Panel data analysis of energy conservation and emission reduction on high-quality development of logistics industry in Yangtze River Delta of China

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Abstract
With the implementation of Chinese carbon neutrality policy, the Yangtze River Delta calls for great concern. As a benchmark for the development of Chinese logistics industry, it accompanies energy consumption and environmental problems. This study explores how Chinese logistics industry can achieve energy conservation and emission reduction and high-quality development in the context of carbon neutrality. It analyzes the relationship between the logistics industry and economy, energy, as well as environment in Yangtze River Delta. The data is based on China Statistical Yearbook from 2001 to 2019, by means of the entropy method and panel vector autoregressive (PVAR) model. The main findings are summarized as follows: firstly, the economy, industrial structure, energy, and environment have significant impact on the development of logistics industry in Yangtze River Delta. Secondly, the development of logistics industry in Yangtze River Delta is not balanced. The provinces including Jiangsu, Shanghai, Zhejiang, and Anhui have great differences in economy, industrial structure, demographic dividend, energy consumption, and environmental protection, but they show the possibility of complementary advantages. Thirdly, the economic development and energy consumption have bidirectional effects. Environmental protection is relevant to economic development, industrial structure, energy consumption and logistics supply. Finally, some suggestions are provided on how to realize the high-quality development of logistics industry in Yangtze River Delta. In the context of carbon neutrality, it is necessary to consider energy conservation and emission reduction.

Keywords Yangtze River Delta · Energy conservation and emission reduction · High-quality development · PVAR model · Green logistics

Introduction
The main cause of global climate change is carbon emissions (Han et al. 2021). With the sense of responsibility, China has not stopped ecological civilization (Gu et al. 2020). China is striving to peak the emission of carbon dioxide by 2030 and achieve carbon neutrality by 2060 (Liu et al. 2021a; Jia et al. 2020).

By 2030, the overall green transformation of economic and social development will have achieved significant results, and the efficiency of key energy-consuming industries will reach advanced levels. Energy consumption per unit of GDP will drop significantly, and the emission of carbon dioxide will reach a peak and achieve a steady decline. In China, the economic and social development is heavily dependent on transport, which has become the third largest energy consuming sector, generating large amounts of carbon emissions (Wang et al. 2020a). The reduction in energy intensity and the optimization of energy mix cannot offset the rapid growth in consumption and population (Zhao et al. 2020). The mitigation of Chinese environmental problems is of great importance to global ecology (Zeng et al. 2020). The majority of carbon emissions come from the energy sector, with the transport, industrial, and residential sectors
being the main contributors (Akbar et al. 2021). By 2060, the green, low-carbon, and circular economic system as well as the clean, safe, and efficient energy system will be fully established. The efficiency of energy use will reach advanced levels, and the proportion of non-fossil energy consumption will reach over 80%. The goal of carbon neutrality will be successfully achieved, and fruitful results will be achieved with the construction of ecological civilization and harmonious coexistence between human and nature. Through exploring the influence of logistics industry on economy, energy consumption, and environmental protection, this study will expand theoretical research on energy conservation and low carbon. It can promote theoretical innovation on green economy and sustainable development. Therefore, it is of great theoretical importance to explore the relationship between the development of Chinese logistics industry and the economy, energy and environment.

In practice, China has formulated the relevant development plans about the city cluster in Yangtze River Delta to boost economic growth and regional development (Liu et al. 2020). As one of the most developed regions in China, it is supposed to play a leading role in Chinese low-carbon development. Energy-saving and carbon-free technological change plays a key role in the transformation of low-carbon development in the region (Jia et al. 2018). Chinese government clearly puts forward to enhance the development level of integration of Yangtze River Delta. It aims at the advanced technology and industry system, speeding up the construction of G60 high-tech corridor in Yangtze River Delta. It is necessary to speed up the infrastructure interconnectivity and ecological environment to guarantee high-level integration and demonstration area of green development in Yangtze River Delta (Zhang 2021). As a benchmark for Chinese logistics industry, it is particularly important for Yangtze River Delta to focus on the green development of logistics industry. The Yangtze River Delta is one of the key economic strategies for Chinese sustainable development, and the logistics industry is the basis for implementing economic integration in Yangtze River Delta. It plays a role in the exchange of resources and trade flows (Long et al. 2020). The feasible and sustainable growth is the operational objective for all economies globally (Su et al. 2021). China is transforming towards a new path of green, coordinated, and high-quality development in logistics. Based on the data from China Statistical Yearbook 2001–2019, this study explores the high-quality development of logistics industry in Yangtze River Delta from seven dimensions, including economic development, industrial structure, demographic dividend, logistics supply, logistics demand, energy consumption, and environmental protection, in the context of carbon neutrality. Some suggestions are provided for how to achieve high-quality development of logistics industry, energy conservation, and environmental protection in Yangtze River Delta. Therefore, it is of great practical significance to explore how the logistics industry in Yangtze River Delta achieve energy conservation, emission reduction, and high-quality development in the context of carbon neutrality.

Although there is a lot of literature on the development of logistics industry in Yangtze River Delta of China, very little literature focuses on the high-quality development in the context of carbon neutrality. The main contribution of this study lies in exploring the development of green logistics to achieve carbon peaking and carbon neutrality. The logistics industry in Yangtze River Delta is the pioneer of future reform for the development of Chinese logistics industry. Our study will provide theoretical support for the high-quality development of logistics industry in Yangtze River Delta. It can demonstrate the efforts and contributions in energy conservation and emission reduction to achieve carbon peaking and carbon neutrality in the high-quality development of Chinese logistics industry.

The following study includes the following: the “Literature review” section is the literature review; the “Variable description and data interpretation” section is the description of variables and data; the “Empirical analysis” section is an empirical analysis; the “Conclusions and recommendations” section is the conclusion and recommendations; and the “Research deficiencies and future prospects” section is about research gaps and future prospects.

**Literature review**

The logistics industry is known as the accelerator of economic development and the third source of profit (Song et al. 2020), and it has gradually become one of the pillar industries supporting the economic development of cities (Bingru et al. 2019). Previous literature has focused on the logistics industry in four mainstream directions such as Industry 4.0, sustainability, green supply chain management, and circular economy.

From the perspective of Industry 4.0, the supply chain transparency of logistics industry and the availability of data to all stakeholders are seen as key potential for Industry 4.0. They are often associated with complex technology systems (Luo and Choi 2022; Bag et al. 2020; Tseng et al. 2018). In logistics planning, the design and development of software tools link mobile industrial robots with route optimization algorithms. It can generate realistic scheduling and routing options to optimize logistics operations in manufacturing processes (Syrmos et al. 2022; Qadeer et al. 2022). In the development of logistics networks, logistics supply is the material basis for the operation of logistics system because of its specificity. It is not only the key element but also the guarantee for modern logistics system (Shi et al. 2019). Zhang and Li (2020) believe that the sharing platform in
modern logistics information based on big data can attract the inflow of resources and thus forms the leading industry that dominates regional economic development (Shi 2021).

The related research on sustainable development has focused on regression analysis from three dimensions such as economy, the development of logistics industry, and environment. It does not adequately show the impact of development in logistics industry on population, energy, supply and demand, and other dimensions. The concentration of logistics industry can optimize the industrial structure in sustainable development and improve the core competitiveness of enterprises through its professional effect (Xu and Fang 2018). The development of logistics industry has a positive impact on the optimization of industrial structure of neighboring provinces and cities. It can promote the rationalization of industrial structure in sustainable development of the region (Gao and Meng 2013; Liang and Sun 2019). The logistics industry is seen as an effective tool for employment and economic sustainability, and logistics development can be an important factor in driving economic growth in the long term through the influence of policy (Gao et al. 2020). Chinese rapid economic growth and industrial upgrading has led to significant changes in the structure of employment, which often requires more skilled workforce, particularly in high-tech industries (Wang et al. 2020c). Urbanization can also contribute to ecologically sustainable development by concentrating population, stimulating innovation and increasing wealth to solve environmental problems (Wu and Liu 2020). The demographic dividend is therefore particularly important for the economic sustainable development of a region. With the deepening of industrialization and urbanization in China, air pollution has become the most serious environmental problem, threatening the health of residents and sustainable development (Tang et al. 2020).

Green supply chain management is gaining attention from the government and enterprises with the advancement of sustainable development (Li and Yan 2021; Jin et al. 2021; Liu et al. 2021a, b, c; Zekhnini et al. 2021). The low-carbon economic model has posed new challenges to supply chain management, and the exploration of green supply chain has become an urgent issue in theory and practice (Li et al. 2019). The growing concern about global warming has led to legislative enactments, which aim at progressively reducing the amount of greenhouse gases emitted by industrial sector and its supply chain (Anvar et al. 2018). During the development of logistics industry, most of cities focus on economic benefit such as added value rather than pay enough attention to environmental protection. It results in the inefficient state and further demonstrates the phenomenon “environmental Kuznets curve” (Yang et al. 2016). The conflict between economic development and environmental protection has attracted widespread global attention (Hu et al. 2021b). In recent years, the pollution of PM2.5 has become a challenge in the process of industrial development all over the world, and the Yangtze River Delta of China is facing double pressure of economic development and environmental protection (Ji et al. 2021). The government has shifted from low-carbon products to low-carbon technologies in order to improve the level of green supply chain (Li et al. 2021).

With the increasing levels of pollution and waste generation, the development of circular economy has prompted industries to incorporate economies within conceptual circular supply chains (Li et al. 2022; Bressanelli et al. 2022b; Khan and Ali 2022). In circular economy, blockchain practices can support the tracking, traceability, and responsiveness of supply chain (Bressanelli et al. 2022a, 2021; Nandi et al. 2021). Chinese rapid economic growth has been accompanied by the deterioration in air quality (Hu et al. 2021a). It is essential for China to take circular measures in decoupling economic growth from carbon emission (Wu et al. 2019). It is estimated that the world will need to exploit the resources of five times by 2050 if the consumption patterns of economic growth remain at current level (Stegeman et al. 2020). The development of logistics industry is inseparable from economic growth and environmental protection (Wu et al. 2021). The advanced industrial structure, resource endowment, and environmental regulation are conducive to the reduction of environmental pollution (Zhou et al. 2021). Therefore, the logistics industry must adopt circular economy to reduce the waste of resources and harmful effect on the environment.

The previous logistics research shows that energy and environmental issues have become two major threats to sustainable development (Wu et al. 2020). According to the World Bank, China has become one of large energy consumers (Yuan et al. 2020). As the large emitter of carbon dioxide, the energy consumption has increased fivefold since China carried out reform and opening-up in 1978 (Jiang et al. 2018). China is currently in the critical period of transformation and upgrading of green economy (Liu and Fan 2021). It has become an opportunity and challenge for China to promote green and high-quality economic development in the context of new economic norms (Wang et al. 2021b). Dong (2021) believes that the main scope of regional logistics services is relevant to the basic layout of regional industry chain. It includes transport hubs, transport channels, and distribution network in regional economic system, in addition to the micro, meso and macro chain network.

Compared to other regions, the logistics industry in Yangtze River Delta has always been the benchmark of Chinese logistics industry. As the basic platform for transforming the way of economic development, it determines the layout and development of various industries (Wang et al. 2020b). The Yangtze River Delta is the most comprehensive economic center in China and plays the key role in energy transition (Liu et al. 2021c). Wang et al. (2021a) have analyzed the current status of logistics development in
Yangtze River Delta from five dimensions: economy, carrying capacity, industrial performance, technological innovation and green development. The evolution of logistics network in Yangtze River Delta is centered on the grid of eastern cities like Shanghai. It radiates from east to west, and there is “Matthew effect” and “involution” to a large extent (Tang et al. 2021). Some scholars have used cluster analysis to divide the 27 cities in Yangtze River Delta into four echelons. This study argues that simple cluster analysis tends to ignore the policy differences among different regions and the continuity between spatial territories. Therefore, this paper adopts provincial panel data from seven dimensions, including economy, industrial structure, demographic dividend, logistics supply and demand, energy, and environment, to conduct PVAR model regression. The scope of this study is broader, and in addition, the PVAR model breaks the previous boundaries between the independent and dependent variables, making the research more valuable.

Variable description and data interpretation

Description of variables and determination of weights

According to the principles of indicator selection and relevant literature, this study selects 7 level indicators and 19 secondary indicators to construct the evaluation system of influencing factors in logistics industry of Yangtze River Delta, and then uses the entropy-based weight method to calculate the weights of indicators, as shown in Table 1.

In this research, the entropy method has been used to determine the weights of indicators, as follows.

1. Indicator standardization

   When the data is a positive indicator, \( Y_{ij} = \frac{y_{ij} - \min(y_{ij})}{\max(y_{ij}) - \min(y_{ij})} \)  

   When the data is a negative indicator, \( Y_{ij} = \frac{\max(y_{ij}) - y_{ij}}{\max(y_{ij}) - \min(y_{ij})} \)

   where \( y_{ij} \) is the standardized value of the \( j \)th indicator, \( y_{ij} \) is the original value of the \( j \)th indicator, \( \max(y_{ij}) \) is the maximum value in \( y_{ij} \), \( \min(y_{ij}) \) is the minimum value in \( y_{ij} \), \( j = 1 \ldots m \).

2. Weighting of indicators

   In this study, we use the entropy method to measure the indicator weights, and the calculation steps are shown below.

   Step1: calculate the percentage of the \( j \)th indicator,

| Level indicators | Secondary indicators | Type | Weight |
|------------------|----------------------|------|--------|
| Gross domestic product (lnGDP) | X1 = Gross regional product (hundred million yuan) + X2 = Per capita GDP (yuan/person) + | 0.05 | |
| Industrial structure (lnIS) | X3 = Added value of the primary industry (hundred million yuan) + X4 = Added value of the secondary industry (hundred million yuan) + X5 = Added value of the tertiary industry (hundred million yuan) + X6 = Added value of transportation, warehousing and postal services (hundred million yuan) | 0.06 | |
| Demographic dividend (lnDD) | X7 = Permanent population at year-end (10,000 persons) + X8 = Number of students in regular institutions of higher education (10,000 + persons) | 0.03 | |
| Logistics supply (lnLS) | X9 = Railway operating mileage (10,000 km) + X10 = Highway mileage (10,000 km) + | 0.03 | |
| Logistics demand (lnLD) | X11 = Cargo turnover (hundred million ton-km) + X12 = Cargo volume (10,000 t) + X13 = Express quantity (10,000 pieces) + | 0.04 | |
| Energy consumption (lnEC) | X14 = Crude oil consumption (10,000 t) - X15 = Gasoline consumption (10,000 t) - X16 = Diesel consumption (10,000 t) - | 0.14 | |
| Environmental protection (lnEP) | X17 = Forest area (10,000 ha) + X18 = Area of plantation (10,000 ha) + X19 = Forest coverage rate (%) + | 0.08 | |

Table 1 Evaluation system of influencing factors of logistics industry in Yangtze River Delta
of variable selection, the studies are not comprehensive enough and ignore many endogenous factors. Therefore, this research uses the PVAR model to build six different models in order to analyze the relationship between logistics industry and economic development, industrial structure, demographic dividend, energy consumption and environmental protection in Yangtze River Delta respectively.

In order to understand the relationship between the development of logistics industry and economic development, industrial structure and demographic dividend in Yangtze River Delta, three models are constructed in turn. Mathematical Eqs. (8), (9), and (10) correspond to model 1, model 2, and model 3 in Table 4, respectively, as follows.

$$Y_gidl_{it} = \mu_0 + \sum_{j=1}^{k} \mu_j \cdot Y_{gidl_{it}} + j + \Omega_{it} + \varepsilon_{it}$$  \hspace{1cm} (8)

$$Y_idll_{it} = \mu_0 + \sum_{j=1}^{k} \mu_j \cdot Y_{idll_{it}} + j + \Omega_{it} + \varepsilon_{it}$$  \hspace{1cm} (9)

$$Yilee_{it} = \mu_0 + \sum_{j=1}^{k} \mu_j \cdot Yilee_{it} + j + \omega_{it} + \varepsilon_{it}$$  \hspace{1cm} (10)

In order to understand the relationship between logistics industry and economic development, energy consumption and environmental protection in Yangtze River Delta, three models have been constructed in turn. The mathematical Eqs. (11), (12), and (13) correspond to model 4, model 5, and model 6 in Table 4, respectively. They are shown in the following.

$$Y_gile_{it} = \mu_0 + \sum_{j=1}^{k} \mu_j \cdot Ygile_{it} + j + \phi_{it} + \varepsilon_{it}$$  \hspace{1cm} (11)

$$Yglee_{it} = \mu_0 + \sum_{j=1}^{k} \mu_j \cdot Yglee_{it} + j + \omega_{it} + \varepsilon_{i}$$  \hspace{1cm} (12)

$$Yilee_{it} = \mu_0 + \sum_{j=1}^{k} \mu_j \cdot Yilee_{it} + j + \omega_{it} + \varepsilon_{it}$$  \hspace{1cm} (13)

where $i = 1, 2, 3, 4$ represent Jiangsu, Shanghai, Zhejiang, and Anhui respectively; $t = 1, 2, \ldots, t$, represents the year; $Y_gidl_{it} = [\lnGDP_{it} \lnIS_{it} \lnDD_{it} \lnLS_{it}]^T$ is a four-dimensional column vector containing economic development (\lnGDP), industrial structure (\lnIS), population dividend (\lnDD), logistics supply (\lnLS); $Y_idll_{it} = [\lnIS_{it} \lnDD_{it} \lnLS_{it} \lnLD_{it}]^T$ is a four-dimensional column vector containing economic development, industrial structure, demographic dividend, and environmental protection.

### Description of the data

The data for this study were obtained from China Statistical Yearbook 2001–2019. It contains annual provincial statistics for Jiangsu, Shanghai, Zhejiang, and Anhui, and some missing values in some years of data adopt mean interpolation. The PVAR model was applied and the results were derived by using the software STATA15, and some figures were formed by using R4.1.1. In order to eliminate the inertia problem of time series data, all the data were logarithmized and all the variables in the model were first order differenced.

### Empirical analysis

#### Model construction

Sims (1980) created the vector autoregressive (VAR) model, which features all variables as endogenous variables to truly reflect the relationship among variables. Holtz-Eakin et al. (1988) extended it to panel data and proposed the PVAR model (Christiano 2012).

The relationship between logistics industry and the factors such as the economy, population and energy have generally been studied by previous scholars using fixed effect models or random effect models, but ignoring the possible endogeneity of variables. Due to the limitation of variable selection, the studies are not comprehensive enough and ignore many endogenous factors. Therefore, this research uses the PVAR model to build six different models in order to analyze the relationship between logistics industry and economic development, industrial structure, demographic dividend, energy consumption and environmental protection in Yangtze River Delta respectively.

In order to understand the relationship between the development of logistics industry and economic development, industrial structure and demographic dividend in Yangtze River Delta, three models are constructed in turn. Mathematical Eqs. (8), (9), and (10) correspond to model 1, model 2, and model 3 in Table 4, respectively, as follows.

$$Y_gidl_{it} = \mu_0 + \sum_{j=1}^{k} \mu_j \cdot Y_{gidl_{it}} + j + \Omega_{it} + \varepsilon_{it}$$  \hspace{1cm} (8)

$$Y_idll_{it} = \mu_0 + \sum_{j=1}^{k} \mu_j \cdot Y_{idll_{it}} + j + \Omega_{it} + \varepsilon_{it}$$  \hspace{1cm} (9)

$$Yilee_{it} = \mu_0 + \sum_{j=1}^{k} \mu_j \cdot Yilee_{it} + j + \omega_{it} + \varepsilon_{it}$$  \hspace{1cm} (10)

In order to understand the relationship between logistics industry and economic development, energy consumption and environmental protection in Yangtze River Delta, three models have been constructed in turn. The mathematical Eqs. (11), (12), and (13) correspond to model 4, model 5, and model 6 in Table 4, respectively. They are shown in the following.

$$Y_gile_{it} = \mu_0 + \sum_{j=1}^{k} \mu_j \cdot Ygile_{it} + j + \phi_{it} + \varepsilon_{it}$$  \hspace{1cm} (11)

$$Yglee_{it} = \mu_0 + \sum_{j=1}^{k} \mu_j \cdot Yglee_{it} + j + \omega_{it} + \varepsilon_{i}$$  \hspace{1cm} (12)

$$Yilee_{it} = \mu_0 + \sum_{j=1}^{k} \mu_j \cdot Yilee_{it} + j + \omega_{it} + \varepsilon_{it}$$  \hspace{1cm} (13)

where $i = 1, 2, 3, 4$ represent Jiangsu, Shanghai, Zhejiang, and Anhui respectively; $t = 1, 2, \ldots, t$, represents the year; $Y_gidl_{it} = [\lnGDP_{it} \lnIS_{it} \lnDD_{it} \lnLS_{it}]^T$ is a four-dimensional column vector containing economic development (\lnGDP), industrial structure (\lnIS), population dividend (\lnDD), logistics supply (\lnLS); $Y_idll_{it} = [\lnIS_{it} \lnDD_{it} \lnLS_{it} \lnLD_{it}]^T$ is a four-dimensional column vector containing economic development, industrial structure, demographic dividend, and environmental protection in Yangtze River Delta respectively.
column vector containing industrial structure (lnIS), population dividend (lnDD), logistics supply (lnLS), logistics demand (lnLD); \( Y_{gil} = [\lnGDP_{it}, \lnIS_{it}, \lnLD_{it}, \lnEC_{it}]^{\top} \) is a four-dimensional column vector containing economic development (lnGDP), industrial structure (lnIS), logistics supply (lnLS), logistics demand (lnLD); \( Y_{glic} = [\lnGDP_{it}, \lnIS_{it}, \lnLD_{it}, \lnEC_{it}]^{\top} \) is a four-dimensional column vector containing economic development (lnGDP), industrial structure (lnIS), logistics supply (lnLS), energy consumption (lnEC), and environmental protection (lnEP); \( \Omega_{it} = [\lnIS_{it}, \lnLD_{it}, \lnDD_{it}, \lnEC_{it}, \lnEP_{it}]^{\top} \) is a five-dimensional column vector containing economic development (lnGDP), industrial structure (lnIS), logistics supply (lnLS), logistics demand (lnLD), population dividend (lnDD), logistics consumption (lnEC), and environmental protection (lnEP). \( \varphi_{it} = [\lnGDP_{it}, \lnEC_{it}] \) is a two-dimensional row vector containing economic development (lnGDP), logistics demand (lnLD) and population dividend (lnDD); \( \omega_{it} = [\lnEC_{it}, \lnEP_{it}] \) is a two-dimensional row vector containing energy consumption (lnEC) and environmental protection (lnEP); \( q_{it} = [\lnGDP_{it}, \lnEP_{it}] \) is a two-dimensional row vector containing population dividend (lnDD) and environmental protection (lnEP). \( \mu_{0} = [\lnEC_{it}, \lnEP_{it}] \) is a two-dimensional row vector containing logistics demand (lnLD) and population dividend (lnDD); \( \mu_{j} \) denotes the intercept term vector; \( k \) denotes the number of lags; \( \mu_{j} \) denotes the parameter of the \( j \)th order of lag matrix; \( \varepsilon_{it} \) is the random disturbance term.

**Smoothness tests and selection of optimal lags**

**Smoothness tests**

In this study, unit root tests were conducted using four tests, IPS (heterogeneous root test), LLC (homogeneous root test), ADF-Fisher test, and PP-Fisher (as shown in Table 2). All seven series (lnGDP, lnIS, lnDD, lnLS, lnLD, lnEC, lnEP) rejected the original hypothesis of smoothness of variables in all four tests, and all of them were significant at the 1% level, indicating that the data had good smoothness and could be estimated in the PVAR model.

**Selection of the optimal number of lag periods**

In order to ensure the validity of parameter estimation of PVAR model, AIC, BIC, and HQIC criteria were used to select the optimal lag period. As shown in Table 3, the six models in this paper are optimal and the model fitting effect is the best when the lag period is one stage.

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**Table 2** Panel unit root test

| Variable | IPS | LLC | ADF-Fisher | PP-Fisher |
|----------|-----|-----|------------|-----------|
| \( \lnGDP \) | -4.601 | -4.3877*** | 107.143* | 81.404 5*** |
|          | (0.000 0) | (0.000 0) | (0.000 0) | (0.000 0) |
| \( \lnIS \) | -5.756 | -3.4736*** | 21.713 8*** | 83.576 4*** |
|          | (0.000 0) | (0.000 0) | (0.000 0) | (0.000 0) |
| \( \lnDD \) | -5.142 | -5.6870 2*** | 44.963 0*** | 49.049 1*** |
|          | (0.000 0) | (0.000 0) | (0.000 0) | (0.000 0) |
| \( \lnLS \) | -8.121 | -8.7180 0*** | 176.841 | 174.160 8*** |
|          | (0.000 0) | (0.000 0) | (0.000 0) | (0.000 0) |
| \( \lnLD \) | -5.257 | -5.2640 0*** | 41.645 1*** | 124.192 6*** |
|          | (0.000 0) | (0.000 0) | (0.000 0) | (0.000 0) |
| \( \lnEC \) | -6.366 | -3.6733 3*** | 45.749 7*** | 189.233 9*** |
|          | (0.000 0) | (0.000 1) | (0.000 0) | (0.000 0) |
| \( \lnEP \) | -3.663 | -14.622 0*** | 48.854 8*** | 171.789 0*** |
|          | (0.000 0) | (0.000 0) | (0.000 0) | (0.000 0) |

P values for unit root tests are in brackets; ***, **, and * indicate significant at the 1%, 5%, and 10% levels respectively

**Table 3** Optimal lag period selection

| Model | Lag | AIC | BIC | HQIC |
|-------|-----|-----|-----|------|
| Model 1 | 1 | -19.913 | -18.836* | -19.4878 |
|        | 2 | -19.6957 | -18.0202 | -19.0403 |
|        | 3 | -20.5595* | -18.2448 | -19.6621* |
|        | 4 | 5.09663 | 8.09854 | 6.24749 |
| Model 2 | 1 | -12.3569* | -11.2775* | -11.9317* |
|        | 2 | -12.0947 | -10.4192 | -11.4393 |
|        | 3 | -11.9791 | -9.66442 | -11.0817 |
|        | 4 | 28.47 | 31.4719 | 29.6208 |
| Model 3 | 1 | -13.2389* | -12.1594* | -12.8136* |
|        | 2 | -12.9424 | -11.2669 | -12.287 |
|        | 3 | -13.0316 | -10.7169 | -12.1342 |
|        | 4 | 19.2588 | 22.2607 | 20.4096 |
| Model 4 | 1 | -13.4314* | -12.352* | -13.0062* |
|        | 2 | -12.9572 | -11.2817 | -12.3018 |
|        | 3 | -13.0695 | -10.7549 | -12.1721 |
|        | 4 | 26.8832 | 29.8851 | 28.034 |
| Model 5 | 1 | -6.19565* | -5.11621* | -5.7704* |
|        | 2 | 7.73508 | 9.40855 | 8.38845 |
|        | 3 | 10.0574 | 12.3721 | 10.9548 |
|        | 4 | 28.6425 | 31.6444 | 29.7933 |
| Model 6 | 1 | -6.31925* | -5.23981* | -5.894* |
|        | 2 | 23.7999 | 25.4754 | 24.4553 |
|        | 3 | 10.7155 | 13.0302 | 11.6129 |
|        | 4 | 26.6912 | 29.6931 | 27.8421 |

*Represents the optimal lag order
Stability tests and Granger causality tests of the model

Stability test of the model

As can be seen from Figs. 1, 2, 3, 4, 5, and 6, all variables of the six models fall within the unit circle, indicating that the stability of six models is good.

Granger causality test

From Table 4 below, we can see that logistics supply is the cause leading to industrial structure, economic development, energy consumption, and environmental protection. Energy consumption is the cause leading to economic development and industrial structure. Environmental protection is the cause of influencing economic development, industrial structure, logistics supply, and energy consumption. Industrial structure is the cause of influencing demographic dividend and energy consumption. Economic development is the cause leading to demographic dividend and energy consumption.

Regression results of PVAR model for Yangtze River Delta

The regression results of PVAR for the six models are shown in Figs. 7, 8, 9, 10, 11, and 12.

1. It can be seen from Fig. 7 that economic development has a strong impulse response to itself and has a significant positive impact continuously from the first stage to the sixth stage. The impulse response of economic development to logistics supply is strong, and it has a
significant positive impact continuously from the first stage to the sixth stage. Industrial structure has a strong impulse response to economic development and has a significant positive impact from the first stage to the sixth stage. Industrial structure has a strong impulse response to logistics supply and has a significant positive impact from the first stage to the sixth stage. Demographic dividend has a strong impulse response to itself and has a significant positive impact from the first period to the sixth period. The impulse response of logistics supply to industrial structure is strong, and it has a significant positive impact continuously from the first stage to the sixth stage. Logistics supply has a strong impulse response to itself and has a significant positive impact on the first stage. Logistics demand has a strong impulse response to itself and has a significant positive impact in the previous stage.

2. It can be seen from Fig. 8 that the industrial structure has a strong impulse response to itself and has a continuous and significant positive impact from the first phase to the sixth phase. Industrial structure has a strong impulse response to logistics supply, which has a significant positive impact continuously from the first stage to the sixth stage. Demographic dividend has a strong impulse response continuously from the first stage to the sixth stage. Logistics supply has a strong impulse response to itself and has a significant positive impact from the first period to the sixth period. The impulse response of logistics supply to industrial structure is strong, and it has a significant positive impact continuously from the first stage to the sixth stage. Logistics supply has a strong impulse response to itself and has a significant positive impact on the first stage. Logistics demand has a strong impulse response to itself, and has a significant positive impact on the first stage.

3. It can be seen from Fig. 9 that economic development has a strong impulse response to itself and has a significant positive impact continuously from the first stage to the sixth stage. The impulse response of economic development to logistics supply is strong, and it has a significant positive impact continuously from the first stage to the sixth stage. Industrial structure has a strong impulse response to economic development and has a significant positive impact from the first stage to the sixth stage. Industrial structure has a strong impulse response to logistics supply, which has a significant positive impact continuously from the first stage to the sixth stage. Logistics supply has a strong impulse response to economic development and has a significant positive impact from the first stage to the sixth stage. Industrial structure has a strong impulse response to logistics supply, which has a significant positive impact continuously from the first stage to the sixth stage. Logistics supply has a strong impulse response to itself and has a significant positive impact in the previous stage. Logistics demand has a strong impulse response to itself and has a significant positive impact in the previous stage.

4. It can be seen from Fig. 10 that economic development has a strong impulse response to itself and has a significant positive impact continuously from the first stage to the sixth stage. The impulse response of economic development to logistics supply is strong, and it has a significant positive impact continuously from the first stage to the sixth stage. Economic development has a strong impulse response to energy consumption, which has a significant positive impact continuously from the first stage to the sixth stage. Economic development has a strong impulse response to energy consumption, which has a significant positive impact continuously from the first stage to the sixth stage. Economic development has a strong impulse response to energy consumption, which has a significant positive impact continuously from the first stage to the sixth stage. Industrial structure has a strong impulse response to energy consumption, which has a significant positive impact continuously from the first stage to the sixth stage. Industrial structure has a strong impulse response to energy consumption, which has a significant positive impact continuously from the first stage to the sixth stage. Logis-
### Table 4: Results of Granger causality test

| Model 1 | Causal relationship | chi2  | df  | P     | Model 2 | Causal relationship | chi2  | df  | P     |
|---------|---------------------|-------|-----|-------|---------|---------------------|-------|-----|-------|
| lnIS → lnGDP | 1.357 5 | 1 | 0.244 0 | lnDD → lnIS | 0.108 2 | 1 | 0.742 0 |
| lnDD → lnGDP | 1.935 6 | 1 | 0.164 0 | lnLS → lnIS | 38.431 0 | 1 | 0.000 0*** |
| lnLS → lnGDP | 44.660 0 | 1 | 0.000 0*** | lnLD → lnIS | 1.249 4 | 1 | 0.264 0 |
| ALL → lnGDP | 46.128 0 | 3 | 0.000 0*** | ALL → lnIS | 51.769 0 | 3 | 0.000 0*** |
| lnGDP → lnIS | 0.785 4 | 1 | 0.375 0 | lnIS → lnDD | 0.004 1 | 1 | 0.949 0 |
| lnDD → lnIS | 0.736 6 | 1 | 0.391 0 | lnLS → lnDD | 1.823 0 | 1 | 0.177 0 |
| lnLS → lnIS | 43.691 0 | 1 | 0.000 0*** | lnLD → lnDD | 0.366 2 | 1 | 0.545 0 |
| ALL → lnIS | 44.951 0 | 3 | 0.000 0*** | ALL → lnDD | 3.834 4 | 3 | 0.280 0 |
| lnGDP → lnDD | 7.707 9 | 1 | 0.005 0*** | lnIS → lnLS | 2.943 7 | 1 | 0.086 0* |
| lnIS → lnDD | 7.642 7 | 1 | 0.006 0*** | lnDD → lnLS | 0.126 3 | 1 | 0.722 0 |
| lnLS → lnDD | 4.824 0 | 1 | 0.028 0* | lnLD → lnLS | 2.595 2 | 1 | 0.107 0 |
| ALL → lnDD | 9.073 5 | 3 | 0.028 0* | ALL → lnLS | 4.790 8 | 3 | 0.188 0 |
| lnGDP → lnLS | 2.617 6 | 1 | 0.106 0 | lnIS → lnLD | 0.199 3 | 1 | 0.655 0 |
| lnIS → lnLS | 2.828 0 | 1 | 0.093 0* | lnLD → lnLD | 0.410 0 | 1 | 0.522 0 |
| lnDD → lnLS | 0.948 1 | 1 | 0.330 0 | lnLS → lnLD | 0.894 5 | 1 | 0.344 0 |
| ALL → lnLS | 5.677 1 | 3 | 0.128 0 | ALL → lnLD | 2.775 9 | 3 | 0.427 0 |

| Model 3 | lnIS → lnGDP | 0.014 9 | 1 | 0.903 0 | Model 4 | lnIS → lnGDP | 0.019 4 | 1 | 0.889 0 |
|---------|--------------|-------|-----|-------|---------|--------------|-------|-----|-------|
| lnIS → lnGDP | 33.217 0 | 1 | 0.000 0*** | lnIS → lnGDP | 40.187 0 | 1 | 0.000 0*** |
| lnLD → lnGDP | 1.083 8 | 1 | 0.298 0 | lnEC → lnGDP | 6.299 6 | 1 | 0.012 0** |
| ALL → lnGDP | 52.805 0 | 3 | 0.000 0*** | ALL → lnGDP | 69.644 0 | 3 | 0.000 0*** |
| lnGDP → lnIS | 0.013 3 | 1 | 0.908 0 | lnGDP → lnIS | 0.048 6 | 1 | 0.826 0 |
| lnLS → lnIS | 35.295 0 | 1 | 0.000 0*** | lnLS → lnIS | 40.590 0 | 1 | 0.000 0*** |
| lnLD → lnIS | 1.138 9 | 1 | 0.286 0 | lnLD → lnLS | 7.018 4 | 1 | 0.008 0*** |
| ALL → lnIS | 51.474 0 | 3 | 0.000 0*** | ALL → lnLS | 67.513 0 | 3 | 0.000 0*** |
| lnGDP → lnLS | 0.035 6 | 1 | 0.850 0 | lnGDP → lnLS | 0.081 4 | 1 | 0.775 0 |
| lnIS → lnLS | 0.519 5 | 1 | 0.471 0 | lnIS → lnLS | 0.530 9 | 1 | 0.466 0 |
| lnLD → lnLS | 2.229 5 | 1 | 0.135 0 | lnLD → lnLS | 3.818 3 | 1 | 0.051 0* |
| ALL → lnLS | 5.280 1 | 3 | 0.152 0 | ALL → lnLS | 5.620 4 | 3 | 0.132 0 |
| lnGDP → lnLD | 0.221 8 | 1 | 0.638 0 | lnGDP → lnEC | 0.172 6 | 1 | 0.678 0 |
| lnIS → lnLD | 0.416 1 | 1 | 0.519 0 | lnIS → lnEC | 1.766 7 | 1 | 0.184 0 |
| lnLS → lnLD | 0.654 8 | 1 | 0.418 0 | lnLS → lnEC | 4.478 3 | 1 | 0.034 0** |
| ALL → lnLD | 2.268 6 | 3 | 0.519 0 | ALL → lnEC | 22.320 0 | 3 | 0.000 0*** |

| Model 5 | lnIS → lnGDP | 39.329 0 | 1 | 0.000 0*** | Model 6 | lnIS → lnGDP | 37.312 0 | 1 | 0.000 0*** |
|---------|--------------|-------|-----|-------|---------|--------------|-------|-----|-------|
| lnEC → lnGDP | 7.452 1 | 1 | 0.006 0*** | lnEC → lnIS | 8.150 4 | 1 | 0.004 0*** |
| lnEP → lnGDP | 7.026 7 | 1 | 0.008 0*** | lnEP → lnIS | 9.608 7 | 1 | 0.002 0*** |
| ALL → lnGDP | 62.817 0 | 3 | 0.000 0*** | ALL → lnIS | 63.330 0 | 3 | 0.000 0*** |
| lnGDP → lnLS | 3.301 9 | 1 | 0.069 0* | lnGDP → lnLS | 3.769 2 | 1 | 0.052 0* |
| lnEC → lnLS | 3.637 2 | 1 | 0.057 0* | lnEC → lnLS | 3.585 9 | 1 | 0.058 0* |
| lnEP → lnLS | 14.537 0 | 1 | 0.000 0*** | lnEP → lnLS | 16.744 0 | 1 | 0.000 0*** |
| ALL → lnLS | 25.904 0 | 3 | 0.000 0*** | ALL → lnLS | 20.892 0 | 3 | 0.000 0*** |
| lnGDP → lnEC | 11.516 0 | 1 | 0.001 0*** | lnGDP → lnEC | 11.588 0 | 1 | 0.001 0*** |
| lnIS → lnEC | 4.385 6 | 1 | 0.036 0** | lnIS → lnEC | 5.075 4 | 1 | 0.024 0** |
| lnEP → lnEC | 18.316 0 | 1 | 0.000 0*** | lnEP → lnEC | 13.867 0 | 1 | 0.000 0*** |
| ALL → lnEC | 31.884 0 | 3 | 0.000 0*** | ALL → lnEC | 31.599 0 | 3 | 0.000 0*** |
| lnGDP → lnEP | 0.520 7 | 1 | 0.471 0 | lnGDP → lnEP | 0.579 5 | 1 | 0.447 0 |
| lnLS → lnEP | 6.442 7 | 1 | 0.011 0** | lnLS → lnEP | 5.017 7 | 1 | 0.025 0** |
| lnEC → lnEP | 0.541 7 | 1 | 0.462 0 | lnEC → lnEP | 0.558 4 | 1 | 0.455 0 |
| ALL → lnEP | 6.539 8 | 3 | 0.088 0* | ALL → lnEP | 5.189 1 | 3 | 0.158 0 |

***, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.
tics supply has a strong impulse response to economic development and has a significant positive impact from the first stage to the third stage. Logistics supply has a strong impulse response to itself and has a significant positive impact in the previous stage. Logistics supply has a strong impulse response to energy consumption, which has a significant positive impact continuously from the first stage to the sixth stage. Energy consumption has a strong impulse response to economic development and has a significant positive impact from the first stage to the sixth stage. Energy consumption has a strong impulse response and has a significant positive effect on the impulse response in the previous stage.

5. It can be seen from Fig. 11 that economic development has a strong impulse response to itself and has a significant positive impact continuously from the first stage to the sixth stage. The impulse response of economic development to logistics supply is strong, and it has a significant positive impact continuously from the first stage to the sixth stage. Economic development has a strong impulse response to energy consumption, which has a significant positive impact continuously from the first stage to the sixth stage. Economic development has a strong impulse response to environmental protection and has a significant positive impact continuously from the first stage to the sixth stage. Economic development has a strong impulse response to energy consumption and has a continuous and significant positive impact from the second stage to the sixth stage. Energy consumption has a strong impulse response to economic development and has a continuous and significant positive impact from the second stage to the sixth stage. Energy consumption has a strong impulse response to environmental protection and has a significant positive impact continuously from the first stage to the sixth stage. Logistics supply has a strong impulse response to economic development and has a significant positive impact from the first stage to the sixth stage. Logistics supply has a strong impulse response to energy consumption and has a significant positive impact continuously from the first stage to the sixth stage. Logistics supply has a strong impulse response to environmental protection and has a significant positive impact continuously from the first stage to the sixth stage.
sixth stage. Environmental protection has a strong impulse response to itself, and has a significant positive impact in the previous stage. The impulse response of energy consumption to environmental protection is strong, and it has a significant positive impact continuously from the first stage to the sixth stage. Environmental protection has a strong impulse response to itself and has a significant positive impact from the first stage to the sixth stage.

6. It can be seen from Fig. 12 that the industrial structure has a strong impulse response to itself and has a continuous and significant positive impact from the first stage to the sixth stage. Industrial structure has a strong impulse response to logistics supply, which has a significant positive impact continuously from the first stage to the sixth stage. Industrial structure has a strong impulse response to energy consumption, which has a significant positive impact from the first stage to the sixth stage. Industrial structure has a strong impulse response to environmental protection and has a significant positive impact from the first stage to the sixth stage. The impulse response of logistics supply to industrial structure is strong, and it has a significant positive impact continuously from the first stage to the sixth stage. Logistics supply has a strong impulse response to itself and has a significant positive impact in the previous stage. Logistics supply has a strong impulse response to energy consumption, which has a significant positive impact continuously from the first stage to the sixth stage. Logistics supply has a strong impulse response to environmental protection and has a significant positive impact continuously from the first stage to the sixth stage. The impulse response of energy consumption to industrial structure is strong, and it has a continuous and significant positive impact from the second stage to the sixth stage. Energy consumption has a strong impulse response to logistics supply, and has a continuous and significant positive impact from the second stage to the sixth stage. Energy consumption has a strong impulse response and has a significant positive effect on the impulse response in the previous stage. The impulse response of energy consumption to environmental protection is strong, and it has a significant positive impact continuously from the
first stage to the sixth stage. Environmental protection has a strong impulse response to itself and has a significant positive impact in the previous stage.

**Provincial GMM estimation results**

1. As can be seen from Fig. 13, GMM estimation results of Jiangsu province in model 1 have a significant positive impact; that is, the development of logistics industry has a significant positive impact on economic development in Jiangsu province. The GMM estimation of Shanghai has a significant negative impact, which reflects the significant spillover effect of logistics development in Shanghai. The GMM estimation results of Anhui province have significant positive and negative effects, which reflects the present situation that the development of logistics industry varies greatly among different regions in Anhui province. The GMM estimation results of Zhejiang province are not significant.

2. As can be seen from Fig. 14, GMM estimation results of Zhejiang province in model 2 have a significant positive impact; that is, the development of logistics industry has a significant positive impact on the industrial structure and regional economic development in Zhejiang province. The GMM estimation results of Jiangsu and Shanghai have a significant positive impact, which reflects that the proportion of logistics development is equal in industrial economic structure of Jiangsu and Shanghai. The GMM estimation results of Anhui province are not significant.

3. As can be seen from Fig. 15, GMM estimation results of Zhejiang province in model 3 have a significant positive impact; that is, the development of logistics industry has a significant positive impact on the industrial structure and regional economic development in Zhejiang province. The GMM estimation results of Anhui and Jiangsu have a significant positive impact, which reflects that the development of logistics industry takes a larger proportion in the development of industrial economic structure in Anhui and Jiangsu. The GMM estimation of Shanghai
is not significant, which reflects that the logistics industry does not take a prominent proportion in the economic structure of Shanghai.

4. As can be seen from Fig. 16, GMM estimation results of Jiangsu province in model 4 have a significant positive impact; that is, the development of logistics industry has a significant positive impact on economic development, and energy consumption is also the largest in Jiangsu province. The GMM estimation results of Shanghai have a significant negative impact, which reflects that the spillover effect of logistics industry development is significant and the problem of overcapacity is prominent in Shanghai. The GMM estimation results of Zhejiang and Anhui have a significant positive impact, which reflects that Anhui province has a better performance in energy consumption from the perspective of logistics development.

5. As can be seen from Fig. 17, GMM estimation results of Jiangsu province in model 5 have a significant impact; that is, the development of logistics industry has a significant impact on energy consumption and environmental protection, and energy consumption is also the largest in Jiangsu province. The GMM estimation result of Shanghai have a significant negative impact, which reflects the poor energy consumption and environmental protection of logistics industry in Shanghai. The GMM estimation results of Zhejiang and Anhui have a significant effect, but it has better performance in environmental protection and energy consumption in Anhui than in Zhejiang.

6. It can be seen from Fig. 18 that GMM estimation results of Jiangsu province in model 6 have a significant impact; that is, the development of logistics industry has a significant impact on the industrial structure, and demographic dividend and logistics demand also have the greatest impact on the industrial structure in Jiangsu province. The GMM estimation results of Shanghai have a significant positive impact, which reflects that logistics demand has a significant positive impact on local economic development in Shanghai. The GMM estimation...
Impulse-responses for 1 lag VAR of dlnGDP dlnLS dlnEC dlnEP

Fig. 11 Results of PVAR regression for model 5

To sum up, in terms of economic development, Jiangsu > Shanghai > Zhejiang > Anhui showed a trend of sustained growth. Since 2010, Jiangsu has overtaken Shanghai. In terms of industrial structure, Jiangsu > Zhejiang > Shanghai > Anhui showed a trend of continuous growth. In terms of demographic dividend, Jiangsu > Anhui > Zhejiang > Shanghai showed a trend of continuous growth. In terms of energy consumption, Jiangsu > Shanghai > Zhejiang > Anhui showed a trend of first increasing and then decreasing. In terms of environmental protection, Anhui > Zhejiang and Jiangsu > Shanghai showed a steady and sustainable growth trend. In terms of logistics demand, Zhejiang > Jiangsu > Shanghai > Anhui, Zhejiang began to grow rapidly after 2013. In terms of logistics supply, Anhui > Jiangsu > Zhejiang > Shanghai, Anhui began to grow rapidly after 2010.

Conclusions and recommendations

Conclusions

1. Logistics supply is the cause leading to economic development, industrial structure, energy consumption, and environmental protection. That is, the construction of national infrastructure such as railway and highway operating mileage has a significant impact on economic development, industrial structure, energy and environment of Yangtze River Delta. Environmental protection and logistics supply have bidirectional effects. That is, the construction of national infrastructure such as railway and highway operating mileage has a direct impact on the forest coverage rate in Yangtze River Delta. Industrial structure is the cause leading to energy consumption and demographic dividend. That is, the proportion of primary, secondary and tertiary industries has a direct impact on the consumption of crude oil and other energy as well as the population in Yangtze River Delta.
2. The development of logistics industry in Yangtze River Delta is not balanced, and there is the possibility of complementary advantages. Logistics industry does not take up a large proportion in industrial structure of Shanghai, and it has poor performance in environmental protection. Although there are many universities in Shanghai, it is not dominant in demographic dividend. In the recent 10 years, Anhui has made great progress and improvement in logistics supply and environmental protection, and the consumption of crude oil and other energy is the least. It reflects the development of Anhui is positive in the field of new energy, but the disadvantage of its location in the inland is not dominant in economic development and industrial structure. In the face of strong competition and siphon effect from the other three provinces, the logistics demand of Anhui is slightly insufficient; Jiangsu has great advantages in economic development, industrial structure, and demographic dividend, but it consumes too much energy such as crude oil, so it needs to transform and upgrade to new energy and seek green and sustainable development. The advantage of Zhejiang lies in logistics demand and industrial structure, and it has good performance in environmental protection, but it has poor performance in demographic dividend, and logistics supply has not kept pace with the growth rate of logistics demand.

3. Economic development and energy consumption have bidirectional effects. That is, crude oil and other strategic energy have a vital impact on economic development of Yangtze River Delta. Environmental protection is the cause leading to economic development, industrial structure distribution and energy consumption. That is, environmental protection has a significant and direct impact on regional economic development, industrial structure distribution and energy consumption.

**Recommendations**

1. In terms of logistics supply, the construction of 5G network infrastructure should be accelerated to form the integration of Internet of things in Yangtze River Delta, form the basic conditions for upgrading industr-
Fig. 13 Box scatter coefficient of provincial GMM estimation results in model 1

Fig. 14 Box scatter coefficient of provincial GMM estimation results in model 2

Fig. 15 Box scatter coefficient of provincial GMM estimation results in model 3
trial chain, and lay a good foundation for the consumption cycle. From supply end to product end, the green and healthy development should be carried out to help the rise of some brands. Logistics domestic demand should be promoted through upgrading industrial chain and external demand should be expanded through the Belt and Road initiative. Consumption demand should be released through keeping housing from speculating and the construction of urban agglomeration should be accelerated in Yangtze River Delta. It is necessary to form a large Internet of things, accelerate the construction of rural revitalization, and exploit the potential of rural consumption.

2. The government should vigorously promote the development of new energy industry, relying on science and technology to reduce energy consumption, such as the photovoltaic industry, wind, and tidal power generation. In terms of environmental protection, the government should vigorously promote the development of new energy vehicle through tax subsidy policies to reduce the emission of carbon dioxide and make preparation for carbon neutrality by 2060. The construction of urban agglomeration should be divided into urban core area, agricultural ecological area and ecological protection area according to functions, in order to promote sustainable economic development.

3. In terms of demographic dividend, local governments should increase preferential policies for talent introduction, relax household registration restrictions to promote talent flow and education equity. In terms of industrial structure, we will increase investment in key areas such as biotechnology, information technology, block chain, artificial intelligence, integrated circuits, and quantum information. It is necessary to make up for the weak-
nesses in core technologies to form the integration of industries, universities and research institutes.

4. The four provinces in Yangtze River Delta are provided suggestions respectively. The proportion of logistics industry is small in industrial structure of Shanghai, so we should increase the proportion of logistics industry in economic structure appropriately. Shanghai has a poor record in environmental protection and should increase the area covered by forests. Although Shanghai has many colleges and universities, it is not advantageous in terms of demographic dividend. Shanghai should relax the settlement policy and increase the introduction of talents. Anhui has a great progress and improvement in logistics supply and environmental protection, and the consumption of crude oil and other energy is the least. It shows the development of Anhui province is positive in the field of new energy. The disadvantage of location in the inland is not dominant in the economic development and industrial structure. In the face of fierce competition and siphon from the other three provinces, there is slightly less logistics demand at the same time. Anhui should increase the demand for logistics, attract excellent enterprises to settle in through preferential tax policies, and open the settlement policy to attract talents. Jiangsu province enjoys great advantages in economic development, industrial structure and demographic dividend, but it consumes too much energy such as crude oil, so it needs to transform and upgrade to new energy and seek green and sustainable development. In photovoltaic power generation and new energy vehicles, preferential tax policies should be adopted to attract new energy industries to open up upstream and downstream supply chains. It is necessary to realize green transformation and upgrading in Jiangsu. Zhejiang province performs well in logistics demand, industrial structure, and environmental protection, but it does not have an advantage in demographic dividend, so it should liberalize the settlement policy and provide high salary to attract talent inflow. Logistics supply has not kept pace with the growth rate of logistics demand, and it is necessary to increase the construction of transportation infrastructure to meet the growth of logistics demand.

5. Considering from the supply side, we should upgrade the international brands, open up the upstream and downstream industrial chain, adjust the industrial structure. It is necessary to invest in new energy and environmental protection industries and form the internal circulation of logistics industry in Yangtze River Delta. Considering from the demand side, we should accelerate the rural revitalization to exploit the potential of rural consumption, adhere to the prevention and control of consumption demand to promote domestic demand. Through the international trade of Belt and Road and other countries, we should expand external demand and form the external cycle of logistics industry in Yangtze River Delta. The dual circulation including internal cycle and external cycle can promote the rapid development of logistics industry in Yangtze River Delta.

**Research deficiencies and future prospects**

Although we have used the data of Yangtze River Delta in China Statistical Yearbook from 2001 to 2019, we believe that it is not comprehensive to use the data in the past 20 years since China has been carrying out reform and opening-up for more than 40 years. In the future, we will collect more data for research. Despite the background of carbon neutrality, we explore the relationship between logistics and economy, energy and environment in Yangtze River Delta from seven dimensions. They include economic development, industrial structure, demographic dividend, logistics supply, logistics demand, energy consumption, and environmental protection. However, there are still many indicators related to regional logistics development, and we will add more indicators for research in the future. In addition, due to limited space, part of variance decomposition is omitted in this paper, which we think has no impact on the conclusion of the study.

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**Data availability** We promise that all data and materials in the article are true and reliable.

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