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An Empirical Research Based on STIRPAT Model: CO_2 Emission Accounting and Influencing Factors of China's Macro Infrastructure Life Cycle

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Abstract

With the development of modernization and industrialization in China, the infrastructure energy consumption increases, which shows the process of modernization in our country. Despite there are a lot of researches about the energy consumption in the field of construction, transportation and other infrastructure, in academia, there are less statistics about energy consumption for the infrastructure as a whole in the life cycle, and its proportion in total energy consumption in the whole country. Thus, this paper tries to characterize infrastructures of China, which include construction, transportation, energy, water supply and drainage, post and telecommunications communication system by establishing an estimation model of infrastructure system CO_2 emissions in the life cycle through national official macro-level statistical data. The results show that CO_2 emissions from the infrastructure have rapidly grown over the past decades. And based on the extension of STIRPAT model framework, we make an empirical analysis of the important factors on China's macro infrastructure systematic CO_2 emissions from the population, urbanization level, residents' consumption level, the third industry development, and investment in fixed assets using dynamic panel data. Results show that in the above factors, the contribution rate of infrastructure investment is the highest, followed by family size, 30.9% and 22.6%, respectively, and the urbanization rate is the highest in the elasticity of all the factors affect the carbon emissions, whenever the urbanization rate increases by 1%, the macro infrastructure carbon emissions increase 1.624. In this paper, from the perspective of the overall environmental benefits, we provide a more comprehensive environmental assessment analysis method for the policy makers. And the infrastructure construction of China has periodic characteristic. We analyze the specific features of the infrastructure CO_2 emissions in the life cycle, and put forward emission-reduction measures in consideration of the current conditions. In addition, the method of building the model of infrastructure CO_2 emissions in the operation stage development is also important for future quantifications of CO_2 emissions of other sectors in China and beyond.

Keywords: macro infrastructure, life cycle, CO_2 emissions, STIRPAT, China

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INTRODUCTION

Driven by a series of social factors such as the development of the modern industry, the progress of the urbanization and the change of the human's lifestyle and consumer attitude, the infrastructure, which is the premise and carrier of the national construction and modernization, updates and develops constantly. And infrastructure-related activities are always accompanied by a lot of fossil fuel consumption. While greenhouse gases emitted by the burning of fossil fuels obstacle the long waves emitted from the earth to the universe, which has become the most important cause of the greenhouse effect through playing a role like a greenhouse on the earth. In recent years, people have gradually recognized disastrous consequences which may result in the circumstance that greenhouse gas concentrations breakthrough the threshold. Among all greenhouse gases, CO_2 emissions, making up 82.9% of the whole greenhouse gas emissions, represent the largest portion (Lin and Sun 2010). So infrastructure-related activities inevitably become an important subject of energy saving. Recently, China's industrialization

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process has been speeding up with the rapid growth of the economy. Stepping into the 12th Five-Year, china has started to enter into late industrialization. At the same time, its development and modernization presents new features. How to coordinate the infrastructure construction and the environmental protection under this new situation is very crucial. Therefore, it is meaningfully important to understand the relationship between energy, environment and China's infrastructure construction in a correct way for promoting "steady growth benefiting people's livelihood" and achieving a healthy and sustainable development of the economic society.

Currently, the existing literature on China's CO_2 emission is mainly focused on the national or regional level (provincial and municipal) and is based on the research of the total amount. While the research is rarely on the infrastructure perspective. Besides, the research on the infrastructure perspective focuses mainly on two aspects of the construction and the transportation. And research topics include the establishment carbon emission accounting framework (Bengtsson 2000, Demurger 2001, Mackellar et al. 1995, Shang and Zhang 2010), the construction of low-carbon evaluation system and the determination of its low-carbon level (Li and Qu 2012, Sakamoto et al. 2010), analysis of influencing factors and so on (Bengtsson 2000, Dietz and Rosa 1994, Wu et al. 2012). In the relative studies of carbon emission accounting, the life cycle assessment method which uses the bottom-up or top-down approach to compile statistics is mostly adopted to determine carbon emission accounting border (Ehrlich and Holdren 1971, Holdren and Ehrlich 1974, Waggoner and Ausubel 2002). Wherein, a specific building or type of the transportation infrastructure is taken as an example to be accounted from a microcosmic angle. The research of accounting the CO_2 emissions by regarding the infrastructure as a whole is principally based on analyzing its composition of the total amount and constructing an ideal carbon emission model (Schulze 2002, Tian et al. 2011) while lack of the actual calculation of the total amount. Through estimating carbon emissions put into industrial sectors during the infrastructure construction, Zhuang Guiyang calculated the carbon emission situation of China's urban infrastructure in the 2006 (York et al. 2002). The methods employed in the relevant studies on influencing factors of the CO_2 emission from the infrastructure mainly include the Structure Analysis Method (SDA), the Logarithmic Mean Divisia Index (LMDI) (Song 2012, Wu 2012), the Kaya Identity (Lin and Liu 2010), STIRPAT model (Ji and Jiang 2012), etc.

In order to make up for the relatively insufficient parts of the existing research, this paper attempts to start from a macro perspective to construct the accounting framework of the infrastructure life cycle CO_2 emissions, calculate specific emissions from 1993 to 2012, and analyze emissions' development trend and characteristics; to conduct a systematic empirical analysis on the important factors of China's macro infrastructure CO_2 emission with Dynamic panel data in the framework of the extended STIRPAT model from the angle of population, urbanization level, the level of consumption, the development of the tertiary industry and investment in fixed assets and so on, whereby this paper provides more extensive empirical data and theoretical support for the policy formulation of carbon emissions reduction from the whole infrastructure level.

ACCOUNTING AND DEVELOPMENT TREND OF CO2 EMISSIONS OF CHINA'S MACRO INFRASTRUCTURE LIFE CYCLE

CO_2 Emissions Boundary Determination of China's Macro Infrastructure Life Cycle

Boundary determination of the macro infrastructure

According to *World development report 1994: infrastructure for development*, Published by the World Bank, the infrastructure is divided into two types: economic infrastructure and social infrastructure. The economic infrastructure is defined as "the long-lived engineered structures, equipment, and facilities, and the services they provide that are used in economic production and by households." The social infrastructure is defined as "the infrastructure other than the economic infrastructure" (Hulten et al. 2006). There is no uniform standard for the definition of the content covered, while it is generally based on its own research direction and scope to choose (Si and Xu 2007). Division methods mainly include: the division according to the location; the division according to the nature of the usage and the objective. **Table 1** lists current main classifications and contents covered of China's infrastructure.

Table 1. Infrastructure Division

Geography-based System		**Class of service-based System**		
Rural Infrastructure	**Urban Infrastructure**	**Productive Infrastructure**	**Social Infrastructure**	**Public Institutions**
Agricultural productive infrastructure	Residential building project	Water supply, power supply	Housing and utilities	Department of public security, political science and law, and urban construction planning and management
	Office and commercial building projects	Roads and traffic	Public transportation	
Agricultural living infrastructure	Transportation project	Storage and post and telecommunication equipment	Transport and communications agency	
Ecological environment construction	Environmental protection and water conservancy project	Sewage, greening and other environmental protection and disaster prevention and control equipment	Commercial, catering and service industries	
	Energy power project		Education and health institutions	
Ecological environment construction	Post and Telecommunications Project		Culture and sports facilities	

Table 2. Macro Infrastructure Partition

Infrastructure System Classification	**Building System**	**Transportation Systems**	**Energy Supply System**	**Water Supply and Drainage System**	**Post and Telecommunication System**	**Social Service System**
Region Range	Rural and urban	Rural and urban	Rural and urban	Rural and urban	Rural and urban	Rural and urban
Content	Residential buildings, Office and commercial buildings, Industrial buildings, Agricultural buildings	Rural road, Urban road, Railway, highway, Aviation, water Transport, Bridge, Tunnel, port；Public transport equipment, Transport equipment	Oil, Coal, Natural gas, Electric power and other energy projects, equipment	The facilities of water supply and drainage, sewage disposal, irrigation and water conservancy	Telecommunications, communications, information network equipment, Postal facilities, storage facilities	Medical education, health, security mechanism, Institution guarantee institution, Scientific research management organization

This paper, focused on the CO_2 emission issue, is to study the environmental load caused by the input and output process of the infrastructure system, which only consider the main parts that affect the CO_2 emission in the infrastructure systems. Strategy Research Report on the low carbon development in the 12th Five-Year Report proposes "China is currently faced with the arduous task of improving the majority of the people's living standards. Because of the large population, the ongoing large-scale infrastructure construction is being launched on covering energy, transportation, construction and so on." For these reasons, taking the availability of carbon emission data into account, this paper is combined with the existing infrastructure classification basis and the contents covered to divide the infrastructure system into six parts: building system, transportation system, energy supply system, water supply and drainage system, post and telecommunications system and social service system from the macro perspective. Their specific contents contained and the scopes are shown in **Table 2**. This classification method basically covers most of the content in China's infrastructure system.

Boundary determination of the macro infrastructure life cycle

In the light of "from cradle to grave" thought, the infrastructure system life cycle is investigated to generally include planning and design, material preparation, construction, operation and management, demolition recycling of several stages. As the CO_2 emission issue of the infrastructure system is what this paper studies, the division of the life cycle also needs to consider the contribution of each stage to the total CO_2 emissions. And in accordance with the cut-off rule in the life cycle assessment, the life cycle stage which has a relatively smaller impact on the environment is ignored. Based on the research objective of the infrastructure life cycle carbon emission, this paper divide the main energy-consuming stage into four parts: infrastructure material production, infrastructure construction, infrastructure operation and maintenance, infrastructure demolition recycling.

Specifically, the carbon emission source in the infrastructure material production stage contains the energy consumption generated in building materials and components during the course of the production, the manufacture and the processing. These materials are used in the construction of various factories, mines, railways, bridges, ports, roads, pipelines, residential and public facilities, structures and facilities. They mainly include iron and steel, nonferrous metals, cement and other non-metallic building materials and chemical materials; although the transportation equipment manufacturing including parts manufacturing, parts assembly and so on is covered in the manufacturing industry, it is the starting point of the transportation infrastructure from the perspective of the infrastructure life cycle; in addition, as the carrier of the post and telecommunications, the post and telecommunications-related equipment such as the computer, also belongs to the component parts of the infrastructure material production. The carbon source in the infrastructure construction stage comprises the energy consumed in the installation of machinery and equipment during the infrastructure construction. The infrastructure operation and maintenance stage primarily involves the energy consumption from residential buildings and public buildings in the heating, air conditioning, ventilation, lighting, hot water supply, appliances and so on; the energy consumption of railway, highway and other transportation tools during operation; the energy consumption in the process of production and supply of electricity, heat and gas; the energy consumption from the water during the course of production, supply and sewage treatment; the energy consumption involved the maintenance and refurbishment activities in the infrastructure use phase. The infrastructure demolition recycling stage corresponds to the infrastructure construction stage. And demolition recycling objects include residential buildings and public facilities' buildings, factories, mines, railways, bridges, ports, roads, pipelines and other structures and engineering facilities, while exclude the scrappage and recycling of water, communications equipment and energy such as transportation tools, electricity, heat and gas.

CO_2 emission model of the macro infrastructure life cycle

The CO_2 emissions of the macro infrastructure life cycle is relative to the CO_2 emissions of the micro infrastructure life cycle, and what the macro level reflects is the sum of carbon emissions generated from the energy consumption of all infrastructure in a certain area during a certain period of time. Therefore, there is a big difficulty to adopt the tracking-like data collection. It also cannot be obtained by simply accumulating the carbon emission amount of individual infrastructure. Based on the Statistical Yearbook, this paper re-classifies and re-inducts the part of statistic data scattered in the three existing industrial energy consumption which is in line with the boundary of the system herein by taking the macro analysis method to calculate the carbon emissions amount of the macro infrastructure life cycle. The correspondence between the classification of the national economy and the energy consumption of the macro infrastructure life cycle this paper studies can be seen in the Appendix table. It should be noted especially that railways, shipping, aerospace and other transportation equipment manufacturing industry; computer, communications and other electronic equipment manufacturing industry; building materials industry; electricity, heat and fuel vapor; water production and supply industry, which all belong to belong to the manufacturing industry in the second industry, pertain to the material production stage of the infrastructure transportation system, post and telecommunications systems, energy supply, water supply and drainage system, and building system. However, acting as a "world factory", China contracts a large number of manufacturing activities in the international division system, which leads to its enormous industrial exports. Hence, all CO_2 emissions cannot be classified within the scope of China's infrastructure material production and the part for export need to be deducted. In this paper, the ratio of export delivery value to industrial sales output value is selected to indicate the proportion of the industry export which reflects the proportion of cases between the equipment manufacturing for infrastructure and for export in China. The CO_2 emissions which deduct the export proportion are the CO_2 emissions of China's infrastructure material production. This paper divides the carbon dioxide emissions of the macro infrastructure life cycle into three categories: CO_2 emissions of the infrastructure material production, CO_2 emissions of the new infrastructure construction and the CO_2 emissions of the existing infrastructure operation.

On the basis of this, the CO_2 emission model of the macro infrastructure is constructed as follows:

The CO_2 emission model in the infrastructure material production stage:

$$JA_{mac} = JA + TA_1 + NA + GA + XA_1 - HA$$

In the above formula, JA_{mac} is the CO_2 emissions of the construction material production; JA is the carbon emissions of the building infrastructure material production; TA_1 is the carbon emissions of the traffic engineering facility material production; NA is the carbon emissions of the energy engineering facility material production; GA is the carbon emissions of the water supply and drainage facility material production; XA_1 is the carbon emissions of the post and telecommunication engineering material production; HA is the carbon emissions of waste material recovery and utilization.

$$LSC_{mac} = JA_{mac} + TA_2 + XA_2$$

In the above formula, LSC_{mac} is the CO_2 emissions of the infrastructure material production in the macro level; TA_2 is the carbon emissions of the transportation equipment manufacturing; XA_2 is the the carbon emissions of computer communications and other electronic equipment manufacturing.

The CO_2 emission model in the infrastructure construction stage:

$$LJS_{mac} = JB + TB + NB + GB + XB + SA + CA$$

In the above formula, LJS_{mac} is the CO_2 emissions of the infrastructure construction in the macro level; JB is the carbon emissions of the building infrastructure construction; TB is the carbon emissions of the traffic engineering facility construction; NB is the carbon emissions of the energy engineering construction; GB is the carbon emissions of the water supply and drainage engineering construction; XB is the carbon emissions of the post and telecommunication engineering construction; SA is the carbon emissions in the infrastructure repair and maintenance stage; CA is the carbon emissions in the infrastructure removal and waste disposal stage.

The CO_2 emission model in the infrastructure operation stage:

$$LYX_{mac} = JC + TC + NC + GC + XC$$

In the above formula, LYX_{mac} is the CO_2 emissions of the infrastructure operation in the macro level; JC is the carbon emissions of the energy consumption in the building; TC is the carbon emissions in the transportation infrastructure operation process; NC is the carbon emissions in the energy infrastructure production and supply process; GC is the the carbon emissions in the water production and supply process; XC is the the carbon emissions in the post and telecommunications infrastructure operation.

The CO_2 emission model of the macro infrastructure life cycle:

$$LCE_{mac} = LSC_{mac} + LJS_{mac} + LYX_{mac}$$

LCE_{mac} is the total CO_2 emission amount of the macro infrastructure life cycle.

CO_2 Trend Characteristics of China's Macro Infrastructure Life Cycle

The fossil energy consumption goes throughout the infrastructure life cycle. In the infrastructure life cycle course, the combustion of fossil fuels produces CO_2 and releases heat. The *Guideline for the Compilation of the Provincial Greenhouse Gas Inventory (for Trial Implementation),* developed by China's National Development and Reform Commission in May 2011, provides the parameter values based on the actual situation of China's variety of fossil fuels. This research select several major fossil energy, namely coal, coke, coke oven gas, crude oil, gasoline, kerosene, diesel oil, fuel oil, natural gas and liquefied petroleum gas to carry out statistics on their energy consumption. The carbon content per unit of fuel and oxidation rates of combustion of these fossil energy varieties are all selected from the relevant data in *Trial Implementation)*, while low calorific values of the fossil energy are selected from the *China Energy Statistics Yearbook*. And their CO_2 emission factors are obtained by the calculation. Besides, statistics is carried out on the annual usage from 1993 to 2012 of the selected several major fossil energy which is consumed by the thermal power. The annual usage is converted into the corresponding CO_2 emission amount which is divided by the annual terminal total consumption after deducting the losing power during the transmission and distribution and the power consumed by power plants themselves. At last, the annual CO_2 emission factor of China's electricity consumption is calculated. The circumstance that some statistical data only gives the statistics of the related total energy consumption but lacks the composition situation of the each energy in the consumption is encountered in the course of calculating the carbon emissions of the infrastructure life cycle. In this research, the taken calculation method for the CO_2 emission factor of 1kg standard coal is as follows: to conduct the statistics on the final consumption amount of China's major kinds of the energy from 1993 - 2012; then respectively multiply the final consumption amount by the corresponding CO_2 emission factor and sum up the number multiplied to get the CO_2 emission amount; finally, divide the sum by the total energy consumption amount of the year to get the CO_2 emission factor under the comprehensive energy consumption of 1kg standard coal (See Appendix for calculation results). The infrastructure CO_2 emission amount can be acquired through the infrastructure energy consumption in each stage/system multiplying by the corresponding emission factor. The calculation formula is as shown below.

$$CO_2 = \sum_{i=1}^{11} E_i \times I_i$$

Hereinto, $i = 1,2,3,\ldots,11$ respectively represents the above-mentioned 10 main fossil fuels and electric energy. E_i is the specific energy consumption of different carbon sources in different stages of the infrastructure life cycle. L_i is the CO_2 emission factor of major fossil energy and electric energy.

As shown in **Table 3**, the total CO_2 emissions of the infrastructure life cycle is obtained via the calculation of the above-mentioned CO_2 emission model of the infrastructure life cycle. The total CO_2 emissions of China's macro infrastructure life cycle in 1993 was about 1.21 billion tons and increased to about 88 tons in 2012, which means that it increased by 6.3 times during 19 years with an average annual increase of 11%. Its accounting for the proportion of China's total CO_2 emissions always remains between 50% - 65% with the mean of 58.03%. That is to say, more than half of China's CO_2 emissions are caused by activities related to the infrastructure. It can be seen that the

Table 3. Total CO_2 Emissions of the Macro Infrastructure

Year	Macro infrastructure CO2 emissions (10000 tons)	Infrastructure material production stage CO2 emissions (10000 tons)	Infrastructure construction stage CO2 emissions (10000 tons)	Infrastructure operation and maintenance stage CO2 emissions (10000 tons)	National CO2 Emissions (10000 tons)	Share of Total National Emissions (%)
1993	120513.74	37523.79	3087.84	79902.11	231540.34	52.05%
1994	202415.90	38062.93	5672.60	158680.37	413191.10	48.99%
1995	237996.84	60563.28	3083.25	174350.32	446006.62	53.36%
1996	256522.59	65166.25	4932.31	186424.03	469695.44	54.61%
1997	255563.38	60629.49	4665.95	190267.95	472047.01	54.14%
1998	253685.53	57152.22	5265.50	191267.81	456857.44	55.53%
1999	259349.01	55462.51	3346.20	200540.30	463412.50	55.97%
2000	279012.27	59709.08	3565.89	215737.30	510292.46	54.68%
2001	287894.18	68945.31	3472.76	215476.11	510624.94	56.38%
2002	331352.85	78260.37	3825.47	249267.01	543968.68	60.91%
2003	390577.10	92841.73	4224.21	293511.17	630473.57	61.95%
2004	446415.75	104577.82	4798.34	337039.59	719332.83	62.06%
2005	502228.10	117957.07	5069.05	379201.98	856151.88	58.66%
2006	570356.41	139954.37	5648.77	424753.28	947572.89	60.19%
2007	632345.34	162898.80	5862.56	463583.99	1026127.09	61.62%
2008	653002.36	172529.52	6131.73	474341.11	1066502.26	61.23%
2009	702352.17	192491.58	6865.41	502995.18	1127808.72	62.28%
2010	751808.13	217575.37	7591.00	526641.76	1227150.31	61.26%
2011	832296.29	241533.71	8321.46	582441.11	1347998.64	61.74%
2012	886161.41	266810.76	8574.86	610775.78	1405460.45	63.05%

environmental impact due to the infrastructure cannot be ignored.

CO_2 EMISSION INFLUENCING FACTORS OF CHINA'S MACRO INFRASTRUCTURE LIFE CYCLE: VARIABLE, MODEL AND DATA

Selection of Variable: Explained Variable and Explanatory Variable

In this paper, CO_2 emission amount of China's macro infrastructure life cycle is taken as the explained variable and the changing trend of their gradual increase are jointly driven by many human factors such as population growth, advance of urbanization and development and progress in various aspects of the economic society. In order to comprehensively study the carbon emission influencing factors of China's infrastructure, the following aspects are selected as the explanatory variables in this paper.

Total population

The population growth inevitably leads to the demand growth for various aspects of the infrastructure system. Followed by this, the growth of the energy consumption causes the rigid increase of CO_2 emissions.

Level of urbanization

In the infrastructure system, the urban demand for quantity and quality of the infrastructure is large. Population gathering to towns and cities can undoubtedly boost the demand for infrastructure, which leads to the rising related energy consumption. And these play a catalytic role in the increase of CO_2 emissions.

Average household size index

In the background of the fertility decline, industrialization and urbanization, the miniaturization of the family size has become the worldwide trend of population development, which results in an increase of CO_2 emissions in the infrastructure system, mainly because the scale effect cannot play a role. Although there is no change in the total population, the related infrastructure energy consumption consumed by separate households, increases with the growth in the number of households.

Proportion of labor force index

The proportion of the labor force index investigates the impact of demographic factors on the infrastructure CO_2 emission from the perspective of the population structure.

Consumption level of residents index

The improvement of consumption level means that there will be more willing income used for consumption, driving the increased demands of products in various fields such as the infrastructure construction, transportation and energy to cause related changes in CO_2 emissions. From another perspective, the increase of residents' income and the improvement of consumption level highlight the contradiction between the growing consumer demand and the backward productive force. The continuous development of production, living services infrastructure and the tertiary industry is asked to meet the consumption demand. Accordingly, more requirements for the development of the infrastructure system are put forward and this will also affect the CO_2 emission of the system. This paper chooses the consumption level of residents to characterize the

Table 4. Names and Descriptions of indicators

Variable Name	Symbol	Definition	Unit
Total Population	P	Total population amount	thousands of people
Urbanization Rate	U	Urban population accounts for the population proportion	%
Average Household Size	PH	The ratio of the total population and the family number	Person/household
Proportion of Labor Force	WP	The ratio of the working-age population aged 15 to 59 and the total population	%
Consumption Level of Residents	CL	According to the accounting is equal to 100 in 1993	
The Third Industry Added Value Index	SA	According to the accounting is equal to 100 in 1993	
Investment in Fixed Assets of The Infrastructure	FIA	Used for construction and installation engineering investment in fixed asset investment	One hundred million yuan

impact of wealth factors on the infrastructure CO_2 emissions.

Development level of tertiary industry

To analyze the impact of wealth factors on CO_2 emissions of the infrastructure system from the perspective of industrial structure, this paper selects the third industry added value index to reflect the development level of the tertiary industry.

Investment in fixed assets of the infrastructure

The increase of the investment in fixed assets greatly develops and improves the infrastructure, which promotes the economic growth in various periods and lays a good foundation for further development in the next phase. This paper chooses the investment in fixed assets of the infrastructure as one of the factors affecting the production unit to inspect its influencing validity on the CO_2 emissions growth of the infrastructure life cycle.

According to the above seven aspects which have massive impacts on the carbon emission of China’s macro infrastructure, this paper designs specific indicators such as total population amount, urbanization rate, average household size index, proportion of labor force index, consumption level of residents index, the third industry added value index and investment in fixed assets of the infrastructure. Moreover, in this paper, the selected time interval is from 1993 to 2012. Each indicator data is mainly derived from China Statistical Yearbook (1994 - 2013), China Energy Statistical Yearbook (1994 - 2013) and so on. Names and the description of each index are shown in **Table 4**.

STIRPAT Model and its Development and Improvement

As a widely used framework for assessing the impact of human activities on the environment, IPAT model describe the influence of the growing population, developing economy and technology on the environment. This model has been developed and improved by some scholars such as Waggoner and Ausubel (2002) who redefined IPAT identity as ImPACT and decomposed T into the consumption per capita GDP (C) and the impact per unit of consumption (T); Schulze (2002) turned the equation into I=PBAT by adding the behavior factor (B). However, the above-mentioned IPAT model and its variants only allows the estimation of the proportional impact of the environmental change by altering one factor while keeping the other factors constant. Although it is meaningful as a heuristic or exploratory approach, IPAT model is actually an identity which does not allow the hypothesis test. That means both sides of the equation must be balanced. In order to overcome this serious limitation, Dietz and Rosa improved IPAT model to a stochastic model, named STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model in 1997. It can make a statistical modeling as follows for the disproportionate impact of the variable in the environmental aspect.

$$I = aP_i^b A_i^c T_i^d e_i$$

Hereinto, I, P, A, T respectively represents environmental impact, population, wealth as well as technology; a is a model coefficient; b, c and d are the corresponding population quantity, wealth status and human driving force of technology index; e is the error term; i represents the number of changes of each factor (P, A, T, e) in different observation units, which can not only represents the year of the time series, but also can represents the cross-section unit such as country or city. The STIRPAT model is developed and improved according to characteristics and the particularity of China’s macro infrastructure.

(1) As for the demographic factor in the STIRPAT model, the infrastructure system, the most concentrated expression of human activities, create conditions and provide services for human activities and is also the product of human activities. In order to more clearly articulate the effects of anthropogenic activities on the carbon emission from infrastructure, this paper divide the demographic factor into total population (P), urbanization rate (U), average household size (PH) and proportion of working population (WP) to investigate the influential effectiveness of demographic factors from aspects of size,

geographical mobility, existing form, structure and so on.

(2) In this paper, the affluence level is decomposed into two factors: the residents' consumption level index (CL) and the tertiary industry added value (SA).

(3) At present, there is no uniform standard of technology factor's representation. Because the technological advance is an invisible variable and there is a great controversy in the operational measurement of any kind of technology; on the other hand, three kinds of indexes are adopted to indirectly measure the technological progress in the current study. One is the R&D input; two is the number of patents; three is the total factor productivity. However, what is studied in this paper is the carbon emission from the infrastructure level so that these three indexes which reflect the overall technical progress cannot be generally taken. While specifically isolating the contents of the infrastructure level from the overall data lacks the operability; additionally, many existing studies decompose T of the original model into other factors can affect the productivity of the unit except the demographic factor and the affluence factor. Based on the above considerations, this paper intends not to the directly incorporate the technology factor into the model, but to introduce other factors affect the carbon emission of the infrastructure for substitution according to the characteristics of China's macro infrastructure.

(4) The indicator, infrastructure fixed asset investment (FIA) is introduced in this paper. In line with the investment multiplier theory, increase in fixed asset investment causes the gross domestic product doubled, which drives the economic growth, the introduction of advanced technology, the transformation of backward industrial technology, and the improvement of unit productivity. Therefore, FIA can be incorporated into the model here as the alternative factor of the technological factor.

The logarithmic transformation is processed on related variables to establish the STIRPAT analysis model of the CO_2 emission of the macro infrastructure life cycle as follows.

$$\begin{aligned}\ln CE = \ln a + \beta_1 \ln P + \beta_2 \ln U + \beta_3 \ln PH \\ + \beta_4 \ln WP + \beta_5 \ln CL \\ + \beta_6 \ln SA + \beta_7 \ln FIA + \ln e\end{aligned}$$

EMPIRICAL RESULTS AND ANALYSIS

Multicollinearity Inspection between Variables

The ordinary least square (OLS) method is mostly used for the linear regression fit on the model. But there is an important prerequisite for this method. That is, no strict or approximate linear relationship can exists between correlation variables. If this assumption is violated, the least square method cannot accurately obtain parameter estimates and various tests also create problems. The matrix form of the multivariate linear regression model is $Y = X\beta + \varepsilon$, while the ordinary least square of the parameter β is estimated to be $\hat{\beta}_{LS} = (X^T X)^{-1} X^T Y$ 38. If variables in X are completely correlated, $(X^T X)$ is an irreversible matrix. Thence, the regression coefficient $\hat{\beta}_{LS}$ cannot be obtained with this formula. If variables in X have a strong correlation, the determinant $|X^T X|$ is almost equal to 0. At this time, solving the inverse matrix of $(X^T X)$ contains serious rounding errors, which will increase the sampling variability of the estimated value. Therefore, the direct consequence of the multicollinearity is the enlarged estimated standard error of the regression coefficient parameter, the widened confidence interval, and the reduced stability of the estimated value. It means that the probability of accepting alternative hypothesis's mistakes and the coefficient t's failure to pass the test both increases so that the correct coefficient estimates cannot be obtained usually.

In view of this, when using the ordinary least square method to fit the linear regression, the multicollinearity test is need to be put on variables in advance. From the point of view of this paper, when total population, urbanization, consumption level of the residents, and the tertiary industry development of these factors are used to explain the dependent variable, the CO_2 emissions of the macro infrastructure, there is a certain overlap in the information provided. Furthermore, they have a common upward trend with the economic development and there is a great possibility of the existence of the collinearity. So the correlation matrix analysis is conducted for the independent variables involving the regression of the model and it is found that there is a significant correlation between any two of these variables with the absolute value of the correlation coefficient all above 0.9 shown in **Table 5**.

Table 5. Variable Correlation Analysis

	lnCE	**lnP**	**lnU**	**lnPH**	**lnWP**	**lnCL**	**lnSA**	**lnFAI**
lnCE	1							
lnP	0.965	1						
lnU	0.966	0.995	1					
lnPH	-0.968	-0.985	-0.978	1				
lnWP	0.917	0.927	0.954	-0.923	1			
lnCL	0.974	0.967	0.979	-0.958	0.947	1		
lnSA	0.980	0.983	0.993	-0.971	0.958	0.992	1	
lnFAI	0.981	0.957	0.971	-0.951	0.946	0.994	0.992	1

Table 6. Regression Analysis and Multicollinearity Test

	Unstandardized Coefficients		**Standardized Coefficients**	**T**	**Sig.**	**Collinearity Statistics**	
	B	**Std. Error**	**Beta**			**Tolerance**	**VIF**
(Constant)	-180.049	127.266		-1.415	.183		
P	16.973	10.501	1.251	1.616	.132	.002	465.511
U	-3.643	2.954	-1.364	-1.233	.241	.001	951.502
PH	-1.250	1.599	-.194	-.782	.450	.021	47.987
WP	.995	2.991	.066	.333	.745	.032	30.789
CL	-.486	.455	-.405	-1.067	.307	.009	112.309
SA	.031	1.182	.033	.026	.980	.001	1289.941
FAI	.644	.388	1.232	1.658	.123	.002	429.421

In this paper, the variance inflation factor (VIF) is applied to diagnose the multicollinearity. VIF_j, the variance inflation factor VIF_j of the independent variable x_j, is defined as the j-th diagonal element c_{ij} in the matrix $(X^TX)^{-1}$. And here is the equation.

$$VIF_j = c_{jj} = 1/(1 - R_j^2), j = 1,2, \dots, p$$

In the equation, R_j^2 is the decision coefficient obtained from establishing the multivariate linear regression model with x_j as the dependent variable and other p-1 independent variables as the independent variable, which is also called the multiple correlation coefficient between the dependent variable and the independent variable. The larger the R_j^2, the more serious the collinearity between independent variables. The VIF is consistent with the R_j^2. When the VIF of a variable is greater than 10, it can be considered that the collinearity between independent variables is serious.

By SPSS19.0, the least squares (OLS) regression analysis and the multicollinearity VIF test is carried out on the model. The results are shown in **Table 6**. According to the VIF test, it has been found that VIF values of the seven independent variables in this paper are all much greater than 10, which shows that there is a serious multicollinearity between independent variables. From the OLS regression results, the urbanization rate, the family size and the level of consumption coefficients are all negative, which does not meet the expectations of this study. Therefore, the ordinary least squares cannot be used on this model for regression fitting.

Ridge Regression Analysis

In order to eliminate the independent variable multicollinearity problem, the model is fitted by (ridge regression) estimation in this paper. The ridge regression, proposed by Hoerl and Kennard in 1970, is a biased estimate regression method dedicated to the analysis of data collinearity. Actually, it is an improved method of least squares estimation which gets the regression coefficients in the cost of losing some information and reducing the accuracy by giving up the unbiasedness of the least squares method. It is a more realistic and more reliable regression method. When multicollinearity exists between independent variables, the traditional least squares lack the stability and the reliability. The ridge regression algorithm pluses the loss function with a regularization term called normal matrix kI(k>0). Therefore, the degree of $|X^TX + kl|$'s proximity to the singularity will become smaller, and the ridge regression parameter is estimated to be:

$$\hat{\beta}_{RR} = (X^TX + kl)^{-1}X^TY$$

Here k>0 is called the ridge parameter which may also be written as:

$$\begin{gathered}\hat{\beta}_{RR}(k) = \left[\hat{\beta}_1(k), \hat{\beta}_2(k), \dots, \hat{\beta}_p(k)\right] \\ = (X^TX + kl)^{-1}X^TY \\ W_kX^TY\end{gathered}$$

Thereinto, $W_k = (X^TX + kl)^{-1}$

As the estimation of β, $\hat{\beta}(k)$ is more stable than the least squares estimation $\hat{\beta}$. When k=0, the ridge regression estimation $\hat{\beta}(0)$ is the ordinary least squares estimation. Usually the R^2 value of the ridge regression equation is slightly lower than that of the normal regression, but the significance of the regression coefficient is significantly higher than that of the ordinary regression.

With the increase of K, absolute values of all elements of $\hat{\beta}(k)$ all tend to be smaller, and they are also getting bigger and bigger with respect to the correct value β. When k approaches the infinity, $\hat{\beta}(k)$ tends to 0. The trajectory of $\hat{\beta}(k)$ varies with the change of k,

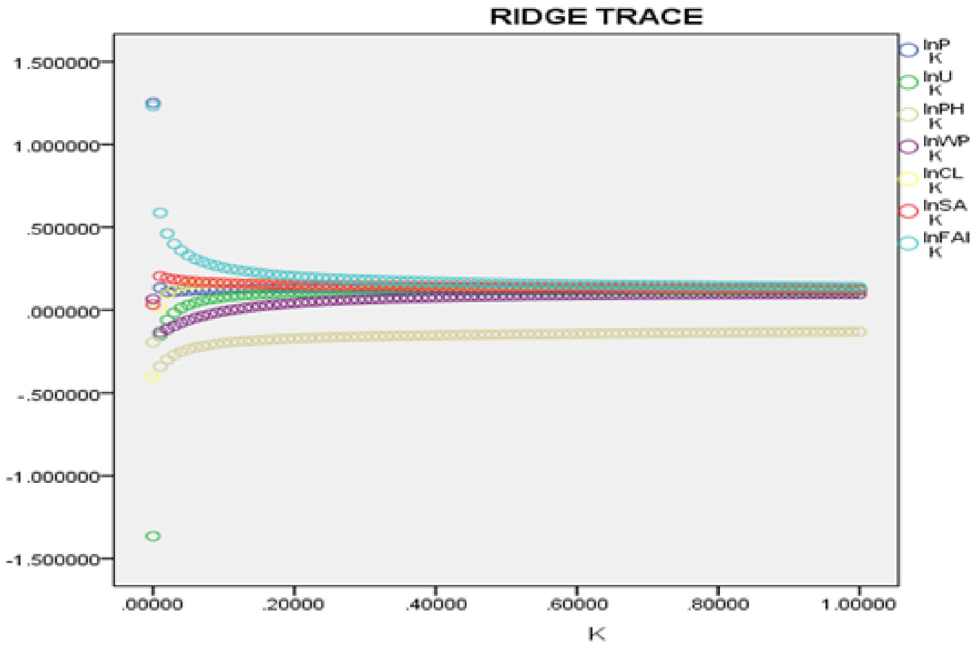

Fig. 1. Model Regression Initial Ridge Trace

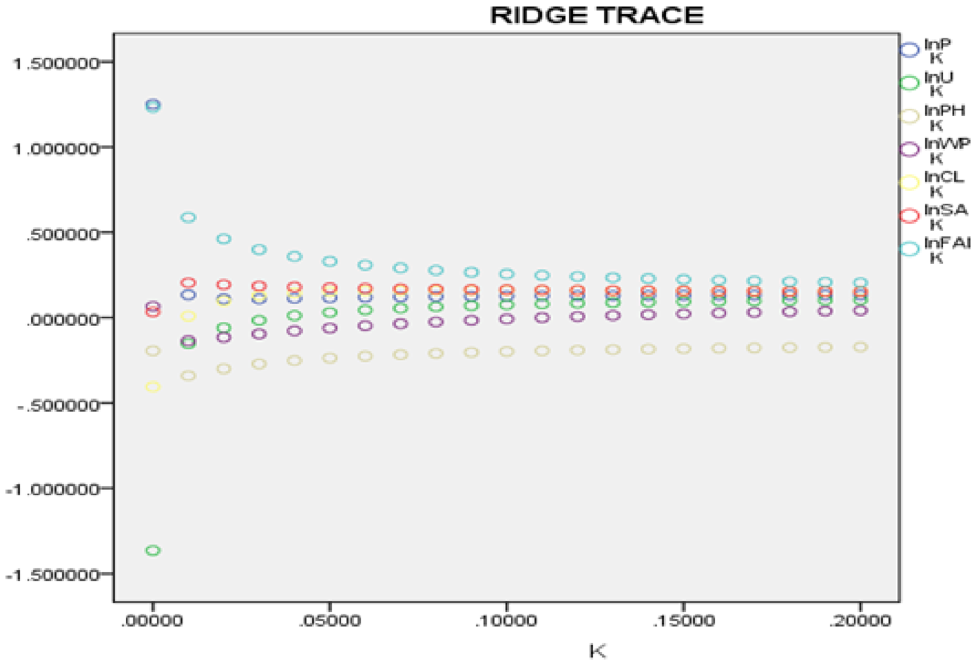

Fig. 2. Model Regression Adjusted Ridge Trace

and it is called the ridge trace. Several k values can be selected for calculation to get the ridge trace figures and then the k value, which makes the ridge track to be stable, is finally determined based on the research experience. After the regression fitting to the model, the **Fig. 1** initial ridge trace is as follows.

From the figure of the initial ridge trace $k \in [0,1]$, when k>0.2, seven ridge tracks are beginning to become stable. At the same time, the coefficient of determination is slowly declining. So the value range of k is adjusted into $k \in [0,0.2]$ to analyze the ridge trace more precisely and determine the value of k. From **Fig. 2**, when $k \geq 0.06$, the regression coefficient begins to tend to be stable. According to the principles of value determination of k, $k = 0.06$ is determined in this paper, and the ridge regression results are shown in **Table 7**.

Table 7. Ridge Regression Analysis

	Regression Coefficient	**Standard Regression Coefficient**
lnP	1.623714	0.119650
lnU	0.119019	0.044577
lnPH	-1.452160	-0.225645
lnWP	-0.714165	-0.047517
lnCL	0.187989	0.156927
lnSA	0.157785	0.172028
lnFAI	0.161242	0.308581
Constant term	-5.875311	
R	0.98	
R^2	0.97	
Adjust R^2	0.95	
Standard error	0.12	
F	56.6	
F significance	0.00	

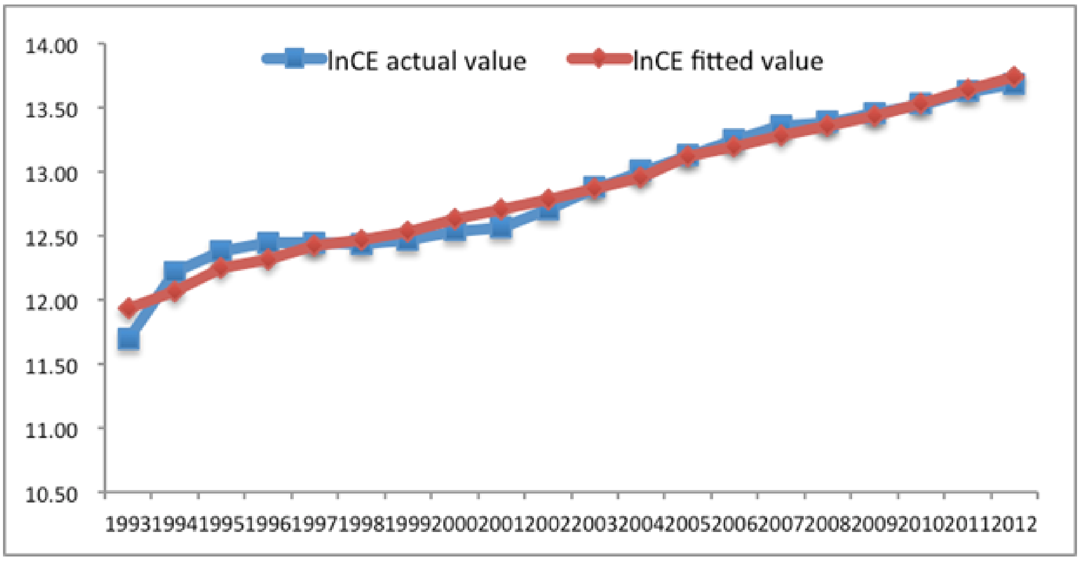

Fig. 3. Comparison between the regression values and the actual values of the model

Model significance test results show that the coefficient of determination R^2 is greater than 0.97 and the model has a high goodness of fit. The analysis of variance shows that the significance of F test $p<0.00001$, the variance inflation factor VIF of the standard regression coefficient of each independent variable is less than 0.31 and regression coefficient symbols are in line with the test of the economic significance. Thereby the fitting equation of the model is:

$$\begin{aligned} ln\,CE = {} & 1.623714\,ln\,P + 0.119010\,ln\,U - 1.45216\,ln\,PH \\ & - 0.714165\,ln\,WP + 0.187989\,ln\,CL \\ & + 0.157785\,ln\,SA + 0.161242\,ln\,FIA \\ & - 5.875311 \end{aligned}$$

The comparison of model fitting value and the actual value are shown in the **Fig. 3**, and it turns out that the whole fitting effect of the model is good.

From the ridge regression estimation results of this model, measuring based on the absolute value of the standard regression coefficient of each variable, and the influencing factors of CO_2 emissions of China's macro infrastructure from 1993 to 2012 in accordance with the degree of influence are followed by infrastructure investment in fixed assets, accounting for 30.9%; household size, 22.6%; tertiary industry development, 17.2; level of household consumption, 15.7%; total population, 12%; proportion of the labor population, 4.8%; urbanization rate, 4.5%. Among them, the household size and the proportion of the labor population are negatively correlated with the carbon emissions of the macro infrastructure and other factors are all positively correlated with them. Otherwise, each variable regression coefficient obtained by the model fitting is the elasticity of the dependent variable to the independent variable. It can be seen that when total population, urbanization rate, level of household consumption, tertiary industry added value and infrastructure investment in fixed assets increase by 1% during the research period, the corresponding added elasticity of CO_2 emissions of the macro infrastructure is 1.624, 0.119, 0.188, 0.158, and 0.161 respectively. However, when household size and proportion of the labor population falls 1%, CO_2 emissions of the macro infrastructure will increase by 1.452 and 0.714.

CONCLUSIONS AND POLICY IMPLICATIONS

In this paper, the carbon emission accounting border of the macro infrastructure life cycle has been determined, the two-dimensional boundary of the infrastructure system and the life cycle process has been established, and the CO_2 emission accounting model of the macro infrastructure life cycle has been constructed in this paper. Through the calculation of CO_2 emissions from 1993 to 2012, it can be found during the study period that the CO_2 emissions of China's macro infrastructure life cycle shows an overall upward trend, accounting for 53% to 64% of national total emissions. In recent years, its growth speed has slowed down and is slower than that of national total emissions. It can be seen that the CO_2 emission in the course of infrastructure life cycle should bear a great responsibility for China's overall environmental issues. Recently, China has achieved some success on the energy saving and emission reduction of the infrastructure. Although, the CO_2 emission growth rate of the infrastructure has declined, the continued growth in total carbon emissions shows that the carbon emission reduction of the infrastructure still has great potential.

STIRPAT model is used in this paper to analyze the major influencing factors of the CO_2 emission of macro infrastructure lifecycle. What can be seen from the analysis of the results is as follows.

(1) Among the seven major influencing factors designed in this paper, the infrastructure investment in fixed assets has the biggest impact. The rapid development and construction of the urbanization spawns a huge infrastructure needs. Such as major water conservancy project construction, food storage facilities, high-speed railways, airports, highways, subway and other transportation infrastructure, urban underground pipe network and other public facilities, as well as pensions, education, health care and other public utilities still have a huge investment in space. The large-scale investment in the infrastructure must be accompanied by a large number of direct and indirect energy consumption, which virtually pushed up the CO_2 emissions of China's infrastructure-related activities.

(2) The influential degree of the average household size on the carbon emission of the infrastructure is second only to the investment in fixed assets. And there is a negative correlation between the carbon emission of the infrastructure and the average household size. It means that carbon emissions of the infrastructure increase as the size of the household shrinks. The reason is that the miniaturization of the household size has become a worldwide demographic trend under the background of declining fertility, industrialization and urbanization in recent years. Due to the miniaturization of the household size, the scale effect cannot play a role. In addition, the increase of requirements for infrastructure-related systems and carbon sources inevitably bring CO_2 emissions to rise.

(3) The effect and contribution of the tertiary industry development and the consumption level to the carbon emission of the infrastructure are 17.2% and 15.7% respectively. The rapid development of the tertiary industry has adjusted the industrial structure and is one of the essential features of the modern economy. At the same time, China regards developing the tertiary industry and actively carrying out the industrial restructuring as an important way to the overall energy conservation. While, the main energy consumption of the tertiary industry is the electricity. Individuals covered by the tertiary industry are very wide. Although compared with industrial enterprises single emissions are very small, the total amount of emissions cannot be ignored. The effect of enhancement of household consumption level on the CO_2 emission in the infrastructure system is mainly reflected in the consumption growth on construction, transportation, energy and other related products; otherwise, personalized and diversified consumption gradually become the mainstream and the renewal rate accelerates driven by the new normal economy; the improvement of the level of consumption also covers a number of bad habits and wasteful behaviors, leading to the rising CO_2 emissions of the infrastructure.

(4) The impact proportion of the total population on the carbon emission of the macro infrastructure is 12%. It is first reflected in that the increase in the total population inevitably leads to an increase in the demand for all aspects of the infrastructure system and the consequent growth in the energy consumption also results in the rigid rise of CO_2 emissions. Secondly, if the

growth rate of the population is higher than that of the infrastructure development, the infrastructure per capita consumption is low. Although the infrastructure consumes a lot of energy, it is unable to resolve the contradiction between population and development fundamentally. Therefore, how to ensure the infrastructure construction meet the required conditions of the healthy growth of the population and effectively inhibit the CO_2 emission of the infrastructure system under this premise at the same time of controlling the excessive expansion of the total population is the current important task.

(5) The impact degree of the proportion of the working population and the urbanization rate is relatively low and is respectively 4.8%and 4.5%. The declining proportion of the labor force implies that there is a fundamental change in China's population structure. China has bid farewell to the agricultural society into the industrialized society, which presents great challenges to the pension, health care system and puts forward higher requirements for related infrastructure services. The declining proportion of the labor force also indicates that the increase of the population transferring from the state of the labor to the retirement makes the minor population and the aging population become the mere consumer population. Thus the increasing demand for related goods and services affect the CO_2 emissions of the infrastructure system to a certain extent. On the other hand, the average person of the labor force has to take on more responsibility for the maintenance of the elderly. The increased burden will pass the pressure onto the society. As the carrier of the social public service, the infrastructure will bear more pressure and be faced with more requirements for improvement and construction. Thereby its output of CO_2 will be affected. At present, the problem of China's urbanization is that the "land urbanization" is faster than the population urbanization. Furthermore, the inefficient extensive construction land and the irrational urban spatial distribution, size and the structure lead to the low utilization rate of partial infrastructure and the invalid energy consumption. How to integrate the ecological civilization, green carbon, saving and intensity into the infrastructure construction during the urbanization process, building the intensive compact urban infrastructure system of high density, oriented transit and functional mix is an important issue to be addressed in the current.

Above conclusions contain rich policy implications.

(1) Comprehensively configure, further improve, and constantly update the existing policy system to adapt to the current infrastructure so as to provide institutional guarantee for energy conservation and emission reduction system

Currently, China's policies and measures of the energy conservation and emission reduction mainly focus on the construction and transportation. The policy support for other infrastructure subsystems is relatively few, and there is no unified planning of the infrastructure system as a whole. Subsystems of the infrastructure depend and affect each other and they have much in common. So if the policies and measures for the reduction of infrastructure can be formed from the whole to play their overall effect, it is more conducive to improve the emission reduction efficiency of the infrastructure. Simultaneously, the design of energy saving and control policy should be configured by synthetically considering the construction of infrastructure, technological progress, macroeconomic environment, environmental regulation policy and other aspects.

(2) Strengthen the efforts to further promote the energy-saving and emission reduction of the existing infrastructure

Characteristics of the infrastructure are long life cycle, slow update speed, the aging of the infrastructure and the decreasing use efficiency, which all become the important reason for the increase of the energy consumption during the operation stage. Consequently, the transformation of the old infrastructure should be strengthened. Besides, the construction quality, operational standards and management levels of distribution network, drainage waterlogging, fire, transportation, sewage and waste management and other infrastructures should be improved to enhance their use efficiency. Taking building infrastructure as an example, the northern long heating time, the high energy consumption and excessive emissions of the heating ask for increasing efforts to carry out the energy-saving transformation and comprehensively and upgrading old residential and non-energy-efficient buildings so as to reduce the CO_2 emissions. At the same time, the existing statistical monitoring, energy audits and the energy efficiency publicity of the CO_2 emission should be strengthened and the overall energy saving monitoring system covering every system of the infrastructure should be established.

(3) Raise standards and improve the energy efficiency of newly built infrastructure

At the same time of doing a good job in the emission reduction regulation of the newly built infrastructure, we should continue strengthening the supervision on the implementation of reduction standard of the new infrastructure, incorporating the mandatory energy conservation and emission reduction standards into the whole process of supervision in the construction phase. In addition, we also should strengthen the quality control on the building materials, products and equipment from the link of production, circulation and use and add the emission reduction standard to achieve the full life cycle emission reduction target. We also should continuously improve the emissions standard, spreading from big cities to small cities. Besides, with the deepening of the emission reduction, the standard should be constantly adjusted to further improve the energy efficiency of the new infrastructure.

(4) Promote the application of the renewable energy infrastructure system in scale

At present, the ministry of finance, the ministry of housing and urban-rural development has organized and implemented the demonstration of the renewable energy construction application project, which has achieved significant results. The application scale of the renewable energy should be further extended to the entire infrastructure system and be applied in all aspects of transportation, water supply and drainage, energy, etc. We also should enrich the application forms of the renewable energy, increase the proportion of solar energy, shallow energy, biomass energy and other renewable energy sources in the infrastructure as well as reducing the CO_2 emissions through changing the energy structure.

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