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Carbon Emission Scenario Modelling in Shanghai (Yangtze River Delta)

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Climate governance is an important issue common to the international community currently, and the international community has signed several agreements to combat greenhouse gases. China is the country has the largest CO_2 emissions among the world and the government is current under tremendous pressure to reduce and mitigate carbon emissions. Emissions controlling of greenhouse gas will mitigate the global climate problem, it can also be an important prerequisite for economic and social development of China, and a guarantee for the sustainability of mankind. Shanghai (Yangtze River Delta) is the heart of China's economy and an important area for reducing carbon emissions. Based on the actual development foundation and emission reduction space of Shanghai, this paper constructs a local emission reduction plan. By setting different growth rates for factors that affect carbon emissions, multiple scenarios under different growth rates are obtained, and carbon emissions in the next 40 years are modelled. The development scenarios suitable for achieving carbon peaking and carbon neutrality goals economically and efficiently are analysed, which has certain reference timeline for Shanghai (Yangtze River Delta) to achieve carbon neutrality.

1. Introduction

Along with the world population increase rapidly and the rapid growth of the economy, human production and activities have caused a large amount of emissions of the greenhouse gas. Greenhouse gas cause the risen of global temperature which leads to the frequent emergence of extreme climatic phenomena, and it has become one of the most critical challenges faced by the government and regions in the world (Yu and Zhou, 2022). To ensure the comprehensive and sustainable development of society of human beings and promote the development of global climate governance, efforts to reduce carbon emissions have become a top priority for governments around the world.

Katanoa and Masui (2023) used AIM/Enduse to analyze two high carbon dioxide emitting sectors in Tokyo, commercial and residential, in order to determine the measures needed to achieve zero carbon dioxide emissions and achieve carbon neutrality in the Japanese capital Tokyo by 2050. Jaitiang et al. (2023) has established a technological roadmap for achieving carbon neutrality at Map Ta Put, the largest industrial park in Thailand, demonstrating the starting point for achieving the greenhouse gas emission reduction goals of the Industrial Estate Authority of Thailand (IEAT). From 2023 to 2050, appropriate greenhouse gas mitigation technologies will be adopted through different scenario assumptions to achieve Thailand's goals of carbon neutrality and net zero greenhouse gas emissions respectively by 2050 and 2065.

In March 2016, China listed the improvement of low-carbon development level and effective control of total carbon emissions as the goals of the national plan. In the past few years, China has achieved remarkable results in green and low-carbon transition development and effective response to ecological threats caused by climate change. China has fulfilled its promised climate governance goals by 2020 (Gong, 2016) ahead of schedule, laying a solid practical foundation for the next step to achieve carbon peaking and carbon neutrality faster.

Shanghai is an international economic, financial, trade and shipping center with strong comprehensive economic strength, high industrial energy level and strong gathering and radiation ability. In the future, Shanghai will play

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an important leading role in the integration of the Yangtze River Delta, which can drive the industrial agglomeration of surrounding cities and narrow the income gap. It is of great significance to study the carbon emission of Shanghai. This paper aims to adopt different carbon emission reduction scenarios, analyze the pathway to carbon neutrality in Shanghai (Yangtze River Delta).

2. Carbon Emission Features of Shanghai

With the carbon peak carbon neutral policy, saving energy and emission reduction work of Shanghai has achieved greater results, energy consumption structure of Shanghai has undergone more obvious changes. The percentage of coal consumption has been steadily decreasing, but the main sources of carbon emissions in Shanghai remain power, industry, transportation and construction. The main characteristics of the carbon emissions of Shanghai are summarized in Figure 1.

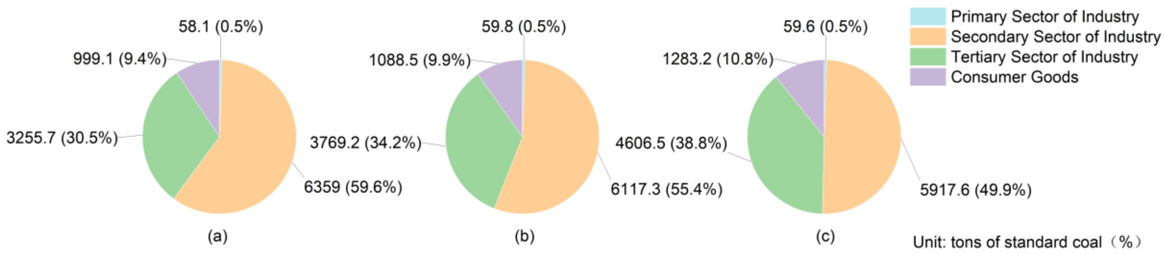

Figure 1: Energy consumption of Shanghai. (a) energy consumption in 2011 (b) energy consumption in 2015 (c) energy consumption in 2019

The overall carbon emissions have been steadily decreasing, with a significant reduction in carbon emission intensity. Within recent years, the overall carbon emissions of Shanghai have declined from 197 million tons to 105 million tons, with an overall cumulative decline of about 6.3 %. In 2020, carbon emission of Shanghai intensity declined by about 15.2 % compared with 2017. Overall, carbon emissions in Shanghai in total is gradually decreasing, and carbon emissions are experiencing a significant decline in intensity.

The industrial sector's share of energy consumption has declined, while the residential sector's share has risen. From 2011 to 2019, the overall energy consumption of Shanghai has entered a phase of low-speed growth. Domestic energy consumption accounted for only 9.4 % in 2011, while that has risen to 10.8 % in 2019. The proportion of domestic energy consumption is rising, and just as carbon emission reduction in developed countries focuses on areas closely related to the lives of residents, there is still a lot of potential to reduce domestic energy consumption in Shanghai.

The share of coal is falling, and the share of clean energy is rising. China's rapid industrialization and urbanization in recent years has continued to be driven mainly by coal, but with the share of clean energy sources such as natural gas and external electricity on the rise, the share of coal in Shanghai's primary energy consumption has fallen from 50 % in 2007 to 30 % in 2020. With the implementation of the Anhui Electric Power Sending to the East and Western Electric Power Sending to the East projects, the amount of local thermal power in Shanghai has been decreasing as each year passes, and the carbon emissions from the use of thermal power have decreased by about 3.8 %, but with the increased use of external power in Shanghai, the carbon emissions from external power have risen to over 30 %.

Carbon emissions from transportation rebound and grow as oil consumption surges. Shanghai's oil consumption is growing rapidly along with the rapid rise of vehicles in the city, and the massive promotion of new energy vehicles has had little effect on curbing the massive consumption of oil. Oil has a lower carbon emissions factor than coal, but its share of the total carbon emissions has risen to more than 30 % by 2020. Huge urban transportation vehicle ownership not only puts pressure on the carbon emissions of Shanghai but also on the air quality of Shanghai's central city.

Carbon emissions from the construction sector are on a continuous rise, and it is noteworthy that public buildings are the primary contributors to this increase. The overall consumption of energy and carbon emissions in the construction sector maintain the growth trend, and over the past decade, Carbon emissions of Shanghai from civil buildings have continued to rise. In 2019, the carbon emissions from civil buildings in total in Shanghai accounted for 22.1 % of the city's total carbon emissions, and the main carbon-emitting buildings in Shanghai are public buildings, which accounted for 59 % of the overall carbon emissions from the public floor area of about 400 million square meters in Shanghai in 2019, and 32 % of the overall carbon emissions from residential buildings, building construction accounts for 9.0 %. The growth rate of carbon emissions from public buildings in Shanghai over the past decade has been about twice that of residential buildings. The initial section of the guidelines provides general style recommendations, which are then followed by specific cases. It is advised to avoid placing a lower-level heading immediately after a higher-level one. It is recommended to include at least one sentence between the headings.

3. Methodology

Carbon emission scenario simulation research methods mainly include STIRPAT model, scenario analysis method, IPAT model, LEAP model, Monte Carlo dynamic simulation, China's energy and environment comprehensive policy evaluation model, ARIMA model, BP neural network combination model and system dynamics model (Li, et al., 2022). Through a literature search, nowadays STIRPAT model, contextual analysis method and China's energy environment comprehensive policy evaluation model are more commonly used, so the three methods are introduced in detail.

3.1 Stochastic Impacts by Regression on Population, Affluence and Technology Model (STIRPAT)

IPAT equation was proposed by Ehrlich in 1971. While to improve the drawbacks of the IPAT equation, Dietz and Rosa (1994) expanded the stochastic model to STIRPAT model. STIRPAT model makes up for the defects of proportional change of the dependent variable in the IPAT equation. This model has been extensively utilized in the analysis of carbon emissions and their influencing factors, allowing for a more adaptable representation of the diverse factors' impact on the environment. The model can analyse the impact of population, GDP, and technology level on carbon emissions from energy consumption. The equation is shown in Eq(1):

$$I = aPATe^{bcd} \tag{1}$$

where I denotes the environmental impact, P is population, A is wealth, T is technology, a is the scale of the equation, and b, c, and d are the elasticity coefficients of population, wealth, and technology.
Gong et al. (2018), quantitatively analyzed the influencing factors of carbon emissions in the Yangtze River Delta (YRD) region using the STIRPAT model, and the study showed that population is the main driver of carbon emissions in the YRD region. Yang et al. (2018) used the STIRPAT model to study the driving factors affecting carbon emissions in China and analysed the elasticity coefficients of each factor to provide reference for policymakers. After China put forward the goal of "reaching the carbon peak by 2030", scholars not only used the STIRPAT model to analyse the influencing factors of carbon emissions but also used it to predict the national and regional carbon emissions (Yan et al., 2021). The STIRPAT model is also used to predict national and regional carbon emissions.

3.2 Scenario Analysis

Scenario analysis was formally introduced by Walker in 1971 (Duinker and Greig, 2007). Scenario analysis refers to predicting the possible outcomes of the dependent variable under the assumption of the development trend of various independent variables, analysing the various outcomes and their impacts, to remind the decision maker of the possible risks and improve the scientific feasibility of decision-making (Aversa, 2024). This method is mainly used to analyse and evaluate the enterprise's own situation and the social environment to make corresponding decisions, change the coefficients of uncertainty factors to establish the direction of the enterprise's future development to formulate a strategy based on the prediction results and realize the optimal allocation of resources (Victor, 2012). The method is based on three perspectives: retrospective, efficiency, and equity, and sets up different allocation scenarios to forecast the allocation of carbon quotas.

3.3 Integrated Policy Assessment Model of China (IPAC)

IPAC is a model developed by the Energy Research Institute National Development And Reform Commission. The model conducts a comprehensive evaluation of China's energy and environmental policies. The model consists of three main parts: the energy and emissions model, the environmental model, and the impact model which has been widely applied.

4. Case Study

The Yangtze River Delta region currently consists of Jiangsu Province, Zhejiang Province, Anhui Province and Shanghai municipality, a total of four provincial and municipal administrative regions, covering a total area of 358,000 square kilo meters, accounting for about 4 % of China's land area. The Yangtze River Delta region ranks first among all economic zones in China, with its total GDP accounting for roughly a quarter of the country's total economy. Despite its developed economy, the Yangtze River Delta region is not rich in resources, and at the same time has small energy reserves. Economic development will inevitably lead to a large amount of energy consumption, which in turn will lead to an increase in carbon emissions. In terms of total energy consumption and carbon emissions, the Yangtze River Delta region has accounted for a large proportion of China's total energy consumption and carbon emissions over the past 20 years and has become a region of special concern to the Chinese government in terms of CO_2 emissions reduction. The work required to regulate and curb energy consumption and carbon emissions will be very difficult, and the challenges encountered will be even more brutal.

This paper chooses 2015 as the baseline year since it is the exchange year of the 13th and the 14th Five-Year Plan for National Economic and Social Development. According the different factors of gross domestic product (GDP), energy consumption per unit of GDP, energy and carbon emission intensity, and technological, defining the baseline scenarios, low carbon scenario and high carbon scenario of carbon emission scenarios of Shanghai which is illustrated below (Li, et al., 2022). Based on the STIRPAT model, the energy and industrial carbon emission scenarios of provinces and cities in the Yangtze River Delta region from 2015 to 2060 are simulated.

4.1 Baseline Scenario

The baseline scenario takes full account of the objective of the 13^{th} and the 14^{th} Five-Year Plan for National Economic and Social Development, and takes the current situation of the economic development into consideration. It constructs a scenario which is guided by the 14^{th} Five-Year Plan to carry out rigorous energy conservation and emission reduction in order to improve the efficiency of energy utilization, and reduce the unit of GDP energy consumption and CO_2 emissions per unit of GDP. Table 1 presents the peak carbon timing and carbon emissions in the Yangtze River Delta Region. Table 2 presents the GDP growth under baseline, high-carbon, and low carbon three different scenarios.

Table 1: Peak Carbon Timing and Carbon Emissions in the Yangtze River Delta Region

Region	Baseline Scenario		High-Carbon Scenario		Low Carbon Scenarios	
	Peak Carbon Time	Carbon Emissions	Peak Carbon Time	Carbon Emissions	Peak Carbon Time	Carbon Emissions
Shanghai	2020	166.43	2020	160.879	2030	175.678
Jiangsu	2025	1,034.391	2020	996.188	2040	1,161.936
Zhejiang	2030	457.954	2020	427.46	2045	545.963
Yangtze River Delta	2025	1,650.57	2020	1,584.527	2040	1873.537

Carbon Emissions Unit: Million t

Table 2: GDP growth in the Yangtze River Delta region under different scenarios

Time	Baseline Scenario			High-Carbon Scenario			Low Carbon Scenarios		
	Shanghai	Jiangsu	Zhejiang	Shanghai	Jiangsu	Zhejiang	Shanghai	Jiangsu	Zhejiang
2015-2020	0.065	0.075	0.07	0.07	0.08	0.075	0.06	0.07	0.065
2020-2025	0.05	0.055	0.055	0.055	0.06	0.06	0.045	0.05	0.05
2025-2030	0.045	0.05	0.05	0.05	0.055	0.055	0.04	0.045	0.045
2030-2035	0.04	0.045	0.045	0.045	0.05	0.05	0.035	0.04	0.04
2035-2040	0.035	0.04	0.04	0.04	0.045	0.045	0.03	0.035	0.035
2040-2045	0.03	0.035	0.035	0.035	0.04	0.04	0.025	0.03	0.03
2045-2050	0.025	0.03	0.03	0.03	0.035	0.035	0.02	0.025	0.025
2050-2055	0.02	0.025	0.025	0.025	0.03	0.03	0.015	0.02	0.02
2055-2060	0.015	0.02	0.02	0.02	0.025	0.025	0.01	0.015	0.015

4.2 Low-carbon Scenarios

The low carbon scenario is based on the baseline scenario, but with a greater reduction in energy consumption per unit of GDP and carbon dioxide emissions, and a substantial improvement in the efficiency of energy use. In this scenario, it is assumed that more attention has been paid to the introduction of advanced low-carbon technologies and increased investment in low-carbon technologies. The government, enterprises and individuals have a stronger awareness of low carbon. The measures are optimizing the industrial structure, transforming the mode of economic development, and optimizing the structure of energy consumption.

4.3 High-carbon Scenario

The high-carbon scenario is not fully align the requirements of the 14th Five-Year Plan for National Economic and Social Development, it is assumed that energy consumption per unit of GDP and carbon dioxide emissions have been declining, more attention has been paid to the speed of economic development.

5. Results and Discussion

The significance of carbon emission scenarios and common methods are elaborated in detail, and the energy and industrial carbon emission scenarios of provinces and municipalities in the Yangtze River Delta region in 2015-2060 are simulated using 2015 as the base year and the three perspectives of the scenario analysis method, namely, the base scenario, the low-carbon scenario, and the high-carbon scenario. The results are as follows.

Commonly used research methods for carbon emission scenarios include the STIRPAT model, the contextual analysis method, and the China Energy and Environment Comprehensive Policy Evaluation Model (CEECPEM). The STIRPAT model is mostly applied to analyse the main factors of carbon emissions affections. The contextual analysis method is based on the retrospective principal perspective, the efficiency principal perspective, and the fairness principal perspective for predicting carbon allocation. The CEECPEM uses the reference scenario, the alternative government scenario, and the high economic growth scenario as models to predict CO_2 emissions. Carbon emission scenario studies help to simulate future carbon emissions in a combination of scenarios under different growth patterns.

As the Yangtze River Delta region continues to experience rapid economic growth, it has become a major contributor to carbon emissions in China. This study utilizes the STIRPAT model to forecast carbon emissions in the region under different scenarios: baseline, low carbon, and high carbon. The findings indicate that carbon emissions in the Yangtze River Delta region will peak in 2025, 2020, and 2040 under the three scenarios, while in Shanghai, the peak will occur in 2020, 2020, and 2030.

6. Conclusions

Based on the above analysis, by summarizing the effective experience of carbon emissions of Shanghai industries and emission reduction measures and drawing on the carbon peak path choices of other cities, the path choices for Shanghai to achieve carbon peak are summarized as follows.

Increasing the proportion of external clean power is a significant way for Shanghai to conscious carbon peaking. Strengthen the construction of peaking capacity on the power supply, grid system and user demand, improve the level of new energy consumption and power system flexibility, and accelerate the construction of a new type of energy system infrastructure with new energy as the mainstay; relying on the needs of integrated development of the Yangtze River Delta, push forward the interconnection of regional distribution grids of the three provinces and one city, actively strive for low-carbon and clean foreign power, and accelerate the construction of large channels of foreign clean power; plan ahead for new ultra-high-voltage corridors, and push forward the coordinated development of the city's foreign power corridors with urban transmission grids and distribution grids. It has planned ahead for new extra-high voltage corridors, promoted the coordinated development of the city's external power corridors and urban transmission and distribution grids, constructed extra-high voltage grids that meet the high-reliability requirements of international metropolises, adapted to the needs of a large proportion of access to renewable energy sources, and have a strong structure, intelligent interaction and flexible operation, strengthened the construction of supporting energy storage infrastructures, and enhanced the capacity of trans-regional power transmission and dissipation, to make a large incremental increase in the dissipation of external low-carbon and clean power.

Shanghai's petrochemical industry will still maintain its growth momentum, and it needs to control the scale of the petrochemical industry and adjust its industrial structure and product structure. The petrochemical industry should accelerate the pilot landing of key green low-carbon technologies to reduce the level of industrial carbon emissions. The iron and steel industry possesses significant potential for conserving energy and reducing emissions, and should adjust its production structure, accelerate the research and development, and industrialization application of core green and low-carbon technologies, and realize the ultra-low emission transformation of the whole process, all processes, and the whole life cycle.

Constructing a carbon emission monitoring platform in the construction field, creating a smart building platform, relying on the energy consumption monitoring platform for office buildings of Shanghai's state organs and large-scale public buildings, docking the existing Shanghai-level construction management platform and other relevant data resources, and upgrading and constructing a smart monitoring platform for Shanghai's building carbon emissions. Establish a carbon emission map for public buildings based on carbon emission calculation software to quantify the amount of carbon dioxide emissions consumed, reduced and neutralized by each building within a period of time.

Continuously optimize structures of transportation and energy consumption, create a green transportation system, and accelerate the completion of Shanghai's urban transportation and travel structure with rail transit as the backbone, electric buses as the foundation, electric cabs as a supplement, and shared bicycles as an extension.

Strengthening cooperation and exchanges among provinces and municipalities in the Yangtze River Delta region and building a new pattern of regional development of green and low carbon. Continuously promote the interconnection of rail transportation networks, highways and waterways. Strengthen the construction of electric power networks and enhance the ability to maintain regional power supply. Build an information-sharing platform for carbon emission monitoring data to provide strong support for decision-making by relevant governments.

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