Energy Transition and Peak Carbon Neutrality: Implementation Pathways in the Transportation Sector-- A Case Study of Tai'an

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Abstract. As an important part of the national economy, the carbon emission problem of the transportation industry is becoming increasingly prominent. This paper analyzes the current situation of the carbon emission in the transportation field from the two dimensions of energy use and carbon emission.By constructing the LEAP model and designing different scenarios, the “bottom-up” method is selected to take Tai'an city as an example to predict the carbon peak in the field of transportation trend.On this basis, put forward to strengthen the construction of energy infrastructure, promote clean energy and new energy vehicles, strengthen energy technology innovation research and development, improve the carbon emissions statistics and monitoring system, strengthen policy guidance and support implementation path, and combined with the specific situation of Tai'an City analysis, these path green low carbon development in the field of transportation provides an important reference, also for other areas of similar problems provides reference and enlightenment.

1 Introduction

Transportation industry as a fundamental, pioneering, strategic industries and important service industry, make significant contributions to economic development at the same time also inevitably caused the problem of rapid increase in carbon emissions, its industry carbon emissions accounted for about 10% of the total carbon emissions [1-2]. In September 2020, Chinese President Xi Jinping officially announced at the 75th Session of the UN General Assembly: “ China's carbon dioxide emissions will peak by 2030 and strive to achieve carbon neutrality by 2060.” The party's 20th report stressed: actively and steadily promote carbon peak and carbon neutral, based on China's energy and resource endowment, adhere to the first before broken, planned step by step implementation of carbon peak action.

Energy green development is the inevitable requirement of traffic low carbon development strategy, renewable energy is one of the key ways to achieve the goal of carbon peak and carbon neutral [3], from the perspective of energy research traffic carbon neutral and carbon peak is of great significance, how in the pursuit of economic development at the same time make transportation carbon peak carbon neutral become a problem to be solved.

2 Analysis of the status quo of carbon emission in the transportation field

The analysis of the current situation of carbon emission in the field of transportation requires in-depth analysis from the two dimensions of energy use and carbon emission. These two aspects are interrelated and jointly affect the carbon emission level in this field. China's total carbon emission and total energy consumption are shown in Fig. 1.

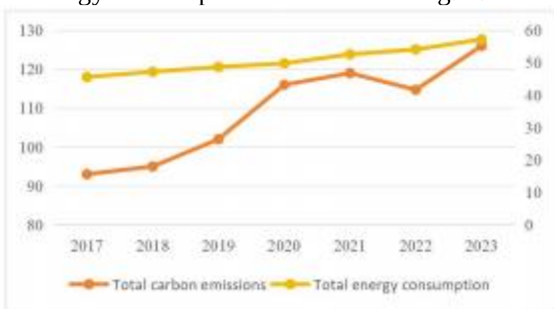

Fig. 1. China's total carbon emissions and energy consumption from 2017 to 2023 (Unit: 100 million tons).

In terms of energy use, the energy consumption structure in the transportation field is mainly oil. This energy consumption pattern not only leads to the vulnerability of energy supply, but also aggravates the problems of environmental pollution and climate change. In response to these challenges, China began to promote non-fossil renewable energy and devote

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itself to the energy transformation in the field of transportation. According to the data of China Energy Administration, the proportion of non-fossil energy consumption reached 18.9% in 2023; the total installed capacity of renewable energy reached 1.516 billion kW, including 305 million kW in 2023, or 82.7% of the national new power generation capacity was nearly 3 trillion KWH, accounting for about 1 / 3 of the total social electricity consumption, equivalent to reducing domestic carbon dioxide emissions by about 2.5 billion tons.

In terms of carbon emissions, it is expected that with the continuous growth of per capita GDP, the carbon emissions in China's transportation sector will maintain greater growth pressure. The carbon emission in China's transportation field is the third largest carbon emission source after industry and buildings. In the field of transportation, the total carbon emission of different transportation modes differ significantly. Therefore, the carbon emission of road transportation with oil as the main energy accounts for as high as 80%. As shown in Fig. 2, according to statistics from the Ministry of Public Security, in 2023, the number of national motor vehicles reached 435 million, including 336 million; the number of new energy vehicles reached 20.41 million, accounting for 6.07% of the total number of vehicles; the number of pure electric vehicles was 15.52 million, accounting for 76.04% of the number of new energy vehicles.

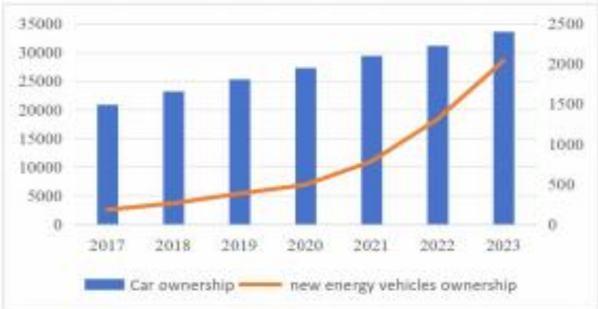

Fig. 2. Ownership of automobiles and new energy vehicles in China from 2017 to 2023 (Unit: 10,000 units).

Tai'an takes “low-carbon transformation and green development” as the main line, deepens the transformation of old and new growth drivers as the central task, vigorously implements the strategy of new industrialized cities, coordinated emission reduction, emission reduction, green and growth, and accelerates the green and low-carbon transformation of urban economic system, energy system and industrial system.According to Taian Statistical Yearbook, the total transportation of goods in 2022 is 73.45 million tons, of which the highway is 73. 14 million tons, accounting for 99.58%; the annual passenger transport volume is 5.88 million, all of which are road transportation. It can be seen from this that road traffic is an important link of energy conservation and emission reduction in Tai'an city transportation industry. How to achieve carbon peak reaching and carbon neutrality in the transportation field while pursuing economic development has become an urgent problem to be solved.

3 LEAP model analysis of carbon peak in transportation field

3.1 Construction of the LEAP model framework for transportation carbon reaching peak

3.1.1 Model structure

Many scholars have used the LEAP model for low-carbon path prediction, Like Sungjun Hong et al. used the LEAP model to analyze the contribution level of the Korean transportation sector to the national greenhouse gas emission reduction target [4], Rivera-Gonzalez, et al. forecast the energy and fuel demand of the sustainable road transport sector in Ecuador based on the LEAP model [5], Hong Jingke , et al. innovatively constructed a new comprehensive evaluation RICE-LEAP model including China's terminal department to simulate China's carbon peak path [6].

This paper uses the LEAP model to divide the research subjects according to the following levels: The first level, the transportation carbon emission is divided into intercity traffic carbon emission, port production carbon emission and urban traffic carbon emission. The second level divides the carbon emission of intercity traffic into the carbon emission of highway, waterway, railway and air transport. The third level divides highway, waterway, railway and air transport into passenger and freight, and the carbon emissions of urban traffic is divided into urban public bus, subway, cruise and taxi carbon emissions. The fourth level classifies the transportation types in each sector by fuel, gas, electricity and soon. Considering the traffic development of Tai 'an city, only the corresponding data of Tai' an city was selected for analysis in the following prediction.

3.1.2 Computational formula

Due to the large number of carbon emission sources in the transportation industry, it is impossible to calculate completely and accurately. The current research mainly includes the “top-down” method, “bottom-up” method and “total-structure” method in the IPCC2006 National Greenhouse Gas List Guide.

(1) The “top-down” method

For traffic energy consumption of carbon emissions, the international pattern is based on the international energy agency (IEA) in the 1990s energy balance system, accounting of transportation terminal energy consumption and CO2 emissions, the mode according to the 2006 IPCC national greenhouse gas list guide combined with energy demand forecasting model, get different scenarios or target of total carbon emissions forecast, specific calculation is as follows:

$$CO_2 = AD \times NCV \times CC \times COF \qquad (1)$$

In the formula, CO2— energy consumption; AD— energy consumption; NCV— the net release value of the energy type; CC — the carbon content of the energy source; COF — the conversion coefficient of carbon emissions for the energy source.

(2) The “bottom-up” method

According to the category of traffic activities, the “bottom-up” method can be divided into the ownership method and the turnover method. Combined with the availability of data, this study uses the turnover method to calculate for carbon emissions in road transport, waterway transport, railway transport, civil aviation transport and urban rail transit, and uses the ownership method of urban public buses and cruise taxis to calculate carbon emissions. The accounting method is as follows:

1) Turnover method

$$C = \sum_1^i \sum_1^j (D_{ij} \times E_{ij} \times \alpha_{ij}) \qquad (2)$$

In the formula, Dij— the activeturnover of j fuel in i mode of transportation; Eij—the energy consumption of j fuel in i mode of transportation; αij — the carbon emission factor of j fuel in i mode of transportation; C— the total carbon emission.

2) Ownership method

Carbon emission = energy consumption per 100 kilometers

$$EC = \sum_{ij} F_{ij} \times EF_i \times M_{ij} \times L_{ij} \qquad (3)$$

In the formula, Mij — the number of j fuel type i vehicles; Lij — , the average annual driving mileage of type i vehicles using j fuel; Fij— the single consumption of class i vehicles using j fuel; EFj—the carbon emission factor of j fuel; EC—the CO2 emissions of urban traffic.

(3) The “total amount-structure” method

In the “total amount-structure” model, the urban traffic carbon emission is estimated according to the different factors affecting the urban traffic carbon emission,the calculation formula is as follows:

$$EC = \sum_i \sum_j = \left(\frac{D \times M_{i,j} \times d_{i,j}}{O_{i,j}} \times F_{i,j}\right) \times EF_{i,j} \qquad (4)$$

$$D = 365 \times P \times N \qquad (5)$$

In the equation, D— the annual total travel volume; P — the number of urban population; N — the number er daily trips; Mij — travel sharing rate; dij — the average travel distance; Oij— average number of passengers; Fij— the average energy consumption; EFij— the j fuel CO2 emission coefficient;EC — annual emissions of urban traffic CO2.

In view of the current statistical system in China and the lack of relevant statistical data, there is great uncertainty that the “top-down” method to calculate the carbon emissions in the transportation field of each province cannot be subdivided into the transportation sub-field. In addition, the “top-down” law is not highly related to policies, and there are some defects in predicting the future traffic carbon emissions and formulating carbon emission reduction policies. The “total-structure” method mainly aims at the accounting of urban traffic carbon emissions. Although it is difficult to obtain some data of the “bottom-up” method, the energy consumption of transportation is determined, so as to solve the problem of incomplete statistical data. Therefore, this study mainly adopts the “bottom-up” accounting method, and calculates CO2 emissions [7] based on the logic of “activity level-energy intensity- carbon emissions”, as shown in formulas (2) and (3).

3.1.3 Scenario setting and description

Situational analysis refers to the research method of exploring the changing space of various possible scenarios by designing different development goals on the basis of various key assumptions about the major evolution of economy, industry or technology. Its biggest advantage is that it can find the trend and path of future changes, so as to better grasp the development direction of the research object. Combining the development of the transportation industry and the development goals of carbon peak and carbon neutrality, this study set three different scenarios: benchmark scenario, low carbon scenario and enhanced low carbon scenario. On this basis, the future energy demand and carbon emission of the transportation industry under different scenarios are analyzed. The scenario settings are shown in the table below.

Table 1. Scenario Setting.

Scenario	Scenario description
Benchmark scenario	Attention should be paid to the clean transformation of vehicles, the energy efficiency of vehicles should reach the planning target, and the requirements of “highway to railway” and “highway to water” should be completed according to the planning intensity.
Low carbon scenario	Accelerate the speed of cleaner vehicles, fully realize clean energy for buses by 2030, encourage the use of hydrogen fuel, and further improve the energy efficiency of vehicles. The “highway to railway” and “highway to water” efforts were further intensified.
Strengthen low-carbon scenarios	The speed of cleaning transportation is further accelerated, the application of hydrogen fuel cell vehicles in the transportation industry is accelerated, and the energy efficiency of vehicles is further improved in the low-carbon scenario.

3.2 Carbon emission trend forecast

3.2.1 Overall trend prediction

According to the objective law of the relationship between transport demand and economic development, the total amount of passenger and cargo transport demand maintains a certain elastic relationship with GDP growth, that is, the development of social economy drives the increase of passenger and cargo transport demand. In the future, with the economic development of the province, the flow of personnel and materials will be further accelerated, and the overall demand for passenger and cargo transportation will show an growing trend. Therefore, assuming that the energy intensity and carbon emission intensity of transportation maintain the current level, there will be more room for the growth of energy consumption and carbon emission in the transportation field in the future.

The carbon emission of transportation industry in Tai'an city is predicted by scenario, and the carbon peak is different under different scenarios. As can be seen from Fig. 3, under the three scenarios, Tai'an transportation carbon emissions showed a trend of rising first and then decreasing. With the different scenario setting, the predicted peak time and peak difference are obvious. Compared with the baseline scenario, the peak of the low carbon scenario and the enhanced low carbon scenario decreased successively, and the peak age was slightly earlier.

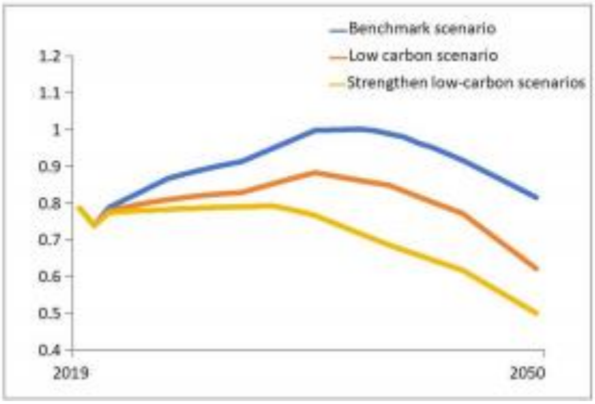

Fig. 3. Forecast trend of transportation carbon emissions in Tai'an.

3.2.2 Trend forecast by domain

(1) Energy utilization situation

According to the forecast results, in the future, the most expensive energy category in the transportation sector will still be oil products. Diesel oil is still the most important energy source for freight transportation, but its proportion continues to decline. In general, the application of clean energy and new energy transport vehicles will promote the reform of energy consumption structure in cargo transport and reduce carbon emissions. Railway electrification is also the future development trend. Under the benchmark scenario, low carbon scenario and strengthening low carbon scenario, railway electrification is gradually accelerated.

(2) Carbon emissions

In the three scenarios, road freight carbon emissions remain the main driving force of the carbon peak. Under the baseline scenario, the carbon emissions of road freight accounted for 97.6% of the total carbon emissions of road, waterway and railway transportation in 2035. Therefore, so from the perspective of transportation mode, road freight should be the main driving force of carbon reduction in the future. On the premise of meeting the demand of freight transportation, the carbon emission intensity of road freight with the same cargo turnover is 4.9 times and 7.8 times that of railway transportation and waterway transportation respectively. Therefore, the optimization and adjustment of transportation structure is the key direction of the reduction of total freight carbon emission and carbon emission intensity in the future.

(3) Urban passenger transport

In the future, urban passenger transport energy consumption will gradually shift from gasoline to electricity, and new energy vehicles will determine the carbon emission structure and trend of urban passenger transport. According to the forecast results, cruise taxi will be the main source of carbon emission in urban passenger transport in the future, but with the continuous update of new energy vehicles, the carbon emission of urban passenger transport will be gradually reduced.

4 Exploration of energy transformation and double-carbon implementation path in transportation field

According to calculation, by 2035, in terms of total carbon emissions, the low carbon scenario is 11.56% compared with the benchmark scenario, and the enhanced low carbon scenario is 23.25% compared with the benchmark scenario. According to the analysis results, the implementation path of carbon peak and carbon neutrality in the transportation field is proposed.

4.1 Formulate energy transformation plans and optimize the transportation structure

By reducing high energy consumption of transportation, increase the use of the use of low energy consumption of energy transformation is the most direct and effective way to ease transport carbon emissions. Tai'an city is speeding up the improvement of the railway network, promoting the “public railway” of bulk goods and medium and long distance freight, at the same time vigorously developing inland waterway transportation, improving the accessibility of waterway, promoting the expansion of locks, accelerating the construction of port berths to improve the waterway accessibility, and promoting the “public water" of bulk goods and medium and long distance freight.

4.2 Strengthen energy infrastructure development and reduce carbon emissions

Increase investment in clean energy infrastructure construction, especially should give priority to remote and relatively backward areas, vigorously promote photovoltaic, wind, tidal power generation facilities and distributed energy storage infrastructure applications, strengthen the power grid, oil and gas pipeline network and other energy distribution facilities construction and renovation, optimize the energy distribution network. Tai 'an City vigorously promote the construction of "green highway", in the ordinary provincial trunk road implementation of "green construction", to carry out the "traffic + photovoltaic" industry development mode, and develop the green port construction, by optimizing the coastline resources, build "nearly zero carbon" port, promote the construction of port power facilities to accelerate the construction of green port and waterway, promoting the Hangzhou canal Tai' an section of ecological channel construction.

4.3 Promote clean energy and new-energy vehicles and improve the energy mix

Encourage the use of new energy vehicles, improve the clean energy transmission network, and improve the supply capacity and stability of clean energy. Tai'an city will purchase and update clean new energy vehicles, promote new energy heavy freight vehicles and urban freight distribution vehicles, promote the clean and new energy of freight vehicles, at the same time actively guide the inland ships to clean and new energy transformation, speed up the elimination and update old ships, promote the development of new energy, clean energy power ship, optimize the structure of ship energy use, continuous implementation of port machinery "oil to gas", "oil to electricity".

4.4 Strengthen innovation and research and development in energy technologies and improve energy efficiency

The high efficiency of tool energy utilization will realize technological innovation from improving the energy efficiency of traditional vehicles and converting to energy vehicles with higher energy efficiency. Tai'an City actively promote the construction of city "wisdom bus", promote electronic ticket into intelligent transportation management, vigorously promote "Internet + freight logistics" new mode, using beidou positioning navigation system to speed up the construction of storage and distribution system, and actively promote Tai' an port wisdom, build wisdom logistics trading platform, channel automatic patrol, ship intelligent brake, information automatic release, etc.

4.5 Improve the carbon emission statistics and monitoring system, and strengthen policy guidance and support

Carry out information supervision on the transportation sector, establish a full-caliber transportation carbon emission monitoring system, establish a more scientific and comprehensive carbon emission database, and grasp the status quo of transportation energy consumption and carbon emission in real time, so as to provide strong support for policy formulation. Centering on the national transformation demand of "double energy control" to "double carbon emission control", Tai'an city has strengthened the statistical monitoring and accounting capacity, actively explored the establishment of a database of transportation carbon emission factors with local characteristics, and tried to build a carbon emission statistics, monitoring and accounting system covering the transportation industry.

5 Conclusion

With the acceleration of urbanization process, traffic demand continues to grow, this paper from the perspective of energy, using LEAP model to simulate different traffic development scenario, Taking Tai'an City as an example, it analyzes the implementation path of carbon peak and carbon neutrality in the transportation field, for green development in the field of transportation provides a comprehensive theoretical support and practical guidance. Although this paper provides a path reference for carbon peak and carbon neutrality in the field of transportation, it are still faces many challenges and uncertainties in the real implementation process. Future research can further focus on the following aspects: first, deeply explore the economy and feasibility of various emission reduction technologies; second, pay attention to the synergistic emission reduction effect between transportation and other fields. Through continuous research and practical exploration, it will provide a stronger support for the carbon peak and carbon neutralization target in the field of transportation.

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