prominent position in environmental protection. Green and low-carbon development has become an important direction. The reports of the 19th National Congress of the Communist Party of China and the 20th National Congress of the Communist Party of China emphasize building an economic system of green, low-carbon and circular development and promoting green and low-carbon economic and social development. With the improvement of economic development and living standards, energy demand has increased, and green and low-carbon transformation has become an inevitable trend. In 2023, the State Council Information Office emphasized unswervingly taking the road of green development and promoting a comprehensive green transformation. At the same time, as the world's largest manufacturing country and the world's largest energy consumption country, the green and low-carbon transformation of China's manufacturing supply chain is particularly urgent [4]. Driven by the dual-carbon goal, how to promote the green transformation of the enterprise development mode and lead more enterprises to the road of green transformation is a key issue that needs to be solved urgently. As a link between upstream and downstream enterprises, the supply chain plays a role that cannot be ignored in promoting the integrated development of large, medium and small enterprises and the green and low-carbon transformation[5]. Under the new development pattern, China's manufacturing supply chain is facing the challenge of

transformation and upgrading. Promoting green and low-carbon transformation will help improve competitiveness and sustainable development capabilities and achieve high-quality development. At the same time, the green and low-carbon transformation is also an important measure for China to deal with global climate change. Therefore, there is a need to strengthen green support and guidance.

2. Literature Review

2.1. Low carbon economy research

The global transition to clean air and a low-carbon economy is included in the United Nations Sustainable Development Goals, providing a common blueprint for humanity and the planet.[6] With the release of documents such as the Paris Agreement, a low-carbon economy has become a concept that governments around the world attach great importance to, especially for developing countries that rely mainly on fossil fuels[7]. As the world's largest developing country, China is required to develop a low-carbon economy[8] whether it is economic development, environmental improvement, increasing international trade competitiveness, or assuming the responsibility of a major power. And with the increasingly serious climate change, China's once extensive economic development mode can no longer be maintained, and various social and economic forms are gradually moving towards low-carbon [9]. In this regard, China has formulated the target strategy of "peak carbon dioxide emissions and carbon neutrality", but in the process of rapid carbon reduction in China, it faces the following challenges: first, China's energy consumption and carbon emissions, currently China's peak carbon dioxide emissions have not yet reached, carbon emissions continue to grow, second, China's transition period from peak carbon dioxide emissions to carbon neutrality is shorter than that of developed countries, which will be a formidable challenge, third, China's current dependence on high-carbon fossil energy is high, and energy consumption is high and efficiency is low. Fourth, China's low-carbon and zero-carbon technologies are still immature[10].

In order to avoid a global average temperature rise of more than 1.5 degrees, it is necessary to reduce net carbon emissions to zero by mid-century[11]. Therefore, in order to help the development of low-carbon economy in China and the world, scholars have launched various studies.

(1) Connotation of a low-carbon economy. In 2003, the United Kingdom put forward the concept of "low-carbon economy" for the first time. This is an economic model that minimizes energy consumption and environmental pollution in economic development and improves economic benefits. Domestic scholars have different interpretations of the connotation of a low-carbon economy. Bao Jianqiang et al. [12] believe that a low-carbon economy is a new economic development model adopted by human beings under the energy crisis and environmental degradation. By changing lifestyles and production methods, reducing dependence on fossil energy, and achieving coordinated economic and environmental development. This revolutionary transformation has a profound impact on human daily consumption choices and various industrial production and development methods. It will change the types and methods of social energy consumption and have a profound impact on the development of human society. Pan Jiahua et al.[13] believe that a low-carbon economy can achieve economic model transformation by improving energy output rate and human development level, etc., in order to achieve the harmonious development of humans and nature. This transformation is of great significance, can reduce environmental pollution and resource waste, is conducive to social stability and sustainable development, and enables people to better enjoy the benefits brought by economic development. Overall, the core characteristics of a low-carbon economy can be summarized as reducing emissions and improving efficiency.

(2) Measurement of the low-carbon economy. At present, the assessment of the level of development of the low-carbon economy has not been unified. Mainstream research mainly selects relevant indicators that can represent the low-carbon economy in the form of indicator systems to comprehensively evaluate the level of development of a low-carbon economy. For example, Liu Tiansen et al.[14] selected four indicators from the stage of economic development, the degree of human development, the level of technology and the policy environment to measure the low carbon economy. Liu Xiaoyu[15] measured the development level of low-carbon economy through entropy method from five aspects: energy, energy consumption, consumption, environment, science and technology and economy. Mohsin M[16] and others have developed a comprehensive index of energy security and environmental sustainability for each of the world's highest greenhouse gases and carbon monoxide. The current literature on measuring the level of low-carbon economic development focuses mainly on hard indicators such as energy, pollution, and the environment, and less on soft power indicators such as policy, advocacy, and awareness.

(3) Low-carbon technologies. The transition to a low-carbon economy will require large-scale structural transformation[17]. In this process, the importance of low carbon technologies is self-evident. Studies show that by 2030, China can generate up to 640 gigawatts of electricity through low-carbon technologies, which can reduce carbon emissions by about 30% over the next 20 years[18]. It is worth mentioning that the development of financial technology can actually help reduce greenhouse gas emissions [19]. Integrated energy systems (IES) have received great attention due to their attractive economic and environmental benefits, particularly electrical coupled energy systems (EGCES) that can reduce carbon emissions and power generation costs to a large extent when combined with methods such as model-free deep reinforcement learning[20]. Renewable electricity is also one of the technologies that scholars are focusing on, which can use carbon dioxide to generate fuels and chemicals, reducing carbon emissions in energy- and product-driven economies[21].

It is worth mentioning that studies have shown that reasonably strict environmental regulations can promote technological innovation in enterprises and achieve a win-win situation for the economy and the environment, that is, a win-win situation for environmental and economic benefits advocated by the Porter Hypothesis can be achieved[22]. However, it also emphasizes the continued need for state regulation to play a role in a just energy and climate transition: renewable energy needs to be made accessible and affordable to all[23].

2.2. Low Carbon Supply Chain Research

In the context of a low carbon economy, manufacturing enterprises and their supply chains are the most important contributors to carbon emissions [24], and their low carbon transformation is imperative. Low-carbon supply chain is a concept born to meet the needs of the new era of low-carbon economy. It integrates green, low-carbon and environmental concepts and technologies into the construction of the supply chain [25]. It emphasizes synergy and cooperation among the main members of the supply chain, and finally achieves the purpose of both economic and environmental benefits, and realizes the optimization of resource allocation and sustainable development. Low carbon supply chain is a relatively new research area with relatively short development to date. This paper mainly reviews the literature from the aspects of performance decision-making, collaboration and influencing factors of low carbon supply chain.

(1) Factors affecting the low-carbon supply chain. With the acceleration of globalization, competition among enterprises has entered the stage of competition among supply chains. In this case, the construction of a low carbon supply chain and the mechanism of its influencing factors are extremely important. Low carbon supply chain financing decisions [26], consumer preferences [27], product emission reductions and goodwill [28], various uncertain disruption risks [29], and green finance subsidies and low carbon subsidies [30] will all have a significant impact on the construction and development of a low carbon supply chain. It is worth mentioning that Ambekar S' research [31] shows that culture also plays a certain role in the capacity of a low carbon supply chain, and proposes a carbon culture adoption model based on this. In addition, factors such as fairness, attention to behavior, and sales services will also have a certain impact on the stability and complexity of a low-carbon supply chain[32].Sun L et al. [33] considered the emission reduction technology lag time and consumers' low-carbon preference for the supply chain carbon emission reduction transfer strategy. The results show that the delay in emission reduction technology and consumers' preference for low carbon have a positive impact on the level of carbon transfer by manufacturers, but have no impact on the level of suppliers.

(2) Low-carbon supply chain collaboration. The core of the supply chain lies in collaboration among members to achieve the goal of optimizing resource allocation. Scholars' research on collaboration among members of the low-carbon supply chain not only considers profitability, but also considers achieving carbon reduction. Zhang Wenyan [34] pointed out that the coordination of the low-carbon supply chain can improve the overall performance of the supply chain, such as reducing inventory levels, speeding up turnover and reducing carbon emissions. Doing a good job in supply chain collaborative knowledge management and the establishment of a low-carbon supply chain are inseparable [35].Supply chain contracts such as cost-sharing contracts and revenue-sharing contracts can promote supply chain collaboration, and low-carbon supply chains are no exception. Wang Y et al.[36] proposed a cost-sharing contract with altruistic preference, which can generate incentive-compatible coordination solutions. Shi J et al.[37]'s research shows that procurement commitment contracts can achieve coordinated improvements in supply chain economic and environmental effects under certain conditions.Yu B et al. [38] studied cost-sharing contracts and revenue-sharing contracts, considering collaboration in low-carbon supply chains with reference emissions and cost-learning effects.Furthermore, collaboration between subject members, such as supply chain partnerships, can improve supply chain visibility[39]

and help improve green supply chain performance. The incentive effect of manufacturer-seller cooperation can be influenced by reputation mechanisms.

3. Problems and Countermeasures of Low Carbon Transformation in Supply Chain

3.1. Development Status of China's Manufacturing Industry

China's manufacturing industry plays an important role on a global scale. First, China's manufacturing industry has the most comprehensive and huge industrial categories in the world, from home appliances, automobiles to communication equipment, and other industries have strong manufacturing capabilities. Since 2010, China has been consistently ranked as the world's largest manufacturing country. The value added of the manufacturing industry has increased from 16.98 trillion yuan in 12 years to 33.50 trillion yuan in 22 years, and its global share has also increased from 22.5% to nearly 30%. Second, China's manufacturing industry has successfully integrated into the global supply chain and has become one of the main hubs of the global manufacturing industry. As the "world's factory", China's low cost has attracted the transfer and cooperation of a large number of foreign manufacturing enterprises, which has promoted the continuous growth of trade volume. In addition, China's manufacturing industry is also constantly improving its mid-to-high-end competitiveness, covering photovoltaics, new energy vehicles and other fields. In the first three quarters of 23 years, China's manufacturing industry investment in technological transformation accounted for nearly 40% of all manufacturing investment, driving traditional industries to accelerate transformation and upgrading to high-end, intelligent and green, and also releasing more growth momentum. Industrial value added above designated size increased by 4% year-on-year. Among them, high-tech manufacturing accounted for 15.3% of industrial added value above designated size, and equipment manufacturing accounted for 32.9%, as shown in Figure 1.

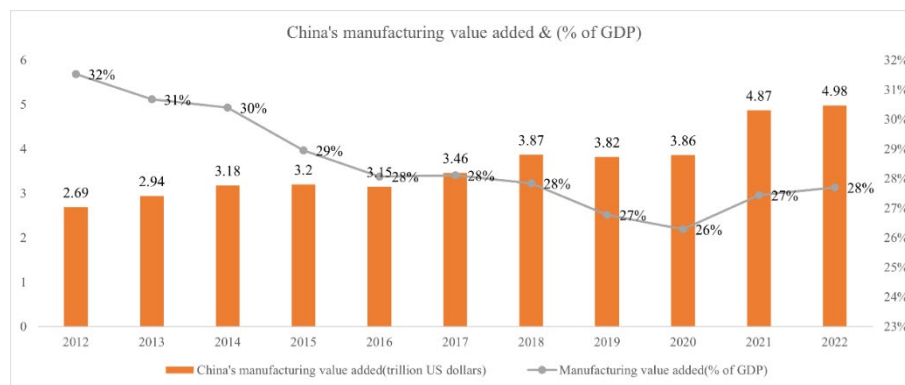


Figure 1: China's manufacturing value added and its share of GDP.

However, China's manufacturing system also has flaws and faces many challenges. The impact of the COVID-19 pandemic has shifted from the inside of the industry to the outside, from the supply side to the two-way impact of supply and demand, which has exacerbated the fragility of the supply chain system, causing Chinese manufacturing enterprises to suffer huge losses in this epidemic. At the same time, the return of manufacturing in some countries led by the United States and Japan and the transfer of some manufacturing industries to South East Asia and Mexico and other regions have also had a negative impact on the development of China's manufacturing industry and supply chain management. Although the scale of China's manufacturing industry is large, it is not strong. On the one hand, it is due to the lack of high-end technology, and on the other hand, it is due to the shortcomings of the supply chain. Compared to developed countries, China's supply chain system is deficient. The supply chain system of manufacturing enterprises is fragmented, fragmented and inefficient, so that the supply chain system of a large number of manufacturing enterprises. The current turnover rate of industrial and distribution enterprises in developed countries is generally more than 10 times, while China has only about 3 times. The product inventory rate of industrial enterprises in developed countries basically does not exceed 5%, while China has reached 9.4%. The logistics cost of enterprises in developed countries is generally less than 15% of the total cost, while China's share often exceeds 30% or even 40%. These are due to the lack of supply chain service systems, which will not only increase the cost of enterprises, but also reduce the operational efficiency of enterprises.

At the same time, with the development of the economy, people's living standards have gradually improved, and demand has gradually shifted from "hoping for food and clothing" to "hoping for

environmental protection." However, the development of the manufacturing industry requires a large number of resources such as energy, water and land, and also generates a large amount of waste and pollutants, which contradicts consumers' gradually strengthening green preference. In order to meet consumers' needs and achieve sustainable and high-quality development, China must accelerate the green and low-carbon transformation of the manufacturing industry, and improve the quality and added value of products while reducing environmental pollution and energy consumption. We need to accelerate the digital, intelligent and green transformation of the manufacturing industry in terms of production methods, management models and marketing models, in order to adapt to the development trend of new technologies, promote high-quality economic development, and gain a firm foothold in international competition.

3.2. Analysis of carbon emissions in manufacturing industry

China's manufacturing industry is the leading industry in the national economy. Although dependence on carbon emissions is accelerating, manufacturing carbon emissions have entered a high adjustment period and are on the rise again. Since reform and opening up, China's investment-driven and factor-driven growth model has made the carbon emissions generated by manufacturing investment and exports more intense. According to the comparison of domestic and external demand, since 2017, about 20% of China's carbon emissions have been used to meet external demand. According to 2017 data, the carbon emissions of China's manufacturing industry to meet export are 1.81 billion tons, accounting for 52.3% of the carbon emissions of the entire industry. Among exports, the chemical, steel, metal products, general equipment, electrical machinery and equipment industries account for only 34.3% of total exports, but account for 52.5% of the carbon emissions of export products. That is, one third of exports generate one half of carbon emissions. It can be seen that the important position of the manufacturing industry in China's economy and the export-oriented structure formed in the long-term development of the manufacturing industry have formed a certain obstacle to its green development.

Relevant data show that China's manufacturing carbon emissions reached a high of 3.86 billion tons in 2014, and then began to decline year by year. However, since 2019, investment and output in high-carbon industries have begun to increase, and manufacturing carbon emissions have increased. According to data released by CEADs, the carbon dioxide emissions of China's major industries in 2019 were: electricity, steam and hot water (4.642 billion tons), manufacturing (3.505 billion tons), transportation, warehousing, post and telecommunications services (732 million tons), mining (122 million tons), agriculture, forestry, animal husbandry and fishery (91 million tons), wholesale, retail trade and catering services (68 million tons). Manufacturing accounted for 55.1% of the country's total energy consumption in 2019, and emissions accounted for 34.2% of the country's total emissions. No matter what statistical caliber is used, manufacturing is undoubtedly the main source of carbon emissions. Among them, taking the steel industry as an example, the energy consumption of China's steel industry in 2020 reached 575 million tons of standard coal, accounting for about 11.6% of the total energy consumption. It has the highest carbon emissions in China's manufacturing industry. Cement, nonferrous metals, building materials, chemicals and other industries also face similar problems.

By the end of 2021, China's manufacturing industry accounted for two-thirds of the secondary industry in terms of total energy consumption and carbon emissions, and accounted for one-third of China's total energy consumption and carbon emissions. Due to the high consumption of electricity by industry, if the electricity consumed in the production and manufacturing process is taken into account, the proportion of total carbon emissions will continue to rise. Therefore, in order to achieve the goal of "carbon neutrality", in addition to vigorously developing renewable energy such as wind energy, solar energy, hydropower, and reducing carbon emissions in the power industry, the transformation of "carbon neutrality" in the manufacturing industry has become the key to achieving global "carbon neutrality".

According to the Energy Big Data Report for 2023, China's manufacturing carbon emissions have decreased by 18% in the past five years, reflecting the remarkable results of the low-carbon energy transformation. In addition, China's total energy consumption in 2022 was 5.41 billion tons of standard coal, of which coal consumption increased by 4.3%, while crude oil and natural gas consumption decreased by 3.1% and 1.2% respectively. These data show that China's energy consumption structure is changing. With the continuous regulation and promulgation of policies, through key measures such as industrial structure adjustment, energy structure optimization and market mechanism improvement, the green manufacturing system of the manufacturing industry has been initially formed. So far, China has completed the construction of 2,121 green factories, 171 green industrial parks, 189 green supply chain enterprises, and nearly 20,000 kinds of green products have been promoted. In recent years, China's manufacturing industry has achieved remarkable results in energy conservation and carbon reduction,

which is not only due to the perfect top-level design, but also relies on the multi-dimensional and full coverage of the industrial low-carbon development system formed for different key areas. To date, MIIT has released a total of 128 green design demonstration enterprises, with a total of 2,170 green design products.

China's regional carbon emissions are mainly determined by the long-term structure of the manufacturing system and industrial distribution. From a spatial perspective, China's carbon emissions are high in the north and low in the south. The total carbon emissions and per capita emissions in the northern provinces are significantly higher than those in the southern provinces, and the carbon emission gap between the north and the south is still widening; from a time perspective, carbon emissions show a trend of rising from west to east, and the per capita carbon emissions in the western provinces are in a continuous upward stage, while the carbon emission intensity in the eastern provinces is significantly reduced. The main reason for the regional differentiation of carbon emissions is that the energy-intensive industries in China's manufacturing industry, such as steel, chemical industry, non-ferrous metals, cement, etc., are more concentrated in the northern and western regions, which makes the per capita carbon emissions in the northern region 1.66 times that of the southern region, and the carbon emission intensity is 2.1 times that of the southern region. At present, China's high-energy-consuming manufacturing industry is in a transition period from extensive to intensive, and its development model still mainly relies on high-intensity energy input and intensive resource use to drive growth. However, more than half of China's southern provinces are in the post-industrialization stage. The manufacturing industry in the region is mainly light, digital and intelligent, and the added value is relatively high, which makes the accumulation of capital, technology and high-quality labor in these regions more significant in promoting the green development of the manufacturing industry. With the establishment of carbon-neutral targets and the adjustment of regional industrial structure, energy-intensive and labour-intensive industries are gradually undergoing a spatial shift from south to north and from east to west. However, the transfer of high-emission industries will further exacerbate the green development gap between regions, posing new challenges to the high-quality development of manufacturing.

3.3. Problems existing in the low-carbon transformation of the manufacturing supply chain

In the process of achieving the goals of peak carbon dioxide emissions and carbon neutrality, the transformation problems and development difficulties faced by China's manufacturing supply chain cannot be ignored. From a macro perspective, China's manufacturing supply chain has achieved certain results in green and low-carbon transformation under the background of high-quality development, which is mainly due to the continuous introduction of various environmental regulation policies by the Chinese government and the continuous enhancement of consumers' environmental awareness. Together, these two are driving the green transformation of China's manufacturing supply chain. On the one hand, the government's environmental regulation policies provide policy support and legal protection for the green transformation of the manufacturing supply chain. On the other hand, the enhancement of consumers' environmental awareness also prompts manufacturing enterprises to continuously improve the level of environmental protection and promote green production.

However, the development of China's manufacturing industry is not smooth sailing, and it is currently facing a series of transformation problems and development difficulties. First, the development of China's manufacturing industry has entered a bottleneck period, and there is a problem of insufficient independent innovation capacity. Although the Chinese government has issued a series of policies to encourage enterprises to increase R&D investment, from the current situation, the R&D investment of China's manufacturing enterprises is still low, and the ability of scientific and technological innovation is relatively weak. Especially in some key low-carbon technology areas, the independent innovation capacity of China's manufacturing enterprises needs to be further improved. Secondly, the diffusion effect of technological innovation is insufficient. The diffusion effect of technological innovation refers to the diffusion and diffusion of technological innovation from the source of innovation to peripheral economies, thus promoting the development of the entire industry. In the process of low-carbon transformation of China's manufacturing supply chain, due to the insufficient diffusion effect of technological innovation, the transmission speed of technological innovation in the supply chain is slow, which also limits the low-carbon transformation of the manufacturing supply chain. From a micro level, the green and low carbon transformation of the manufacturing supply chain faces two key challenges. First, in China's manufacturing supply chain, there is a lack of scientific and effective top-level design, and many manufacturing supply chain enterprises, especially small and medium-sized supply chain enterprises, lack low-carbon strategies, advanced low-carbon technologies and low-carbon operation capabilities. It is difficult to achieve the low-carbon transformation of the supply chain by relying on enterprises

themselves. Therefore, most supply chain enterprises are still in the initial stage of low-carbon transformation, and the overall effectiveness of low-carbon transformation has not been fully reflected. Second, the synergies of the low-carbon transformation system in the manufacturing supply chain are not obvious. Most underdeveloped regions lack low-carbon technology service providers. There is an imbalance between technology supply and demand in low-carbon transformation, and the task of low-carbon transformation is arduous.

3.4. Countermeasure suggestions

Based on the previous research conclusions, some countermeasures and suggestions for promoting the green and low-carbon transformation of the supply chain are put forward from the perspective of supply chain enterprises and local governments.

(1) Supply chain companies. At present, the cost of science and technology investment, equipment purchase and other costs required for the low-carbon transformation of supply chain enterprises will cause greater financial pressure on enterprises, and the performance improvement brought by the low-carbon transformation in the short term cannot cover this part of the cost. However, in the long run, the low-carbon transformation brings not only the improvement of production efficiency, the change of mode, the improvement of reputation, but also the reduction of costs and the improvement of financial performance and green performance to enterprises. When the benefits of low-carbon production are greater than the costs of technology introduction and other costs paid by supply chain enterprises in the transformation process, enterprises will dare to take the initiative to switch to low-carbon production mode, and in this process, whether it is government policy guidance or consumers' low-carbon preferences will push enterprises towards low-carbon production. However, whether low-carbon technologies can be truly applied to actual production and enjoy the financial and green double dividends brought by low-carbon technologies to enterprises depends on whether advanced green and low-carbon technologies can be applied to all aspects of the supply chain, such as product upgrades, materials use, technological innovation, layout optimization, and efficient management. Integrate low-carbon technologies into production and shift to low-carbon production mode. Optimize resource allocation while improving resource utilization efficiency, and achieve a win-win situation for enterprise financial performance and green performance.

(2) Local governments. Local governments play an important role in promoting the green and low-carbon transformation of the supply chain. The subsidies or penalties they issue are universal and effective for the green and low-carbon transformation of the supply chain, and are the main driving force for the current green and low-carbon transformation in China. In the process of green and low carbon supply chain transformation, the government should play a role in promoting and guiding, breaking down the information barrier among various stakeholders, and guiding the direction of market development. The government can promote the green and low-carbon transformation of the supply chain by setting up special project funds to support research and development of low-carbon technologies or to guide social capital towards green and low-carbon transformation. For example, the reward and subsidy policy for high-tech enterprises in green and low-carbon advantageous industries in Sichuan Province and the measures for the development of high-quality services supported by the ecological environment in Nanshan District of Shenzhen encourage enterprises to actively develop low-carbon technologies and apply them to actual production, so as to promote the transformation of the local manufacturing industry to a low- Therefore, local governments should give full play to China's market and institutional advantages, guide enterprises and service providers to cooperate, build a coordinated development ecosystem that adapts to the local green and low-carbon shift, accelerate the application of low-carbon technologies in actual production, and promote the green and low-carbon transformation of the supply chain.

4. Conclusion

At present, the low-carbon transformation of China's manufacturing supply chain is facing problems such as insufficient independent innovation capacity and insufficient diffusion effect of technological innovation, which restrict the low-carbon transformation of the manufacturing supply chain. Lack of scientific and effective top-level design and lack of clear synergies are two key challenges. Based on this, we suggest that the low-carbon transformation of supply chain enterprises requires scientific and technological investment and equipment procurement, which may cause financial pressure in the short term, but in the long run, the low-carbon transformation will bring about production efficiency

improvement, mode change, word-of-mouth improvement, and cost reduction. When the benefits outweigh the costs, companies will switch to low-carbon production. Government policy guidance and consumers' low-carbon preferences will both promote the low-carbon transformation of businesses. The government should play a role in promoting and guiding the establishment of special project funds to support research and development of low-carbon technologies, guiding social capital towards green and low-carbon transformation.

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