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By Li Ping, Yang Danhui, Li Pengfei,
Ye Zhenyu and Deng Zhou, Institute of
Quantitative and Technological
Economics, Chinese Academy of Social
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By Li Ping, Yang Danhui, Li Pengfei, Ye Zhenyu and Deng Zhou, Institute of Quantitative and Technological Economics, Chinese Academy of Social Sciences

Summary

China's speedy industrialization has undertaken mostly a crude path with extensive energy consumption and severe environmental damage. In face of the challenge of global warming and resource restrictions, it calls for urgent green transformation for the sustainable development of China's industry. With huge potentials and more general benefits than costs, the industrial green transformation in China will have more positive effects and accelerate the whole process of the development of China's green economy. From this perspective, China needs to adopt a comprehensive and open mechanism for green transformation with more strict environmental regulations, effective energy conservation and emissions reduction, green technology R&D and application, as well as international cooperation in the related fields with market-oriented reform, government strategies and regulations, proactive response from the industry sector, self-initiative of enterprises and active public participation.

Keywords: Industry, Green Transformation, Technology Roadmap, Cost and Benefit

JEL Classification: Q5, Q55

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Address for correspondence:

Li Ping
Institute of Quantitative and Technological Economics
Chinese Academy of Social Sciences
N.5 Jianguomennei Dajie
100732 China
E-mail: lipingmsn@msn.com

A Study on Industrial Green Transformation in China

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Abstract: China's speedy industrialization has undertaken mostly a crude path with extensive energy consumption and severe environmental damage. In face of the challenge of global warming and resource restrictions, it calls for urgent green transformation for the sustainable development of China's industry. With huge potentials and more general benefits than costs, the industrial green transformation in China will have more positive effects and accelerate the whole process of the development of China's green economy. From this perspective, China needs to adopt a comprehensive and open mechanism for green transformation with more strict environmental regulations, effective energy conservation and emissions reduction, green technology R&D and application, as well as international cooperation in the related fields with market-oriented reform, government strategies and regulations, proactive response from the industry sector, self-initiative of enterprises and active public participation.

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I. Introduction

Industrial production is a major source of modern material wealth, meanwhile human industrialization process results in the destruction of the environment and ecosystem. In the 1950s and 1960s, the environmental pollution problems have become increasingly prominent in the industrialized countries; the resources consumption and environmental damage caused by the development of heavy chemical industries have made developed countries pay a heavy price. Developed countries initially dealt with industrial pollution by mainly adopting end-of-pipe treatment method, while industrial alternative upgrade, which makes large-scale overseas transfer of high-emission and high-polluting industry production capacity, has become an important channel for restructuring of the developed countries. Along with technology advance and economic structure changes, the Environmental Kuznets Curve (EKC) of the developed countries show the inverted U-shaped curve, and the emission of major industrial pollutants declines with economic growth, but relative decline of environmental pressure of the developed countries in the post-industrial era does not mean that these countries and regions will inevitably embark on the path of sustainable development, while the inverted U-shaped EKC, to some extent, is precisely the result of shifting their high-polluting industries to developing countries.

However, the end-of-pipe treatment mode does not cure the industrial pollution in developed countries. In the 1970s~1990s, developed countries still faced many environmental problems such as migration and conversion of heavy metals and other pollutants in the environmental media, reduction in biodiversity, increase in non-point source pollution, etc. In this case, the developed countries transformed environmental governance mode, and implemented "clean production" and preventive environmental policy whose contents include "full-range control" and "source reduction".

After the outbreak of the international financial crisis, the economic growth mode supported by resource consumption and demand pull suffered a huge impact. In post-crisis era, the developed countries have started to re-examine the important role of the industrial sector in the formation and accumulation of wealth, and successively proposed "re-industrialization" ideas, and the world economic growth mode faced comprehensive and in-depth adjustment. In the context of the difficult recovery and in-depth adjustment of global economy, in

October and December of 2008, the United Nations Environment Programme (UNEP) launched a global initiative on “green economy” and “Green New Deal”. This initiative received a positive response from the developed countries, the governments of the United States, the European Union and other developed countries successively increased financial support to encourage domestic enterprises to explore the new direction of the green industrial transformation and low-carbon development of their enterprises, explore new economic growth point, thus occupying a commanding height in strategic emerging industries.

The term “green economy” derives from a book *Blueprint of Green Economy* written by the British environmental economist David Pearce and published in 1989. To date, there is no uniform definition on green economy, the relevant definitions largely emphasized “jointly increase the economic and environmental benefits to achieve sustainable growth through economic behaviors which are beneficial to environment or do not confront with environment” (OECD, 2009; research group of Chinese Academy of Sciences, 2010; Xia Guang, 2010). Combined with the elements and technical characteristics of the industrial sector, as an important part of the green economy, industrial green transformation refers to the realization of green and sustainable development of full range of industrial production and the realization of win-win between economic and environmental benefits, oriented by intensive use of resources and environmental friendliness, with green innovation as the core, through sticking to the road of new industrialization.

From its connotation, green transformation is an industrial process towards “intensive energy resource utilization, reduced pollutant emissions, reduced environmental impact, improved labor productivity, and enhanced sustainable development ability”, and is a negation of negation of the past nearly 300 years of industrialization practice since the industrial revolution. Compared with the traditional “black”, “brown” or “gray” patterns of industrial development, the connotation of industrial green transformation is dynamic, covering various aspects of the entire industrial value chain. Industry boundary facing industrial green transformation is dynamic, with greater extensibility. The application potential of green technology in industrial field and the market space of green industrial goods are both great, and along with gradual deepening of human awareness of industrial production environment impact, the goals and tasks of the industrial green transformation will continue to be adjusted, and this adjustment should be based on carrying capacity of resources and environment, and aims at actively seeking for separation of industrial growth from resource consumption and environmental degradation. At the same time, industrial green transformation needs to be supported by comprehensive innovation of idea, technology and system. Green technology R&D investment is great, with certain risks, while green innovation of industrial technology needs not only conduct green upgrading and transformation of traditional industrial technologies, but also vigorously develop new energy, new materials and other new technologies as well as emerging green industries.

In the past thirty years, the industry is China’s fastest-growing sector which is subject to greatest reform efforts and highest opening-up degree. Accelerated industrialization has made a significant contribution to the continued growth of the Chinese economy. In 2009, China had become the world’s second largest manufacturing country after the United States, and there were more than 220 kinds of industrial products ranking top in the world in terms of output. However, for a long time, China’s economic growth and industrialization development mainly depend on the resource-based growth mode, and lead the industrial development characterized by high investment, high consumption, high pollution, low quality, low efficiency, low output and pollution first and treatment later. During the 12th Five-year Plan Period, China faces an important period of strategic opportunities for transformation and upgrading. On one hand, as an industrial main body of the Chinese economy, the industry has a broad market space; on the other hand, heavy chemical industry still has a strong impetus for expansion, and the resource waste, environmental degradation, structural

imbalance and other problems are still very obvious in industrial sector. In face of changes in the international environment and domestic situation, it is of great strategic significance to accelerate the transformation of the way of China's industrial development, achieve industrial green transformation, and form sustainable competitiveness. Green transformation is a fundamental requirement of new industrialization road, and also the only way to promote China to shift from a big manufacturing country to a manufacturing power. As an industrial main body of the Chinese economy and the field with strongest international competitiveness and highest opening-up degree, the industrial sector's taking the lead to achieve green transformation is not only more operational, but also has a positive demonstration effect on promoting green economic development in China.

This paper discusses the structural and institutional obstacles facing China's industrial green transformation, and designs the technology roadmap of industrial green design, analyzes cost-benefit of industrial green transformation. On this basis, this paper proposes mechanism innovation system and policy measures on industrial green transformation.

II. Mechanism and Institutional Obstacles Facing Industrial Green Transformation

Over three decades of reform and opening up, China's industrial development has made remarkable achievements. The scale of industrial production and exports is expanding, and the growth rate maintains a high level; the industrial structure is further optimized, and the organizational structure is more reasonable; the overall level of industrial technology is significantly improved, and the cutting-edge scientific field makes breakthroughs; progress is made in terms of industrial resource use, and initial effect has been shown in energy saving and emission reduction; industry international competitiveness is gradually enhanced to accelerate the process of internationalization. However, China's industrial structural contradictions are still outstanding, with weak sustainable development ability and some deep-seated problems. A series of problems and challenges facing China's industrial development are closely related to the existing institutional mechanism. When promoting green transformation of the manufacturing industry, governments and enterprises face some obstacles in terms of internal motivation and external conditions. These obstacles are mainly reflected in:

First, local government officials assessment and promotion mechanism are unreasonable. Over the past three decades, local government officials have sped up the development of the local economy and taken a variety of means to seek for all potential investment resources, their enthusiasm may be extremely rare in the world, some scholars view it as a reason for miracle of China's 30 years of economic growth.^①GDP-oriented promotion mechanism is a relatively single incentive method. In this evaluation mechanism, the political promotion pressure causes government officials to tend to ignore the long-term effects but focus on short-term objectives, namely, to promote economic growth as much as possible during their terms of office. Currently, the central and local governments face asymmetrical pressure in the transformation and upgrading. The central government should not only consider the sustainability of risks in macroeconomic performance as well as the sustainability of long-term economic and social development, but also bear increasing pressure from the international response to climate change, while the central government reduces such pressure by merely relying on energy-saving and emission reduction targets and environmental accountability system, it is difficult to push the local government to the track of transformation and upgrading. The real political achievements previously made by some places in the pursuit of GDP have indeed played a significant

^① Zhou Li'an (2008) and Zhang Wuchang (2009) conducted a in-depth study of local competition and economic growth.

demonstration effect, while the central and western regions also tasted the sweetness in undertaking eastern industrial transfer, which made a lot of local governments still pursued GDP and pursued heavy chemical projects during the 12th Five-year Plan Period, especially the introduction of strong will and power of large state-owned enterprises. Therefore, only relying existing energy-saving and emission reduction targets during the 12th Five-year Plan Period plays a limited role in promoting the local economic transformation and upgrading. The reality is that, for over 2,860 county-level economic units, energy conservation target assessment is difficult to pose a threat to their determination to develop the local economy, and these units lack interest in industrial green transformation and other long-term projects which needs high investment and takes long time for achieving effect. It shows that the GDP-oriented political performance evaluation system still plays an important impact in the local government decision-making, and the incentive mechanism has not been formed to encourage the local officials to promote industrial green transformation.

Second, factor price formation mechanism reform is not complete. At present, in the price formation mechanism in the factor resource field, non-market-oriented pricing means still plays a certain role, factor price distortion has impeded industrial transformation and upgrading. Because China has long adopted non-market-oriented pricing means in resource use, the guiding role of such price signals on enterprises as microcosmic bodies will have sluggish or time lag phenomenon, resulting in that enterprises lack motivation to change their management mode or improve technological processes. Meanwhile, rationalizing the prices of natural resources should also consider the environmental costs brought by resource extraction; however, for a long time in the past, the resource tax rate set by the country was too low, much lower than the actual cost of environmental governance, low tax rate was difficult to offset the environmental damage, and curbed the enterprises' behavior of damaging environment. Although China's factor resource prices have increased to large extent in recent years, the price conduction needs a long time before the enterprises make up mind to take initiative to conduct green transformation. In addition, if the factor resource prices rise too fast, which makes a large number of small- and medium-sized enterprises close down due to failure to withstand price increase pressure, and these enterprises will lose the opportunity to participate in the green transformation.

Third, obstacles exist in technological innovation, transfer and application. Promoting the industrial green transformation highly needs supports of the perfect technology innovation system, but there are many problems in terms of technological innovation and application. First of all, investment in technological innovation is not enough. As for Chinese industrial enterprises, the proportion of R&D investment in the total sales revenue is at least 0.5 percentage points lower than that of the advanced countries in the world, showing more obvious gap with the world's top 500 enterprises. The innovation investment projects of Chinese enterprises pay much attention to the technologies with strong applicability, the basic research is relatively weak, which is not conducive to the long-term accumulation of technological innovation. Secondly, technological innovation-related intellectual property protection system is not perfect, which affects enthusiasm of enterprise innovation. Again, technical standards and equipment types are different, which makes it difficult to widely apply green technology in the industrial area in China.

Fourth, environmental compensation mechanism is not perfect. For a long time, China has not really established an ecological environment compensation mechanism across the regions in the country, resulting in ecological fragility or long-term damage to the interests of the resource-rich regions, as well as the loss of opportunities for local economic development. For example, the environmental costs of resource extraction is not priced by market mechanism and not incorporated into raw materials cost accounting, which causes raw material prices to deviate from market price for a long term, and the downstream enterprises or consumers can

not make adjustments of such price distortions, and are difficult to establish a “green consumption” philosophy. In addition, the Chinese industry has not yet formed a green growth accounting system, nor introduced the policy tools with function of market regulation, for example, carbon tax causes the environmental governance cost to be underestimated for a long time, and the tax policy for energy-saving and emission-reduction equipment investment is not matched, and enterprises lack the micro incentives on the use of advanced technology and production equipment.

Fifth, social supervision system needs to be improved. Industrial green transformation has strong externality, and needs extensive participation of social forces to oversee green transformation behavior of enterprises. However, in China, public participation in social affairs is a mere formality for a long term, even subject to the constraints of various forces, so it is difficult to form a joint force to oversee the public affairs of the community, especially in face of major environmental pollution incidents, public opinion is very easily subject to intervention of local governments and parties involved. In addition, there are some problems in vertical oversight systems at central and local levels, for example, the supervision of the local governments is not in place, which leaves a survival space for enterprises with high pollution, high emission and low output.

III. Roadmap of China’s Industrial Green Transformation

Industrial green transformation can not be separated from the macroeconomic development environment. A variety of possibilities exist in external environment for industrial green transformation in next 5 to 10 years. In order to simplify the analysis, this paper analyzes two types of scenarios: baseline scenario and the scenario of accelerating the transformation of economic development modes^①. In the baseline scenario, major changes do not happen in China’s energy conservation and emission reduction policy and external environment, the government will continue series of energy conservation and emission reduction measures taken since 2005, and will not further implement mandatory measures on energy tax or carbon tax; in the scenario of accelerating the transformation of economic development modes, environmental protection is highly valued as an important means to promote the transformation of economic development, the government will increase energy-conservation and emission-reduction efforts, comprehensively implement various energy and environmental policies, especially through levying energy tax or carbon tax, improve energy efficiency and reduce emissions of pollutants and greenhouse gases. From the perspective of industrial enterprises and other microcosmic bodies, in the scenario of accelerating the transformation of economic development modes, because energy resource price tends to be reasonable, the social cost of activities with negative externalities such as pollution emission, is internalized, therefore, the expected revenues for energy-saving and emission-reduction campaigns will be greater, thus providing a stronger incentive to carry out energy effect improvement, emission reduction and other activities. Compared with the baseline scenario, in the scenario of accelerating the transformation of economic development modes, industrial enterprises will have greater demand for advanced technologies which help save energy and reduce emission. Therefore, from an overall point of view, in different scenarios, there are differences existing in technology roadmaps for China’s industrial green transformation from the 12th Five-year Plan Period to 2020.

Two principles should be complied with in determining technology roadmap for China’s industrial green transformation from the 12th Five-year Plan Period to 2020: ① technology is basically mature, and can be promoted and applied in a large scale. At present, whether it is in the baseline scenario, or the scenario of speeding up the transformation of economic development modes, industrial enterprises need certain policy

^①This scenario classification uses classification made by Li Shantong (2010) for reference.

support when they apply the technologies for energy conservation and emission reduction. Seen from the perspective of policy-making, when uncertainty exists in large-scale application prospect of a technology, the government is very difficult to promote such a technology in its application field. ② emphasis should be highlighted, and the core should be key technologies for energy conservation and emission reduction in high-energy-consuming industries. Because there are significant differences in resource conversion process, energy consumption is different sectors, and the emission of pollutants and greenhouse gases based on the consumption of energy resources is significantly different, the energy consumption and the emission of pollutants and greenhouse gases in the electricity, iron and steel, cement, petrochemicals and non-ferrous metals industry account for high proportion in industrial sector^②. In order to fully use limited policy resource, the technology roadmap for designing industrial green transformation puts emphasis on the major energy-saving and environmental protection technology. Based on these two principles, combined with energy-saving technology development status, the roadmap is given below for China's industrial green transformation from the 12th Five-year Plan Period to 2020 for electricity and other major industries and industrial general technologies (see Table 1).

Table 1 Roadmap for Industrial Green Transformation in Major Industries in Different Scenarios

Baseline scenario			Scenario of accelerating the transformation of economic development modes		
Industrial sector	Short Term (2010 ~2015)	Medium Term (2015~2020)	Industrial sector	Short Term (2010 ~2015)	Medium Term (2015~2020)
Electricity industry	Ultra-supercritical coal-fired power generation; Advanced hydropower technology; Large-scale onshore wind power generation; The third generation of large advanced Pressurized Water Reactor (PWR); UHV transmission technology;	New generation of ultra-supercritical coal-fired power generation; Efficient natural gas power generation; Large-scale offshore wind power generation; Solar photovoltaic power generation; Second-generation bio-energy technologies;	Electricity industry	New generation ultra-supercritical coal-fired power generation; Large-scale onshore and offshore wind power generation; Advanced hydropower technology; The third generation of large advanced PWR; UHV transmission technology; Second-generation bio-energy technologies;	IGCC power generation and other advanced clean coal utilization technologies; Large-scale photovoltaic and solar thermal ground power station; Efficient natural gas power generation; Smart grid;
Iron and steel industry	High-pressure coke dry quenching technology; Pulverized coal injection (PCI) technology; Negative energy steelmaking in furnace; Third generation coal moisture control (CMC) technology; Blast furnace gas pressure recovery turbine power generation technology (TRT); Gas - steam Combined Cycle Power Plant (CCPP) technology; Iron and steel production and energy management center construction;	Hot charge and delivery; Hydrogen production through coke oven gas; Thin strip casting; Smelting reduction technology; Next generation coke production technology; Sintering flue gas desulphurization technology; Direct steelmaking technology by adopting microwave, electric arc and exothermic heating;	Iron and steel industry	High-pressure coke dry quenching technology; Pulverized coal injection (PCI) technology; Negative energy steelmaking in furnace; Third generation coal moisture control (CMC) technology; TRT technology; CCPP technology; Next generation coke production technology; Sintering flue gas desulphurization technology; Iron and steel production and energy management center construction;	Hot charge and delivery; Thin strip casting; Itm3 ironmaking technology; Smelting reduction technology; Electric Advanced Furnace (EAF) technology; Direct steelmaking technology by adopting microwave, electric arc and exothermic heating; Exhaust plastic replaces coke to be used in injecting fuel into blast furnace; Medium- and low-temperature waste heat recovery technology;
Cement industry	Large new dry-process kiln; Large and efficient grinding system; Pure low temperature waste heat power generation;	New green cement-based materials; Industrial waste residue and combustible waste application; Urban waste disposal; Low-nitrogen combustion technology;	Cement industry	Large new dry-process kiln; Large and efficient grinding system; Pure low temperature waste heat power generation; Urban waste disposal;	New green cement-based materials; Industrial waste residue and combustible waste application; Low-nitrogen combustion technology;

^② In 2008, the proportion of energy consumption, sulfur dioxide emission, soot emission and wastewater emission in these five industries accounted for 72.37%, 88.20%, 81.38% and 35.15% respectively in the industrial sector.

Petrochemical industry	Large polygeneration system; Advanced coal gasification technology; Energy cascade utilization technology; Waste comprehensive utilization technology;	New deep catalytic cracking technology; New separation technology; Toxic and hazardous raw material substitution technology;	Petrochemical industry	Large polygeneration system; Advanced coal gasification technology; New separation technology; Energy cascade utilization technology; Waste comprehensive utilization technology;	Toxic and hazardous raw material substitution technology; New deep catalytic cracking technology; Ionic membrane technologies; Bio-refinery technology; Biopolymer production technology;
Non-ferrous metal industry	Efficient energy-saving technology and equipment; Self-heating strengthened smelting and electrolytic processes; Hydrometallurgical energy-saving technology; Waste heat recovery and utilization technologies;	Continuous strengthened smelting technology; Short-process copper smelting process; Liquid high lead skim direct reduction process; New alumina reduction technology;	Non-ferrous metal industry	Efficient energy-saving technology and equipment; Self-heating strengthened smelting and electrolytic processes; Hydrometallurgical energy-saving technology; Waste heat recovery and utilization technologies; Continuous strengthened smelting technology;	Short-process copper smelting process; Liquid high lead skim direct reduction process; New alumina reduction technology; Bipolar electrolyzer (inert anode) technology; Spray aluminum processing technology;
Universal technology	Combined heat and power generation; Efficiency motor; Frequency control technology;	Combined heat and power generation; Superconducting motor, permanent magnet motor;	Universal technology	Combined heat and power generation; Efficiency motor; Frequency control technology;	Permanent magnet brushless DC motor; Magnetic coupling speed regulation driver;

Data source: OECD, 2010, *Energy Technology Perspectives 2010 — Scenarios and Strategies to 2050*; IEA, 2009, *Cement Technology Roadmap 2009 — Carbon Emissions Reductions up to 2050*; Xu Kuangdi. *Low-carbon Economy and Steel Industry* [J] *Iron and Steel*, 2010, (3).P1~12; Jiang Kejun, et al. *China's Energy Demand and CO₂ Emission Scenarios in 2050* [J]. *Climate Change Research Progress*. 2008, (9); United Nations Development Programme *China's Human Development Report (2009): Sustainable Future towards Low-carbon Economy and Society*. China Translation & Publishing Corporation, 2010.

IV. Cost-benefit Analysis on Industrial Green Transformation

Based on the reality that industry is China's primary sector of energy consumption, pollutants and greenhouse gas emissions, the industrial green transformation will exert an important impact on China's economic and social development. On one hand, a certain price needs to be paid in the dynamic process of pushing industry into green economy transformation, which includes incremental investment caused by implementing technologies for energy conservation and environmental protection, includes potential macroeconomic losses, includes job loss in high-energy-consumption and high-emission industries, as well as subsidies to poor population. On the other hand, after industrial green transformation goals are achieved, significant benefits can be produced, which include direct benefits such as reduction of energy cost of industrial enterprises, avoidance of lock-in of technologies aiming at high-energy-consumption and high-emission in the industrial sectors, promotion of development of energy-saving and environment-protection industries, creation of green employment opportunities, improvement of finished product trade conditions, positive effect on health and other aspects because of reduced emission of pollutants and green gas.

1. The Cost of Industrial Green Transformation

The costs for promoting industrial transformation to a green economy include direct costs of energy conservation and environmental protection investment, and other indirect losses.

- (1) Direct costs. The direct costs of industrial green transformation include incremental investment made by industrial enterprises in energy saving and environmental protection technology and equipment, including energy-saving investment and environmental protection investment. The applicable advanced energy-saving and environment-protection technologies are widely used in the industrial sector, and are the major reason for improving China's industrial energy efficiency and reducing the industrial pollutants

during the 11th Five-year Plan Period. It can be expected that the technical progress from the 12th Five-year Plan Period to 2020 will continue to play an important role in the industrial green transformation.

- Energy-saving investment. At present, China does not publish statistics data on energy-saving investment, and can only make rough estimate through indirect methods. Between the above-mentioned baseline scenario and the scenario of accelerating transformation of economic development modes, the industrial energy consumption difference is 437.5 million tons of standard coal in 2015, the difference in 2020 is 910 million tons of standard coal. Assuming that the industrial energy consumption growth speed remains unchanged in the above two scenarios, it can be estimated that during the 12th Five-year Plan Period and the period from 2011 to 2020, 2.1875 billion tons and 9.1 billion tons of standard coal will be saved respectively under the baseline scenario and the scenario of accelerating transformation of economic development modes. Further assuming that the rate of contribution of technological progress to energy efficiency improvement in industrial sectors is 50% and 55%, respectively, during the 12th Five-year Plan Period and 13th Five-year Plan Period^①, it can be concluded that compared with the baseline scenario, for the scenario of accelerating the transformation of economic growth modes, the technological progress leads to energy saving amount in industrial sector of 1.0938 billion and 4.8957 billion of standard coal in the 12th Five-year period and the period from 2011 to 2020. According to estimate based on price of RMB 700 Yuan/ton of 5,800 kcal/kg thermal coal, the energy-saving benefit from application of technical means are expected to be RMB 924 billion Yuan and RMB 4.136 trillion Yuan respectively during the 12th Five-year period and the period from 2011 to 2020. Assuming the industrial sector's annual return rate for energy-saving investment is 8%, without considering the construction cycle factors of energy-saving projects, and the beneficiary period for investment in energy-saving projects is over 10 years, in order to realize the above-mentioned energy-saving benefits, RMB 4.62 trillion Yuan and RMB 4.99 trillion Yuan need to be invested in energy-saving technology and related equipment during the 12th Five-year Plan Period and the 13th Five-year Plan Period.
- Environmental protection investment. In recent years, China's investment in environmental pollution control has increased year by year. In 2001, the total investment in environmental pollution control in China was RMB 110.66 billion Yuan, and increased to RMB 449.03 billion Yuan in 2008; investment in industrial pollution source control increased from RMB 17.45 billion Yuan in 2001 to RMB 54.26 billion Yuan in 2008. The proportion of environmental pollution control in GDP is 1.02% in 2001 to 1.48% in 2008. In the scenario of accelerating transformation of economic development modes, environmental protection is an important force for promoting economic restructuring, therefore, the proportion of environmental pollution control in GDP should be greatly enhanced, and should be increased to 1.8% during the 12th Five-year Plan Period and 2% during the 13th Five-year Plan Period. On this basis, combined with GDP growth rate^②, in the scenario of accelerating transformation of economic development modes, the total investment in environmental protection is RMB 4.10 and 6.56 trillion Yuan respectively during the 12th Five-year Plan Period and the 13th Five-year Plan Period. From 2001 to 2008, industrial pollution source control investment accounted averagely for 15.72% of the total investment in environmental pollution control. In addition,

^① From 2000 to 2008, return on fixed assets in China's industrial sector is 14.6% on average. Taking into account that energy-saving investment yield is usually lower than the yields of other types of fixed-asset investment, and some investments in energy-saving technologies should be included in the intangible assets or current expenses of enterprises. From 2000 to 2009, the ratio of profit to cost of China's all state-owned and above-scale non-state-owned industrial enterprises is 6.31% on average. Therefore, it is assumed that the energy-saving investment yield in industrial sector at 8% has certain rationality.

^② Refer to research conclusion of Li Shantong (2010), in scenario of accelerating the transformation of economic development modes, the GDP growth rate is 8.4% during the 12th Five-Year Plan Period and 7.2% during the 13th Five-Year Plan Period.. GDP in 2015 and 2020 are RMB 53 trillion Yuan and RMB 75 trillion Yuan respectively (calculated based on price in 2008).

2001~2008 industrial fixed assets investment accounted averagely for 39% of the society's total investment in fixed assets. Such proportion serves as a basis for estimating the proportion of industrial sectors in construction projects "three simultaneous" environmental protection investment^③, combined with the average proportion (31%) of this investment in total investment in environmental control, it can be estimated that the construction projects "three simultaneous" environmental protection investment averagely accounts for about 12.09% in total investment in environmental control. That is, seen from historical data, the environmental protection investment in industrial sector accounts for about 28% of total investment in environmental pollution control. In combination with estimated data on total investment in environmental protection, it can be concluded that China's industrial sector needs invest RMB 1.15 trillion Yuan and RMB 1.84 trillion Yuan respectively in environmental protection field during the 12th Five-year Plan Period and the 13th Five-year Plan Period.

- (2) Indirect costs. Indirect costs to be undertaken by industrial green transformation mainly include macroeconomic losses caused by relatively low output efficiency of investment in energy conservation and environmental protection and caused by the inhibition of growth of some industries, unemployment in the transformation process, as well as subsidies for the poor population involved in industrial green transformation.

From static resource allocation of the whole society, increasing the investment in energy conservation and environmental protection of the industrial sector, regardless of the source of funds, will result in relative reduction of investment in other areas. Because a considerable part of the return on investment in energy saving and environmental protection can not be monetized, from the point of view of national income statistics, investment in industrial energy conservation and environmental protection, especially the economic benefits of environmental pollution control investment, should be less than productive investment. The relative decline in new investment efficiency is one of macroeconomic losses of industrial green transformation. In addition, in the process of promoting industry's green economic transformation, the industrial sector will relatively reduce the consumption of energy, therefore, the growth of energy industry, especially traditional fossil energy industry, will be subject to certain restrictions. Moreover, along with the continuous progress of industrial green transformation, iron and steel, non-ferrous metal and other high-energy-consumption and high-emission industries will gradually internalize the external cost which needed not be undertaken previously, which thereby will affect the competitiveness of products to some extent. Growth of energy industry and high-energy-consumption and high-pollution industries was suppressed, which is also an important macroeconomic loss of industrial green transformation. Comprehensive assessment of these potential macroeconomic losses of industrial green transformation needs a comprehensive utilization of computable general equilibrium model (CGE) and energy system dynamic optimization model. Considering that reducing greenhouse gas emission, to a considerable extent, also reduces the emission of sulfur dioxide and nitrogen oxide emissions^①, in the scenario of accelerating transformation of economic development modes, the cost of achieving greenhouse gas emission reduction target can approximately describe the potential macroeconomic losses of industrial green transformation. According to the report released by the United Nations Development Programme (UNDP), achieving the reduction of carbon dioxide per unit in 2020

^③ So-called "three simultaneous" means that pollution prevention and control measures in the construction projects must be designed, constructed, and put into use simultaneously with the main projects, according to Article 26 of Environmental Protection Law of the People's Republic of China. Pollution prevention facilities must be approved by the environmental protection department which originally examines and approves environmental impact report. Only after the approval is obtained, can such construction project be put into production or use.

^① See Cao, J., M. S., Ho, & D. W., Jorgenson, 2008, 08-10.

by 40% to 45% from that in 2005 will result in the loss of GDP in 2020 amounting to RMB 338.4 billion Yuan to RMB 586.2 billion Yuan (calculated based on the price in 2005), equivalent to 0.64% to 1.11% of GDP in current year^②. Take into account the proportion of greenhouse gas emissions of the industrial sector in the total emission, the tasks of industrial green transformation not only contain greenhouse gas emission reduction, and also include the energy efficiency improvement and pollutant emission reduction, according to a conservative estimate, potential macroeconomic losses of industrial green transformation from the 12th Five-year Plan Period to 2020 will exceed RMB 100 billion Yuan.

To successfully achieve the industrial green transformation goals, it is needed to adjust industrial structure and apply technologies for energy saving and environmental protection, which will cause direct negative impact on employment in high-energy-consumption and high-emission industries (“double high” industry). In addition, labor income and consumption in the “double high” industries as well as their upstream and downstream industries will be affected because industry growth is blocked. For example, after the employment is reduced and income is decreased in power industry and coal industry, the employees in the electricity and coal industries reduce their consumption, and the employment in the related service sector is also decreased. As far as job loss caused by industrial green transformation is concerned, a rough estimate is made based on the employment impact made by energy saving and emission reduction in thermal power industry. According to research of Pan Jiahua, et al (2009), from 2003 to 2020, the thermal power industry implements energy-saving and emission-reduction policy, reduces the energy consumption of 948.92 million tons of standard coal, and reduces sulfur dioxide emission by 15.18 million tons, at the same time, 413,000 jobs are lost, that is, 43,500 job will be lost if 100 million tons of standard coal is saved^③. According to estimate made on this basis, achieving the target of saving energy equivalent to 2.1875 billion tons and 9.1 billion tons of standard coal during the 12th Five-year Plan Period and the period from 2011 to 2020 in the industrial sector, 952,100 jobs and 3,960,000 jobs will be reduced respectively.

To promote industrial transition to a green economy, the reform of energy resource price formation mechanism and the improvement of energy efficiency standards are essential measures. However, these measures are likely to raise the prices of energy and energy-using equipment, which thereby cause adverse impact on poor population^④. This is mainly because that, compared to the high-income people, the expenditure of poor population on energy and energy-using equipment accounts for higher proportion of their total expenditure, thus they are much subject to the impact of prices of energy and energy-using equipment. In order to reduce the impact on poor population, the government needs to take measures to offer subsidies to poor population, or offer subsidies to energy and energy-using equipment providers, so as to reduce the cost of poor population in consuming energy products and energy-using equipment. The amount of subsidy depends on the policy strength, so it is difficult to make specific estimates.

2. Comprehensive Benefits of Industrial Green Transformation

Comprehensive benefits of industrial green transformation include not only the direct benefits of reducing energy costs, but also avoidance of lock-in of technologies used in high-energy-consumption and

^② See United Nations Development Programme *China's Human Development Report (2009): Sustainable Future towards Low-carbon Economy and Society*, 2010.

^③ Pan Jiahua, et al., *Preliminary Study of Impact of Low-carbon Development on Employment in China*, contained in *Climate Change Response Report (2009) - Leading to Copenhagen* written by Wang Weizhong, et al. 2009.

^④ See Stefan, Speck, 1999, pp. 659-667; OECD, 2005; Cornwell, A. & J. Creedy, 1996, pp. 21-38; Zhang Zhongxiang & Andrea Baranzini, 2004, pp. 507-518.

high-emission industries, the promotion of the development of energy saving and environmental protection industries, and the creation of green job opportunities, as well as indirect benefits such as positive impact on human health due to reduced emissions of pollutants and greenhouse gases.

- (1) Direct benefits. Industrial green transformation, in essence, is to reduce the consumption of energy resources in the process of industrial production, and to reduce emissions of pollutants and greenhouse gases. Because the benefits from pollutants and greenhouse gas emission are difficult to be monetized, and is almost impossible to be internalized, the direct benefits of the transformation of industrial sector towards green economy mainly refer to the reduction of energy cost as result of energy saving. As mentioned above, during the 12th Five-year Plan Period, and the period from 2011 to 2020, compared with the baseline scenario, in the scenario of accelerating transformation of economic development modes, the energy-saving amount in industrial sector will be 2.1875 billion tons and 9.1 billion tons of standard coal respectively. According to conservative estimate based on price of RMB 700 Yuan/ton of 5,800 kcal/kg thermal coal, the costs that the industrial sector will save are RMB 1.8481 trillion Yuan and RMB 7.6879 trillion Yuan due to reduction of energy consumption during the 12th Five-year Plan Period and the period from 2011 to 2020.

However, the green transformation of the industrial sector certainly needs to use more clean energy. Currently, in view that China's energy resource endowment characterized by richness in coal, deficiency of oil, and insufficiency of gas, and that nuclear power, wind power, solar power and other clean energy have relatively high utilization costs, the elevation of the proportion of clean energy in short term will inevitably result in increase in energy price. Only considering two factors, i.e. clean and efficient use of coal, and increase of clean energy utilization, the energy utilization cost will increase about by 8%. During the 12th Five-year Plan Period and the period from 2011 to 2020, the total energy consumption of industrial sector is 6.125 billion tons and 13 billion tons of standard coal respectively; if the cost of energy use increases by 8%, it is equivalent that additional 490 million tons and 1.04 billion tons of standard coal respectively are consumed. Similarly, according to estimate based on price of RMB 700 Yuan/ton of 5,800 kcal/kg thermal coal, it is equivalent that additional RMB 414 billion Yuan and RMB 878.6 billion Yuan of energy cost will be paid during the 12th Five-year Plan Period and the period from 2011 to 2020.

In combination with its impact on energy saving and energy utilization cost, the direct benefits which industrial green transformation brings to the industrial sector are RMB1.4341 trillion Yuan and RMB 6.8093 trillion Yuan respectively in the 12th Five-year Plan Period and the period from 2011 to 2020.

- (2) Indirect benefits. First, green transformation helps to avoid technology lock-in. China is in the period of accelerated development of industrialization and urbanization, and the huge market demand drives the rapid development of electric power, iron and steel, cement, petrochemical, non-ferrous metal and other high-energy-consumption and high-emission industries. The fixed assets formed by investment in these industries have long service life. If the energy utilization efficiency of such production equipment is low, and the pollutants and greenhouse gas emission are high, the characteristics of high energy consumption and high emission will be locked over the long term. If industrial green transformation is promoted from the 12th Five-year Plan Period to 2020, effective measures are adopted to control energy utilization efficiency, pollutants and greenhouse gas emission standards of newly-established, transformed and expanded projects, which will lay a good foundation for future energy saving and emission reduction.

This is important revenue of industrial green transformation. Affected by data availability and other aspects, at present, it is difficult to make a quantitative assessment.

Second, green transformation helps improve trading environment and trading conditions. Since the international financial crisis occurred, some developed countries are trying to guide the evolution of trade rules through the technical rules and standards relevant to carbon tariffs and carbon footprint. In particular, some developed countries try to set green trade barriers in disguised form by this way. Carbon tariffs and relevant trade rules and standards, to some extent, have become a tool used by some developed countries to weaken the export competitiveness of manufacturing industry of developing countries. Once the Europe, America, Japan and other developed economies jointly impose carbon reduction tax and implement the relevant low-carbon economy standards on finished products exported by China, Chinese export enterprises will encounter difficulties and passive situation, and China's trade environment and trade conditions are likely to deteriorate further. Therefore, actively promoting industrial green transformation, to a certain extent, improves the trading environment and trade conditions, thereby helping improve industrial competitiveness.

Again, green transformation helps promote the development of energy-saving and environment-protection industries. Promoting industrial transformation to a green economy needs huge investment. As mentioned earlier, in the 12th Five-year Plan Period and 13th Five-year Plan Period, China's industrial sector needs invest RMB 5.77 trillion Yuan and RMB 6.83 trillion Yuan respectively in energy-saving and environment-protection technologies and relevant equipment. In fact, such huge investment contains huge market demand, and also nurtures and drives the development of green industries such as energy saving and environmental protection industries. The rate of environmental protection investment's driving environmental protection industries is about 1.1, and the investment multiplier of environmental protection to GDP is 1.4^①, assuming the energy-saving investment has same pull rate and investment multiplier towards energy-saving industry, China's total output value of energy-saving and environment-protection industries will reach RMB 6.347 trillion Yuan and RMB 13.86 million Yuan respectively in the 12th Five-year Plan Period and the period from 2011 to 2020. GDP will increase by 8.078 trillion Yuan and RMB 17.64 trillion Yuan accordingly. On this basis, estimated based on per capita annual output value of RMB 300,000 Yuan in energy-saving and environmental protection industries, China's energy-saving environmental protection industry will provide 10.58 million jobs and 23.1 million jobs during the 12th Five-year Plan Period and the period from 2011 to 2020. This estimate result is close to the analysis conclusion of Wang Jinnan et al (2010). The research result shows that the environmental protection industry will offer 5.12 million jobs in 2015 alone.

Finally, industrial green transformation will produce health benefits. Environmental pollution and climate change caused by pollutants and greenhouse gas emissions will ultimately exert adverse impact on human health. As China's State Environmental Protection Administration and the World Bank pointed out in a research report released in 2007, air pollution, especially air pollution in big cities, led to increased incidence of lung cancer, respiratory diseases and other lung diseases, water pollution caused elevated incidence of cancer and diarrhea, especially increased incidence of diarrhea suffered by 5-year-old children; in 2003 alone, economic losses due to premature death and disease caused by air

^①Wang Jinnan et al. *Chinese Environmental Protection Industry Forecast and Policy Analysis for the 12th Five-year Plan Period in China*. [J]. China's Environmental Protection Industry. P24~30. 2010 (6).

pollution was RMB 157.3 billion Yuan, accounting for 1.16% of GDP in that year^①. In view that the industrial pollutants and greenhouse gas emissions account for a higher proportion of the total emissions, promoting industrial transition to a green economy can improve the ecological environment to a considerable extent, and slow down climate change, so that people's living environment can be improved, and the health status of people as much as possible can be maintained.

From the analysis of the costs and benefits of industrial green transformation, it can be concluded that although the promotion of industrial transition to a green economy requires a large amount of investment in energy conservation and environmental protection, and also causes a certain macro-economic losses, and will result in job losses in high-energy-consumption and high-pollution industries and related industries, such promotion has an important positive impact on saving energy costs, improving the finished product trade environment and trade conditions, promoting the development of green industries such as energy-saving and environment-protection industries, creating green jobs and enhancing the level of national health. On the whole, the benefits of industrial green transformation are much higher than its cost (see Table 2).

Table 2 Main Costs and Benefits of Industrial Green Transformation: Preliminary Estimates

Cost Item	Estimated Data		Benefit Item	Estimated Data	
	12th Five-year Plan Period	13th Five-year Plan Period		12th Five-year Plan Period	13th Five-year Plan Period
Investment in energy conservation and environmental protection	RMB 5.77 trillion Yuan	RMB 6.83 trillion Yuan	Decrease of energy cost	RMB 1.43 trillion Yuan	RMB 5.47 trillion Yuan
Loss of jobs in high-energy-consumption and high-emission industries	952,100	2,907,900	Promote development of energy-saving and environment-protection industries	Output value: 6.35 trillion Yuan; Add GDP: 8.08 trillion Yuan	Output value: 7.51 trillion yua; Add GDP: 9.56 trillion Yuan
Potential macroeconomic loss	Exceed RMB 100 billion Yuan		Create green jobs	10.58 million	12.52million
Subsidy provided to poor population	Depends on policy strength		Reduction of pollutants and greenhouse gas emissions is beneficial to human health	Exceed 1% of GDP	
			Avoid technology lock-in of high-energy-consumption and high-emission industries; improve the trading environment and trade conditions	Qualitative analysis	

Data source: sorted out by the author.

V. Mechanism Innovation and Policy Support System

As seen from the evolution of environmental governance mode, the industrial transformation of developed countries is closely linked to their development stage requirements. At present, industrialized development and environmental governance in many places in China still adopt the old methods used by developed countries, and put the emphasis on the end-of-pipe treatment in terms of system design and incentive mechanism, and lack pilot awareness and proactive behavior with regard to green transformation. Although the industrialization characteristics of China at present stage have similarities with those of the developed countries in the 1950s

^① See State Environmental Protection Administration, P. R. China, & The World Bank, 2007, *Cost of Pollution in China: Economic Estimates of Physical Damages*, Washington, D. C..

and 1960s, i.e. China's industrialization also faces the expansion of industrial investment, expansion of demand for energy resources, intensified environmental impact, and other periodic problems of "heavy industrialization", as an emerging industrial country, China has full conditions to learn from the developed countries the experiences and lessons in industrial pollution control, and gradually get rid of "pollution first, treatment later" mode. Through constantly absorbing the world's advanced concepts of industrial upgrading and environmental governance, China will give full play to its advantages and accelerate green development. The industrial green transformation needs to make a major shift in the development concept, growth mode, target and direction, and other aspects, attaches great importance to the strategic level, take a new road to industrialization, strengthen mechanism innovation, and improve and imperfect policy support system designed to perfect green development of manufacturing industry.

1. Mechanism Innovation of Industrial Green Transformation

Mechanism innovation of China's industrial green transformation requires a comprehensive, systematic and open strategic framework as well as the participation from governments, industries, enterprises and the public. Based on perfecting environmental regulation and energy-saving and emission-reduction binding targets, green transformation-related policy instruments will be continuously enriched in terms of technology, capital, trading mechanism, international cooperation and other aspects (see Figure 1).

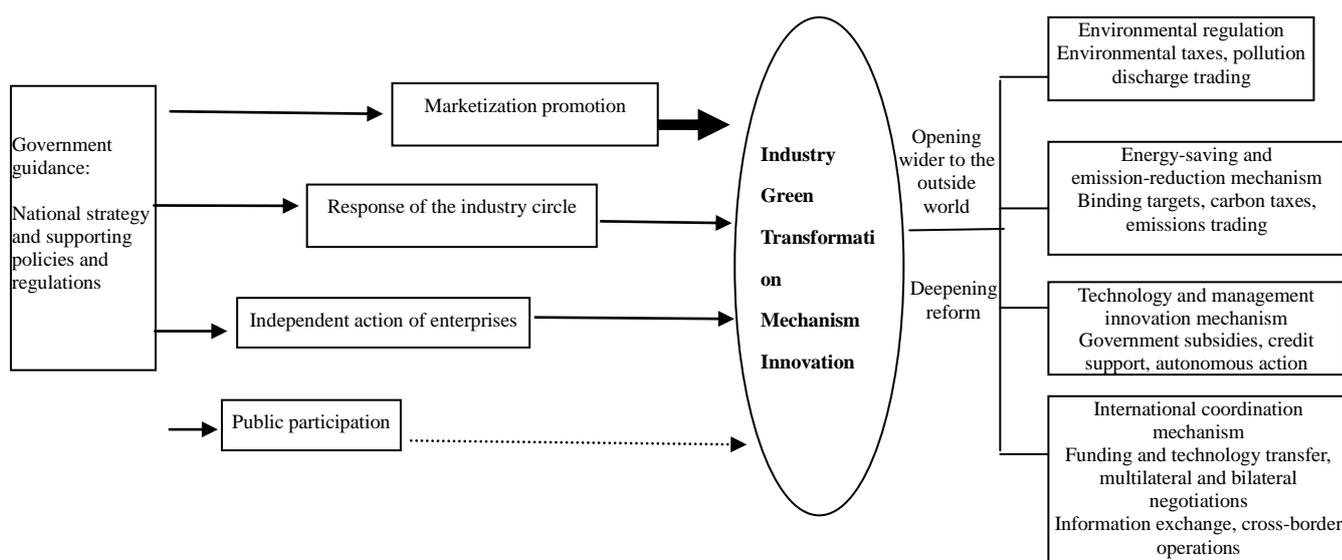


Figure 1 Mechanism Innovation System of China's Industrial Green Transformation

Source: made by the author.

2. Policy Measures Designed to Promote China's Industrial Green Transformation

Green transformation is not only inherent requirements for Chinese industry to change the growth mode, but also an important means of achieving growth pattern change. During 11th Five-year Plan Period, under the guidance of national binding targets of energy saving and emission reduction, China's industrial green transformation has made positive progress, the Green New Deal with Chinese characteristics has been initially formed. The 12th Five-year Plan Period is an important period of strategic opportunities for China's industrial structure adjustment, transformation and upgrading. Should take full advantage of the opportunity presented by global climax in implementing Green New Deal, accelerate the formulation of appropriate policies, and further promote industrial green transformation. Should take green transformation as the guiding ideology of

Chinese industry's becoming stronger, make a unified planning, and formulate strategic framework for green transformation of Chinese industry and national green innovation roadmap, and establish strategic objectives for industrial green transformation, and determine priority areas for development, strategic layout and main tasks. Under the guidance of unified strategic planning, make coordination of responsibilities and obligations of the green transformation of various industries in various regions, fully reflect the regions' transformation willingness and their condition differences, and provide the basis for the central government and various regions to introduce supporting policies and guarantee measures on industrial green transformation. At the same time, should speed up the adjustment of industrial structure, increase green investment, vigorously develop strategic emerging industries, and build an industrial green system; promote coordination between domestic and external demands, encourage export enterprises to speed up transformation and upgrading, increase the development and use of overseas resources and energy, vigorously introduce advanced green technology and key equipment, and further optimize the trade structure; make great efforts to develop and use clean energy and renewable energy, optimize energy structure, and improve the efficiency of resource use. Accelerate the research and development of industrial green technology, and perfect technology standards and management norms with regard to green manufacturing; strive to promote the industrial gradient transfer, and form a green layout for industrial development; reform the achievements appraisal system, improve environmental regulation, and strengthen environmental protection law enforcement; deepen the resources and energy system reform, and improve the fiscal and tax policy support system; guide financial institutions to increase the credit support of emerging green industries; strengthen personnel training system to provide human resource guarantee for industrial green transformation; give full play to the role of industry associations, improve the system of corporate environmental responsibility and promote enterprises to make green management innovation; promote global governance and international coordination in energy, environment, climate change response and other fields, so as to create a favorable external environment.

It should be seen that, as a highly open and responsible big country, China needs to actively participate in the global green governance. During international cooperation in this field, it is necessary to strive to safeguard national interests and industry development space, and also make greater efforts to improve the environment of the global green development.

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