*Pol. J. Environ. Stud. Vol. 31, No. 4 (2022), 3343-3357*
DOI: *10.15244/pjoes/145877* ONLINE PUBLICATION DATE: 2022-04-25

*Original Research*

# A Study on Natural Capital Utilization Efficiency of Cities in the Yangtze River Delta from 2000 to 2019 and the Analysis of Influencing Factors

**Qiuyi Xie[1], Min Yang[2], Nianxing Zhou[1]***

[1]School of Geography Science, Nanjing Normal University, Nanjing 210023, China
[2]Yuezhou High School, Shaoxing 312000, China

*Received: 31 August 2021*
*Accepted: 14 January 2022*

## Abstract

Sustainable development evaluation is a complicated component of system engineering. In ecological economics, capital stock stability is used to evaluate sustainability; however, previous studies have used a single indicator to evaluate natural capital, which cannot reflect the sustainability of regional development. Here, we studied the theories of ecological economics, drew lessons from ecological efficiency and carbon intensity concepts, and introduce the concepts of capital flow and capital stock to analyze the utilization efficiency of natural capital in the Yangtze River Delta. A spatial error model was used to study the influencing factors and determine the sustainable development from 2000 to 2019. The results showed that: (1) From 2000 to 2014, natural capital in the Yangtze River Delta region was intensified and had low efficiency. From 2014 to 2019, capital use gradually balanced and showed sustainable development. (2) Natural capital utilization efficiency was affected by resource conditions, industrial structure, regional location. The higher the tertiary industry proportion, the closer the location to the central city, the better the economic development foundation, the higher the natural capital utilization efficiency, and the better the sustainable development. (3) Natural capital utilization change was due to the regulatory role of the government.The One Belt One Road strategy and urban integration strategy proposed by the Chinese government have greatly changed the market structure.

**Keywords**: natural capital utilization efficiency, spatial error model, sustainable development, Yangtze River Delta

## Introduction

With rapid population and economic growth, tremendous changes have occurred in the spatial and material relationships between humans and nature, and the contradiction between ecosystem health and social welfare of the population continues to intensify [1, 2]. Serious environmental problems have led to the realization that the environment and economy are both in opposition and united. To avoid environmental problems, the pressure of human economic activities on the natural environment must be limited

*e-mail: zhounianxing@263.net

to the carrying capacity of the Earth's ecosystem. Recently, international demand for low-carbon development has increased. Recently, international demand for low-carbon development has increased. The united nation have suggested Carbon peaking and neutrality, and hope to reach the stage of steady decline in carbon emissions. With through tree planting, afforestation, energy saving, and emission reduction, the generated carbon dioxide emissions can be offset and "zero emission" carbon dioxide can be achieved. The carbon peak stage, requires all countries to undertake coordinated development of the economy and ecological environment, and strive to achieve regional sustainable development [3, 4].

Evaluating sustainable development is a complicated component of system engineering [5]. In ecological economics, the stability of capital stock is the basis for evaluating sustainability [6, 7]. Ecologists who have supported strong sustainable theory have stated that natural resources increasingly act as constraints [8, 9]. Economists who support weak sustainable theory state that only accelerated technical progress can offset the reduction of natural resources available per capita, making the output per capita increase [10, 11]. However, studies on natural capital have shown that the theory of natural capital contains the concepts of sustainable development and ecology, and it is necessary to support the combination of economy and economy to play the role of natural capital [12, 13]. Further research on the utilization of natural capital is required based on the findings of dynamic models of world resources [14], human appropriation of net primary production [15], human bearing capacity [16], and energy analysis theory [17]. Rees [18] first proposed the concept of the ecological footprint in 1992, and developed this into the classic ecological footprint model together with Wackernagel et al. [19]. In China, Fang Kai [20] first introduced the three-dimensional ecological footprint and improved it, applying this improved three-dimensional model to research the spatial pattern of different scale natural capital utilization [21-23]. The application of the three-dimensional ecological footprint model included the categorical measure of capital stock and flow, breaking through the limitation of domestic natural capital research, which is limited to a two-dimensional perspective. An increasing number of scholars have started to research the fundamentals of three-dimensional models. Zhu Dajian [13] proposed the need to initiate a "revolution of ecological efficiency" or a "revolution of resource productivity." Jin Xueru [24] used nighttime light data to calculate the ecological footprint of China. Zhang Xixi [25] researched the ecological efficiency of marine ranches in China. Humaira Yasmeen [26] discovered that technological innovation influenced natural capital utilization efficiency.

Although scholars have conducted extensive research on ecological efficiency, there is still a lack of research on natural capital utilization efficiency and the evolution of time and space. Under the current trend of carbon peaking, we must improve the natural resource use efficiency to minimize the use of resources and the amount of waste generated during the production system and maximize carbon neutrality [12].

The Yangtze River Delta region was used as a case study in the present study. We used a three-dimensional model to calculate the urban stock and flow capital from 2000 to 2019. We calculated the utilization efficiency. Finally, the spatial error model was used to determine the influencing factors. The present study comprehensively analyze the efficiency and intensity of natural capital utilization, reducing the errors and shortcomings caused by only one method used in previous studies, and derived a development model of the Yangtze River Delta from 2000 to 2019. The study determined the relevant measures and suggestions for improving regional sustainable development, which is conducive to promoting relevant research in the Yangtze River Delta region and provides a theoretical basis for realizing carbon peaks and neutrality.

## Research Methods

### Regional Overview and Data Sources

As China's largest economic circle and one of the world's sixth largest metropolitan circles, the city agglomeration in the Yangtze River Delta comprises China's most highly urbanized, densely distributed, and economically developed area. The Yangtze River Delta is the largest globalizing city region in China. The development of the Yangtze River Delta can serve as a model for other regions. The economic aggregate in the Yangtze River Delta has been higher than that of the Pearl River Delta and Beijing-Tianjin-Tangshan regions since 2004, and is the economic center with the greatest comprehensive strength in China [27, 28]. In the first half of 2015, the gross domestic product (GDP) of Shanghai was equal to, and the total GDP of Suzhou and Zhejiang exceeded, the national average. However, due to the rapid growth of industrialization and urbanization in recent years, cultivated land resources have been used for non-agricultural purposes, accelerated environmental pollution has aggravated the shortage of ecological resources in the Yangtze River Delta region, and resources and the environment have increasingly restrained social and economic development, making it increasingly difficult to achieve sustainable development.

First, we referenced related research [29] and evaluated the current situation of natural capital in the Yangtze River Delta urban agglomeration. Regarding data availability, reliability, and uniformity, the study established natural capital accounts and analyzed the impact factors based on data from provincial and municipal statistical yearbooks, the China Energy Statistical Yearbook, statistical bulletins of national

Table 1. Data Sources.

| Items | Data details and sources | | |
|---|---|---|---|
| Account of biological resources (t) | Cultivated land | Wheat, rice, potato, maize, soybean, cotton, oil, hemp, sugars, tea, vegetable, honey, fresh egg | Shanghai Statistical Yearbook |
| | Grassland | Pork, beef, mutton, poultry, milk | Prefectural and municipal statistical yearbooks, including Nanjing Statistical Yearbook |
| | Forest products | Forest fruits, camellia seed, dried bamboo shoot, Chinese chestnut, gingko, log | Prefectural and municipal statistical yearbooks, including Hangzhou Statistical Yearbook |
| | Aquatic products | Sea water and freshwater products | China City Statistical Yearbook |
| Account of energy resources (10 kt) | Energy consumption | Raw coal, coal, coke, crude oil, gasoline, diesel, fuel oil, LPG, kerosene, electricity, heat | China Energy Statistical Yearbook |
| Land use area ($km^2$) | Official websites of Shanghai Municipal Administration of Planning and Land Resources, Department of Land and Resources of Nanjing and Hangzhou; China City Statistical Yearbook 1995–2005 Ecological Footprint Analysis of Longitudinal Time Series of Shanghai, Chen Wei et al. 2008 | | |
| Population | Shanghai Statistical Yearbook, Jiangsu Statistical Yearbook, Zhejiang Statistical Yearbook and prefectural and municipal statistical yearbooks | | |
| Global average yield (t) | Food and Agriculture Organization of the United Nations (FAO). FAOSTAT Domains [EB/OL]. http://www.faostat3.fao.org/download/Q/QC/E. | | |
| Balance factor, yield factor and conversion coefficient | Analysis on Balance between Supply and Demand in China's Ecological Capacity based on Ecological Footprint, Liu Dong et al. 2012 | | |

economic development, and the official websites of the Department of Land and Resources of each province and municipality (Table 1).

## Methods

### *Three-Dimensional Ecological Footprint Model*

The improved three-dimensional footprint was calculated as [30-32]:

$$EF_{size,i} = \min\{EF_i, BC_i\} \quad (1)$$

$$EF_{depth,i} = 1 + \frac{\max\{EF_i - BC_i, 0\}}{BC_i} \quad (2)$$

where, $EF_i$ refers to the two-dimensional ecological footprint per capita of the $i^{th}$ type of land ($hm^2$/capita), $BC_i$ refers to the ecological capacity per capita ($hm^2$/capita), $EF_{size,I}$ refers to the footprint size of the $i^{th}$ type of land, and $EF_{depth,I}$ refers to the footprint depth of the $i^{th}$ type of land.

Then, the three-dimensional footprint of a region was calculated as:

$$EF_{3D,region} = EF_{size,region} \times EF_{depth,region} = \sum_{i=1}^{n} \min\{EF_i, BC_i\} \times \left(1 + \frac{\sum_{i=1}^{n} \max\{EF_i - BC_i, 0\}}{\sum_{i=1}^{n} BC_i}\right) \quad (3)$$

### *Natural Capital Flow Utilization*

The size of the ecological footprint cannot accurately reflect the extent to which stress is exerted on the ecological environment. In relation to a region, despite its large ecological footprint, a virtual circle will form in the ecosystem if natural capital flow is consumed entirely. Despite the small ecological footprint, great stress will be exerted on the ecosystem if employing capital stocks can maintain the normal economic and social operation of such regions. Therefore, the sustainability of development cannot fully depend on the size of the ecological footprint. To clarify the actual use of capital flows, the index of flow utilization efficiency was introduced and the natural capital flow utilization was calculated as:

$$\lambda_f = \frac{EF_{size}}{BC} \times 100\% \qquad (EF \leq BC) \quad (4)$$

*Natural Capital Stock Utilization*

When the ecological footprint of a region is larger than its ecological capacity, capital stocks are employed. To clarify the actual use of capital stocks, the index of stock flow utilization efficiency was introduced and the natural capital stock utilization was calculated as:

$$\lambda_f^s = \frac{EF - EF_{size}}{BC} = \frac{ED}{BC} \qquad (EF > BC) \tag{5}$$

*Natural Capital Utilization Efficiency*

Referring to the connotation of ecological efficiency, the maximum efficiency of the ecological environment of natural resources and energy meeting human production and living needs, i.e., the ratio of the output of resources and the environment to the input, the present study defined natural capital utilization efficiency as the GDP of a region created due to the ecological footprint, highlighting the unity of economic value and environmental efficiency, i.e., the maximum economic value achieved with minimum capital consumption.

With this index, the natural resources consumed in the entire system were converted into biologically productive lands. With improvement in resource utilization efficiency, more technical elements are involved in economic production activities. Therefore, the higher the index, the lower the resource utilization efficiency.

Using the corrected DEA model, based on the GDP of the region as a variable output and the ecological footprint as a variable input, the natural capital utilization efficiency of the Yangtze River Delta region was calculated as:

$$\begin{cases} \max \theta_j^* \\ s.t. \sum_{j=1}^{n+1} \lambda_j x_j \le \lambda_j \\ \sum_{j=1}^{n+1} \lambda_j y_j \le \theta_j y_j \\ \sum_{j=1}^{n+1} \lambda_j \le 1, \lambda_j \ge 0 \end{cases} \tag{6}$$

where, $\lambda_j$ refers to the variable weight and θ refers to the overall efficiency (result measured with the DEA model), i.e., the extent to which a technology yields productive efficiency during stable use, by which the ability to obtain a maximum economic output with existing technologies is measured [23].

*The Space Model*

The spatial measurement model used in this article includes the spatial error model and the spatial Dubin model. Spatial error model (SEM) describes spatial disturbance correlation and spatial overall correlation. The Spatial Durbin Model (SDM) assumes that the value of the dependent variable is not only affected by the local independent variable, but also by the independent variable of the neighboring area.

## Calculation and Result Visualization

### Evaluation of Three-Dimensional Ecological Footprint

The three-dimensional ecological footprint of the Yangtze River Delta urban from 2000 to 2019 is calculated using standardized land element data (Table 2). Its actual meaning is the three-dimensional natural capital utilization value based on land use in the Yangtze River Delta. The table shows that the ecological footprint per capita has increased by 20% in 20 years. An increase of 1.26 from 1.01 from 2000 to 2014 indicates that during the period, economic and social development consumes a lot of natural capital in the surrounding areas. The decline from 1.26 to 1.05 from 2015 to 2019 indicates that the economic and social development has shifted to sustainable development. Among them, the consumption of arable land has always been at a relatively fixed level, the consumption of green land has gradually decreased, and the demand for water, garden land, and construction land has increased, indicating that the people's demand for resource utilization has changed.

### Evaluation of Natural Capital Flow Utilization

Evaluate the utilization of natural capital flows (Table 3). From 2000 to 2014, the natural capital flow utilization in the Yangtze River Delta was relatively stable, and from 2014 to 2019, the utilization decreased almost 30%. The decrease does not mean a weakening of the economic level, but a reduction in flow resource consumption. Among them, Shanghai has always maintained a low utilization rate, which may be related to the lack of its own natural resources. Meanwhile the fast reduction of natural capital flow utilization in Suzhou, Wuxi, Hangzhou and other cities indicate the less dependent on flow resource. Domestic scholars have reached similar conclusions by researching on land use and ecological environment [33].

### Evaluation of Natural Capital Stock Utilization

From 2000 to 2009, the capital stock utilization in the Yangtze River Delta increased rapidly. This shows that before 2010, the resource consumption in the Yangtze River Delta was dominated by the consumption of stock capital, which severely restricted ecological

Table 2. Three-dimensional ecological footprint of Yangtze River Delta Region from 2000 to 2019.

| Land classification | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivated land | 0.172 | 0.171 | 0.166 | 0.160 | 0.165 | 0.161 | 0.168 | 0.153 | 0.173 | 0.183 | 0.178 | 0.179 | 0.182 | 0.187 | 0.176 | 0.175 | 0.176 | 0.176 | 0.180 | 0.177 |
| Green land | 0.537 | 0.553 | 0.623 | 0.583 | 0.580 | 0.591 | 0.569 | 0.755 | 0.540 | 0.588 | 0.628 | 0.656 | 0.676 | 0.663 | 0.646 | 0.604 | 0.573 | 0.561 | 0.536 | 0.431 |
| Garden land | 0.009 | 0.018 | 0.016 | 0.018 | 0.020 | 0.019 | 0.021 | 0.022 | 0.023 | 0.022 | 0.022 | 0.023 | 0.023 | 0.023 | 0.024 | 0.025 | 0.024 | 0.025 | 0.024 | 0.025 |
| Waters | 0.297 | 0.304 | 0.312 | 0.313 | 0.327 | 0.329 | 0.335 | 0.333 | 0.344 | 0.337 | 0.353 | 0.361 | 0.369 | 0.374 | 0.385 | 0.409 | 0.398 | 0.401 | 0.397 | 0.395 |
| Construction land | 0.004 | 0.005 | 0.014 | 0.010 | 0.009 | 0.010 | 0.015 | 0.014 | 0.020 | 0.037 | 0.016 | 0.022 | 0.020 | 0.021 | 0.023 | 0.023 | 0.024 | 0.024 | 0.024 | 0.024 |
| Natural capital utilization | 1.018 | 1.051 | 1.130 | 1.083 | 1.100 | 1.111 | 1.108 | 1.277 | 1.099 | 1.167 | 1.197 | 1.241 | 1.269 | 1.269 | 1.255 | 1.236 | 1.195 | 1.186 | 1.161 | 1.052 |

Table 3. Natural Capital Flow Utilization in the Yangtze River Delta Region from 2000 to 2019.

| Region | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nanking | 0.153 | 0.173 | 0.164 | 0.113 | 0.156 | 0.153 | 0.144 | 0.134 | 0.145 | 0.143 | 0.141 | 0.206 | 0.156 | 0.125 | 0.144 | 0.137 | 0.135 | 0.136 | 0.127 | 0.120 |
| Suzhou | 0.178 | 0.149 | 0.136 | 0.112 | 0.114 | 0.109 | 0.115 | 0.094 | 0.108 | 0.122 | 0.120 | 0.119 | 0.119 | 0.117 | 0.114 | 0.102 | 0.103 | 0.099 | 0.069 | 0.079 |
| Changzhou | 0.192 | 0.186 | 0.179 | 0.198 | 0.163 | 0.155 | 0.161 | 0.142 | 0.162 | 0.154 | 0.157 | 0.154 | 0.156 | 0.156 | 0.155 | 0.138 | 0.136 | 0.129 | 0.090 | 0.109 |
| Yangzhou | 0.218 | 0.224 | 0.224 | 0.200 | 0.224 | 0.228 | 0.227 | 0.227 | 0.226 | 0.217 | 0.219 | 0.220 | 0.225 | 0.226 | 0.228 | 0.203 | 0.199 | 0.187 | 0.097 | 0.165 |
| Taizhou | 0.210 | 0.208 | 0.214 | 0.212 | 0.211 | 0.210 | 0.210 | 0.210 | 0.212 | 0.200 | 0.199 | 0.199 | 0.199 | 0.199 | 0.228 | 0.207 | 0.198 | 0.195 | 0.111 | 0.182 |
| Nantong | 0.204 | 0.196 | 0.202 | 0.205 | 0.205 | 0.205 | 0.204 | 0.204 | 0.204 | 0.207 | 0.208 | 0.204 | 0.202 | 0.201 | 0.193 | 0.169 | 0.163 | 0.153 | 0.060 | 0.133 |
| Zhenjiang | 0.202 | 0.202 | 0.200 | 0.171 | 0.200 | 0.187 | 0.193 | 0.189 | 0.211 | 0.217 | 0.217 | 0.215 | 0.220 | 0.219 | 0.219 | 0.185 | 0.188 | 0.178 | 0.079 | 0.170 |
| Xuzhou | 0.213 | 0.223 | 0.222 | 0.170 | 0.224 | 0.209 | 0.224 | 0.223 | 0.220 | 0.220 | 0.226 | 0.224 | 0.222 | 0.219 | 0.213 | 0.208 | 0.207 | 0.204 | 0.077 | 0.204 |
| Lian Yungang | 0.232 | 0.253 | 0.247 | 0.219 | 0.266 | 0.250 | 0.269 | 0.266 | 0.264 | 0.264 | 0.252 | 0.267 | 0.265 | 0.263 | 0.261 | 0.240 | 0.235 | 0.228 | 0.153 | 0.211 |
| Huaian | 0.270 | 0.291 | 0.294 | 0.296 | 0.305 | 0.316 | 0.339 | 0.341 | 0.356 | 0.254 | 0.238 | 0.224 | 0.211 | 0.197 | 0.184 | 0.170 | 0.163 | 0.155 | 0.123 | 0.145 |
| Suqian | 0.254 | 0.251 | 0.245 | 0.171 | 0.243 | 0.245 | 0.267 | 0.260 | 0.271 | 0.267 | 0.264 | 0.260 | 0.258 | 0.253 | 0.252 | 0.234 | 0.222 | 0.214 | 0.134 | 0.200 |
| Yancheng | 0.295 | 0.303 | 0.309 | 0.283 | 0.327 | 0.327 | 0.326 | 0.225 | 0.324 | 0.322 | 0.341 | 0.339 | 0.341 | 0.345 | 0.343 | 0.311 | 0.299 | 0.284 | 0.202 | 0.255 |

Table 3. Continued.

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wuxi | 0.158 | 0.153 | 0.147 | 0.146 | 0.143 | 0.137 | 0.133 | 0.125 | 0.121 | 0.118 | 0.117 | 0.118 | 0.115 | 0.112 | 0.108 | 0.099 | 0.095 | 0.086 | 0.048 | 0.064 |
| Hangzhou | 0.114 | 0.113 | 0.112 | 0.115 | 0.115 | 0.116 | 0.111 | 0.111 | 0.116 | 0.113 | 0.112 | 0.111 | 0.111 | 0.098 | 0.096 | 0.090 | 0.087 | 0.081 | 0.056 | 0.068 |
| Huzhou | 0.178 | 0.184 | 0.179 | 0.176 | 0.199 | 0.191 | 0.201 | 0.101 | 0.199 | 0.199 | 0.192 | 0.190 | 0.185 | 0.185 | 0.162 | 0.143 | 0.137 | 0.130 | 0.098 | 0.109 |
| Taizhou | 0.055 | 0.111 | 0.099 | 0.092 | 0.096 | 0.095 | 0.099 | 0.098 | 0.101 | 0.096 | 0.096 | 0.094 | 0.095 | 0.095 | 0.086 | 0.081 | 0.082 | 0.083 | 0.041 | 0.069 |
| Zhoushan | 0.058 | 0.056 | 0.055 | 0.052 | 0.054 | 0.051 | 0.052 | 0.051 | 0.050 | 0.062 | 0.051 | 0.050 | 0.049 | 0.048 | 0.046 | 0.044 | 0.045 | 0.046 | 0.034 | 0.048 |
| Jiaxing | 0.210 | 0.211 | 0.214 | 0.218 | 0.221 | 0.224 | 0.223 | 0.224 | 0.225 | 0.220 | 0.218 | 0.217 | 0.221 | 0.221 | 0.223 | 0.195 | 0.178 | 0.160 | 0.119 | 0.107 |
| Ningbo | 0.140 | 0.138 | 0.125 | 0.108 | 0.114 | 0.113 | 0.123 | 0.118 | 0.128 | 0.127 | 0.129 | 0.131 | 0.128 | 0.123 | 0.120 | 0.112 | 0.110 | 0.108 | 0.046 | 0.088 |
| Shaoxing | 0.139 | 0.140 | 0.140 | 0.127 | 0.137 | 0.137 | 0.145 | 0.142 | 0.142 | 0.160 | 0.143 | 0.163 | 0.166 | 0.164 | 0.139 | 0.130 | 0.127 | 0.124 | 0.092 | 0.103 |
| Lishui | 0.125 | 0.129 | 0.136 | 0.127 | 0.137 | 0.137 | 0.117 | 0.117 | 0.142 | 0.136 | 0.131 | 0.131 | 0.130 | 0.130 | 0.128 | 0.125 | 0.123 | 0.117 | 0.086 | 0.100 |
| Quzhou | 0.167 | 0.167 | 0.170 | 0.162 | 0.171 | 0.175 | 0.175 | 0.175 | 0.187 | 0.182 | 0.182 | 0.182 | 0.183 | 0.182 | 0.181 | 0.170 | 0.170 | 0.162 | 0.116 | 0.126 |
| Jinhua | 0.138 | 0.132 | 0.116 | 0.101 | 0.112 | 0.116 | 0.116 | 0.117 | 0.122 | 0.115 | 0.114 | 0.124 | 0.124 | 0.122 | 0.106 | 0.097 | 0.093 | 0.090 | 0.101 | 0.074 |
| Wenzhou | 0.076 | 0.075 | 0.070 | 0.064 | 0.067 | 0.062 | 0.064 | 0.056 | 0.063 | 0.066 | 0.063 | 0.064 | 0.063 | 0.058 | 0.057 | 0.054 | 0.056 | 0.054 | 0.016 | 0.047 |
| Shanghai | 0.081 | 0.054 | 0.076 | 0.070 | 0.071 | 0.071 | 0.072 | 0.071 | 0.072 | 0.077 | 0.078 | 0.079 | 0.078 | 0.076 | 0.074 | 0.065 | 0.054 | 0.048 | 0.044 | 0.039 |
| Yangtze River | 0.187 | 0.186 | 0.192 | 0.193 | 0.194 | 0.195 | 0.196 | 0.197 | 0.192 | 0.186 | 0.183 | 0.181 | 0.180 | 0.177 | 0.167 | 0.154 | 0.151 | 0.145 | 0.094 | 0.130 |

Table 4. Natural Capital Stock Utilization in the Yangtze River Delta Region from 2000 to 2019.

| Region | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nanking | 5.71 | 6.23 | 6.55 | 7.32 | 7.76 | 7.94 | 8.01 | 7.50 | 7.69 | 7.56 | 7.48 | 7.07 | 7.06 | 11.73 | 7.96 | 8.03 | 8.09 | 8.21 | 8.42 | 8.63 |
| Suzhou | 14.55 | 14.95 | 15.38 | 14.73 | 14.66 | 15.18 | 15.35 | 14.63 | 14.34 | 8.96 | 12.56 | 12.90 | 13.03 | 12.61 | 12.29 | 12.43 | 12.54 | 12.74 | 12.99 | 13.23 |
| Changzhou | 3.25 | 1.93 | 8.80 | 11.68 | 9.93 | 10.17 | 10.86 | 10.94 | 10.98 | 11.80 | 11.95 | 12.99 | 14.05 | 14.45 | 14.27 | 14.38 | 14.46 | 14.62 | 14.76 | 14.90 |
| Yangzhou | 14.85 | 14.51 | 12.82 | 13.10 | 14.72 | 15.06 | 15.32 | 14.74 | 15.56 | 16.02 | 16.33 | 16.41 | 15.28 | 15.24 | 15.09 | 15.14 | 15.13 | 15.16 | 15.11 | 15.06 |
| Taizhou | 9.70 | 9.99 | 13.70 | 11.75 | 11.35 | 11.28 | 11.64 | 10.87 | 13.75 | 13.92 | 15.59 | 16.81 | 17.02 | 17.62 | 15.09 | 15.11 | 15.09 | 15.10 | 15.02 | 14.95 |
| Nantong | 16.01 | 16.47 | 16.86 | 17.27 | 18.44 | 19.12 | 20.13 | 21.03 | 21.34 | 21.18 | 21.86 | 23.12 | 24.01 | 24.59 | 25.20 | 25.24 | 25.21 | 25.22 | 25.15 | 25.08 |
| Zhenjiang | 4.84 | 5.26 | 5.38 | 5.41 | 6.02 | 5.79 | 5.92 | 6.10 | 6.39 | 6.57 | 6.64 | 6.89 | 7.09 | 7.30 | 7.41 | 7.42 | 7.41 | 7.42 | 7.40 | 7.39 |
| Xuzhou | 5.59 | 6.17 | 6.36 | 6.59 | 6.56 | 7.19 | 7.25 | 7.50 | 7.16 | 7.77 | 8.14 | 8.45 | 9.01 | 8.73 | 9.09 | 9.24 | 9.29 | 9.40 | 9.42 | 9.43 |
| Lian Yungang | 12.48 | 13.10 | 14.34 | 13.78 | 15.10 | 16.27 | 17.20 | 17.83 | 17.80 | 17.08 | 19.99 | 20.31 | 21.56 | 22.58 | 22.82 | 23.10 | 23.27 | 23.43 | 23.43 | 23.43 |
| Huaian | 8.68 | 7.81 | 7.28 | 6.86 | 6.56 | 6.80 | 7.06 | 7.13 | 6.92 | 10.08 | 10.62 | 11.64 | 12.51 | 13.36 | 14.28 | 14.47 | 14.58 | 14.67 | 14.58 | 14.49 |
| Suqian | 5.26 | 5.70 | 5.74 | 5.45 | 6.63 | 7.38 | 7.71 | 8.52 | 7.81 | 7.95 | 8.27 | 8.36 | 8.61 | 8.74 | 11.46 | 11.63 | 11.74 | 11.86 | 11.85 | 11.84 |
| Yancheng | 12.04 | 12.76 | 13.30 | 13.61 | 15.05 | 15.56 | 14.96 | 15.10 | 16.50 | 17.14 | 17.08 | 17.56 | 18.26 | 18.95 | 19.23 | 19.34 | 19.33 | 19.40 | 19.33 | 19.26 |
| Wuxi | 33.43 | 37.08 | 40.00 | 41.12 | 47.30 | 51.08 | 54.12 | 59.21 | 64.02 | 66.01 | 68.59 | 70.05 | 74.27 | 78.12 | 82.92 | 83.78 | 84.45 | 85.34 | 86.31 | 87.27 |
| Hangzhou | 10.41 | 11.70 | 12.10 | 12.33 | 12.79 | 13.18 | 14.03 | 14.46 | 14.55 | 16.03 | 16.41 | 16.71 | 16.72 | 16.33 | 15.10 | 15.30 | 15.46 | 15.73 | 16.13 | 16.54 |
| Huzhou | 13.95 | 14.25 | 14.50 | 15.77 | 15.75 | 16.20 | 17.08 | 17.74 | 18.54 | 19.34 | 19.90 | 20.58 | 21.52 | 21.81 | 21.85 | 21.96 | 21.95 | 22.06 | 22.14 | 22.22 |
| Taizhou | 14.16 | 16.78 | 17.33 | 18.63 | 18.81 | 17.18 | 18.79 | 59.86 | 21.43 | 22.03 | 23.15 | 24.54 | 25.54 | 25.79 | 25.85 | 25.98 | 26.00 | 26.11 | 26.22 | 26.33 |
| Zhoushan | 53.88 | 50.67 | 49.12 | 47.76 | 50.02 | 49.28 | 53.04 | 49.65 | 51.01 | 87.96 | 53.96 | 59.00 | 61.78 | 64.66 | 70.18 | 70.32 | 70.22 | 69.96 | 69.96 | 69.96 |
| Jiaxing | 10.27 | 11.67 | 13.60 | 14.66 | 15.81 | 16.34 | 17.05 | 18.49 | 19.27 | 20.77 | 21.90 | 23.20 | 24.59 | 24.50 | 24.28 | 24.43 | 24.53 | 24.71 | 24.99 | 25.27 |
| Ningbo | 38.50 | 39.65 | 41.61 | 42.71 | 43.71 | 43.09 | 40.54 | 34.82 | 38.25 | 39.73 | 40.94 | 41.47 | 41.56 | 41.35 | 41.44 | 41.70 | 41.89 | 42.21 | 42.64 | 43.07 |
| Shaoxing | 8.13 | 9.07 | 9.49 | 9.54 | 9.03 | 9.74 | 9.04 | 8.77 | 9.60 | 12.09 | 8.44 | 9.50 | 9.07 | 9.28 | 9.47 | 9.50 | 9.50 | 9.54 | 9.56 | 9.58 |
| Lishui | 4.48 | 4.67 | 4.89 | 4.98 | 5.08 | 5.12 | 6.13 | 6.13 | 4.01 | 3.61 | 3.69 | 3.79 | 3.88 | 3.99 | 3.84 | 3.87 | 3.88 | 3.90 | 3.91 | 3.93 |
| Quzhou | 8.38 | 8.86 | 9.26 | 9.72 | 10.15 | 10.60 | 10.81 | 10.79 | 11.77 | 12.87 | 13.22 | 14.58 | 15.29 | 14.74 | 15.09 | 15.18 | 15.22 | 15.26 | 15.29 | 15.32 |
| Jinhua | 7.60 | 6.67 | 13.22 | 7.11 | 7.50 | 7.49 | 7.67 | 7.27 | 8.32 | 8.47 | 9.01 | 9.18 | 9.83 | 10.03 | 9.70 | 9.73 | 9.80 | 9.86 | 9.94 | 10.02 |
| Wenzhou | 37.22 | 38.54 | 38.43 | 38.95 | 39.12 | 38.59 | 38.86 | 38.63 | 38.44 | 37.79 | 34.24 | 34.09 | 35.02 | 34.76 | 35.08 | 35.36 | 35.25 | 35.55 | 35.79 | 36.03 |
| Shanghai | 10.50 | 10.77 | 11.38 | 12.08 | 11.45 | 10.46 | 11.49 | 11.05 | 10.08 | 9.55 | 8.56 | 8.51 | 8.12 | 8.12 | 8.90 | 8.94 | 8.97 | 9.01 | 9.05 | 9.08 |
| Yangtze River | 14.55 | 15.01 | 16.06 | 16.12 | 16.77 | 17.04 | 17.60 | 19.15 | 18.22 | 20.09 | 19.14 | 19.91 | 20.59 | 21.17 | 21.52 | 21.69 | 21.76 | 21.92 | 22.05 | 22.17 |

Table 5. Index System of Natural Capital Utilization efficiency.

| | Index |
|---|---|
| Input index | Ecological footprint of cultivated lands per capita |
| | Ecological footprint of green lands per capita |
| | Ecological footprint of garden lands per capita |
| | Ecological footprint of waters per capita |
| | Ecological footprint of lands for construction per capita |
| Output index | GDP per capita |

deficit. After 2010, the growth rate of stock capital utilization slowed down, indicating that the effect of sustainable use of ecological resources has begun to appear.

## Evaluation of Natural Capital Utilization Efficiency

Natural capital utilization efficiency highlights the unity of economic value and environmental efficiency, that is, maximum economic value is achieved with minimum capital consumption. In the improved DEA model, profit and cost were taken as output and input indexes, respectively. In the present study, natural capital utilization was measured using an ecological footprint. To comprehensively reflect the natural capital utilization efficiency of the Yangtze River Delta region and its changes, an index system of natural capital utilization efficiency was constructed based on the ecological footprint of cultivated lands, green lands, garden lands, water, and land for construction per capita as an input index and GDP per capita as an output index (Table 5).

According to the improved DEA model, referenced related practices [34], with software DEAP 2.1, the natural capital utilization efficiencies of the 25 cities in the Yangtze River Delta region were obtained from 2000 to 2019, as shown in Table 6 .

Malmquist indexes fluctuate roughly between 0.8-1.2. Taking total factor productivity (tfpch) as an example, total factor productivity in 2006-2011 was low, about 0.8-0.9, and the rest were above 0.95.

From 2000 to 2019, the spatial distribution trend of natural capital utilization efficiency in the Yangtze River Delta urban has undergone significant changes. The natural capital utilization efficiency of urban agglomerations has gradually spread from high-value areas with Suzhou, Shanghai, and Hangzhou as the core to northern Jiangsu and southeastern Zhejiang. Shows a core-periphery structure.

Clustering and stratification are carried out according to the utilization rate of natural resources (Table 7). On the whole, the natural capital utilization efficiency

Table 6. Natural Capital Utilization Efficiency of the Yangtze River Delta Region from 2000 to 2019.

| Region | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shanghai | 0.596 | 0.694 | 0.761 | 0.773 | 0.783 | 0.95 | 0.576 | 0.562 | 0.499 | 0.488 | 0.414 | 0.528 | 0.566 | 0.586 | 0.543 | 0.575 | 0.512 | 0.496 | 0.545 | 0.477 | 0.596 |
| Nanking | 0.544 | 0.172 | 0.562 | 0.573 | 0.38 | 0.755 | 0.377 | 0.389 | 0.295 | 0.319 | 0.314 | 0.504 | 0.558 | 0.486 | 0.629 | 0.536 | 0.566 | 0.620 | 0.692 | 0.646 | 0.496 |
| Wuxi | 0.241 | 0.241 | 0.254 | 0.259 | 0.26 | 0.288 | 0.239 | 0.233 | 0.251 | 0.257 | 0.25 | 0.374 | 0.403 | 0.394 | 0.524 | 0.427 | 0.441 | 0.437 | 0.287 | 0.380 | 0.322 |
| Xuzhou | 0.045 | 0.063 | 0.072 | 0.077 | 0.08 | 0.096 | 0.074 | 0.091 | 0.093 | 0.085 | 0.121 | 0.16 | 0.152 | 0.085 | 0.222 | 0.099 | 0.106 | 0.114 | 0.051 | 0.134 | 0.101 |
| Changzhou | 0.511 | 0.232 | 0.364 | 0.219 | 0.218 | 0.236 | 0.254 | 0.321 | 0.274 | 0.279 | 0.27 | 0.406 | 0.394 | 0.302 | 0.403 | 0.312 | 0.330 | 0.343 | 0.284 | 0.338 | 0.315 |
| Suzhou | 0.289 | 0.406 | 0.586 | 0.5 | 0.667 | 0.667 | 0.464 | 0.528 | 0.605 | 0.572 | 0.445 | 0.645 | 0.71 | 0.783 | 0.84 | 0.713 | 0.680 | 0.553 | 0.589 | 0.455 | 0.585 |
| Nantong | 0.073 | 0.111 | 0.112 | 0.108 | 0.136 | 0.184 | 0.11 | 0.15 | 0.154 | 0.063 | 0.111 | 0.149 | 0.152 | 0.141 | 0.348 | 0.141 | 0.145 | 0.149 | 0.070 | 0.152 | 0.138 |
| Lianyungang | 0.042 | 0.046 | 0.047 | 0.035 | 0.034 | 0.04 | 0.03 | 0.04 | 0.036 | 0.085 | 0.041 | 0.063 | 0.067 | 0.04 | 0.103 | 0.043 | 0.045 | 0.048 | 0.038 | 0.052 | 0.049 |
| Huaian | 0.055 | 0.172 | 0.119 | 0.113 | 0.11 | 0.138 | 0.065 | 0.078 | 0.107 | 0.043 | 0.067 | 0.094 | 0.114 | 0.084 | 0.245 | 0.089 | 0.091 | 0.095 | 0.089 | 0.104 | 0.104 |
| Yancheng | 0.025 | 0.031 | 0.032 | 0.03 | 0.027 | 0.034 | 0.029 | 0.031 | 0.028 | 0.025 | 0.032 | 0.055 | 0.061 | 0.037 | 0.102 | 0.038 | 0.039 | 0.040 | 0.034 | 0.042 | 0.039 |
| Yangzhou | 0.152 | 0.3 | 0.304 | 0.3 | 0.299 | 0.376 | 0.192 | 0.311 | 0.214 | 0.11 | 0.406 | 0.366 | 0.373 | 0.266 | 0.636 | 0.273 | 0.286 | 0.294 | 0.182 | 0.305 | 0.297 |

Table 6. Continued.

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zhenjiang | 0.167 | 0.17 | 0.247 | 0.229 | 0.231 | 0.333 | 0.211 | 0.178 | 0.201 | 0.159 | 0.159 | 0.212 | 0.217 | 0.204 | 0.247 | 0.217 | 0.224 | 0.229 | 0.188 | 0.226 | 0.212 |
| Taizhou | 0.235 | 0.096 | 0.082 | 0.08 | 0.121 | 0.323 | 0.253 | 0.26 | 0.261 | 0.271 | 0.36 | 0.488 | 0.497 | 0.297 | 0.56 | 0.303 | 0.311 | 0.335 | 0.227 | 0.367 | 0.286 |
| Suqian | 0.072 | 0.075 | 0.076 | 0.062 | 0.061 | 0.072 | 0.063 | 0.063 | 0.067 | 0.067 | 0.084 | 0.124 | 0.133 | 0.077 | 0.146 | 0.077 | 0.079 | 0.083 | 0.062 | 0.091 | 0.082 |
| Hangzhou | 0.492 | 0.504 | 0.517 | 0.503 | 0.504 | 0.545 | 0.483 | 0.488 | 0.49 | 0.506 | 0.516 | 0.689 | 0.713 | 0.541 | 0.79 | 0.535 | 0.583 | 0.603 | 0.318 | 0.674 | 0.550 |
| Ningbo | 0.24 | 0.283 | 0.255 | 0.242 | 0.24 | 0.343 | 0.226 | 0.259 | 0.642 | 0.167 | 0.189 | 0.275 | 0.275 | 0.257 | 0.311 | 0.266 | 0.281 | 0.300 | 0.154 | 0.288 | 0.275 |
| Wenzhou | 0.229 | 0.229 | 0.242 | 0.21 | 0.204 | 0.298 | 0.208 | 0.231 | 0.196 | 0.177 | 0.191 | 0.295 | 0.273 | 0.205 | 0.294 | 0.211 | 0.232 | 0.247 | 0.086 | 0.249 | 0.225 |
| Jiaxing | 0.237 | 0.139 | 0.262 | 0.18 | 0.155 | 0.183 | 0.118 | 0.128 | 0.101 | 0.052 | 0.122 | 0.158 | 0.155 | 0.196 | 0.371 | 0.189 | 0.185 | 0.182 | 0.161 | 0.141 | 0.171 |
| Huzhou | 0.143 | 0.201 | 0.162 | 0.134 | 0.113 | 0.116 | 0.079 | 0.141 | 0.087 | 0.065 | 0.075 | 0.11 | 0.112 | 0.078 | 0.133 | 0.076 | 0.078 | 0.081 | 0.072 | 0.080 | 0.107 |
| Shaoxing | 0.177 | 0.176 | 0.184 | 0.165 | 0.161 | 0.198 | 0.172 | 0.2 | 0.187 | 0.159 | 0.185 | 0.246 | 0.232 | 0.155 | 0.22 | 0.163 | 0.171 | 0.182 | 0.160 | 0.178 | 0.183 |
| Jinhua | 0.12 | 0.173 | 0.193 | 0.212 | 0.223 | 0.283 | 0.228 | 0.277 | 0.223 | 0.155 | 0.167 | 0.217 | 0.19 | 0.143 | 0.199 | 0.145 | 0.150 | 0.159 | 0.212 | 0.153 | 0.191 |
| Quzhou | 0.077 | 0.098 | 0.105 | 0.102 | 0.103 | 0.126 | 0.097 | 0.145 | 0.106 | 0.084 | 0.097 | 0.125 | 0.107 | 0.07 | 0.102 | 0.074 | 0.079 | 0.082 | 0.070 | 0.075 | 0.096 |
| Zhoushan | 0.307 | 0.277 | 0.367 | 0.371 | 0.377 | 0.682 | 0.44 | 0.46 | 0.474 | 0.451 | 0.543 | 0.742 | 0.749 | 0.482 | 0.683 | 0.574 | 0.629 | 0.691 | 0.617 | 0.859 | 0.539 |
| Taizhou | 0.359 | 0.104 | 0.179 | 0.175 | 0.172 | 0.232 | 0.14 | 0.14 | 0.126 | 0.125 | 0.126 | 0.166 | 0.157 | 0.099 | 0.158 | 0.107 | 0.116 | 0.128 | 0.074 | 0.125 | 0.150 |
| Lishui | 0.121 | 0.171 | 0.183 | 0.185 | 0.182 | 0.225 | 0.179 | 0.186 | 0.206 | 0.194 | 0.255 | 0.351 | 0.36 | 0.187 | 0.381 | 0.207 | 0.218 | 0.227 | 0.199 | 0.228 | 0.222 |
| DMU | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Table 7. Hierarchical Cluster Analysis of Sustainable Development Trends in Cities.

| Hierarchy | Cities |
|---|---|
| First | Shanghai |
| Second | Suzhou, Hangzhou, Zhoushan, Nanjing |
| Third | Wuxi, Changzhou, Yangzhou, Taizhou, Ningbo, Wenzhou, Lishui, Zhenjiang, Shaoxing, Jiaxing, Taizhou |
| Fourth | Nantong, Huzhou, Huai'an, Xuzhou, Quzhou, Suqian, Lianyungang, Yancheng, Jinhua |

of cities in southern Zhejiang is slightly higher than that of cities in northern Jiangsu.

Shanghai ranks first and has the highest utilization efficiency of natural capital [35]. The second-tier cities include developed areas in southern Jiangsu and Zhejiang, such as Nanjing, Suzhou, Hangzhou, and Zhoushan. The relevant ecological footprint is maintained at a high level, and the utilization rate of natural capital is relatively high. These city's natural capital were effectively used and development sustainability was the best. The ecological footprint of such cities has increased with the development of the social economy, and ecological deviation has gradually expanded. However, the development model reflected the rationality of its economic structure and is worthy of attention [36].

Tier 3 and Tier 4 cities, including Lianyungang, Suqian, Yancheng, Jinhua, etc.. They are overloaded from the perspective of relative resource carrying capacity, and the per capita ecological footprint is increasing year by year. Their unreasonable industrial structure leads to low utilization of natural resources. Cities seek economic development at the expense of resource consumption. If cities continue to adopt this development model, a vicious circle will be formed. Combined with the above analysis, the industrial structure of these cities is unreasonable compared to economically developed regions [37].

From the perspective of time series, the natural capital utilization efficiency in cities shows four trends: "rapid growth," "steady growth," "steady decline," and "rapid decline."

Cities such as Suzhou, Xuzhou, Jinhua, Lishui are showing a rapid growth pattern. This is because these cities have better resource reserves and sufficient development momentum. The development foundation of these cities is relatively weak. In the early 20 years, these cities developed with relatively low natural capital utilization efficiency. However, with the support of the local government and the change in development concepts, the capital utilization efficiency has increased. Take Lishui as an example. As a 70% mountainous city, the transportation level is low. However, it has played the tourism function of ecological resources and increased the local GDP.

Cities such as Wuxi, Hangzhou, and Ningbo are showing a steady growth pattern. This is due to insufficient development of its urban hinterland. Twenty years ago, such cities were only medium and large cities. Although they have a good foundation for development, they are mainly driven by the radiation of super large cities. In recent years, with the continuous deepening of reform and opening up, especially Ningbo as a port city for foreign trade The role is gradually significant, and its resource utilization efficiency is also steadily improving. Due to the limited natural capital, their development only appears to be stable.

Cities such as Nanjing and Shanghai are in a steady decline mode, and their natural resource utilization deficits are serious, which has threatened urban development to a certain extent. These are mega cities and central cities that have been large in scale since 2000, and their capital utilization efficiency has always been relatively high. In recent years, they have gradually weakened with the consumption of urban resources. On the surface, the efficiency of their urban economic development has slowed down, but in fact these cities are seeking a structural balance within the city.

Cities such as Changzhou and Jiaxing belong to the rapid decline mode, which have severely ecological deficits during their development in the past 20 years. Since ancient times, these cities have abundant resource endowments, which may be the reason for their "higher starting." Since 2000, with the development of cities, the advantages of these cities have weakened, and the level of per capita GDP has dropped significantly, leading to

Table 8. Types Analysis of Sustainable Development Trends in Cities.

| Types | Cities |
|---|---|
| Rapid growth | Xuzhou, Suzhou, Nantong, Yancheng, Yangzhou, Lishui, Zhoushan |
| Steady growth | Wuxi, Lianyungang, Huai'an, Zhenjiang, Taizhou, Suqian, Ningbo, Hangzhou, Wenzhou, Quzhou, |
| Steady decline | Shanghai, Nanjing, Taizhou, Shaoxing |
| Rapid decline | Changzhou, Jiaxing, Taizhou, Huzhou |

a decline in the utilization rate of natural capital year by year. Of course, since 2014, affected by policies and ideas, such cities have also begun to explore the path of transformation.

## Analysis of Influencing Factors

To further explain its influencing factors, the present study used a spatial error model (SEM) for more in-depth research [39].

We used the three-dimensional ecological footprint with independent variables of population, per capita GDP, the ratio of primary industry added value to total output value, the ratio of secondary industry added value to total output value, tertiary industry added value to total output value, and fixed asset investment. The ratio of total retail sales of social consumer goods, park green area, domestic sewage treatment efficiency, and domestic waste innocuous treatment efficiency were used as explanatory variables for the spatial linear regression of natural capital utilization. The regression results are presented in Table 9.

Then, we obtained the results of the spatial model estimation between the natural capital utilization and 10 major influencing factors in the Yangtze River Delta:

$$\boldsymbol{EF} = 0.1884 - 0.0005\,\boldsymbol{X_1} - 0.0945\,\boldsymbol{X_2} - 9.3006 - X3 - 9.2353 - \boldsymbol{X_4} + 9.4219\,\boldsymbol{X_5} - 0.0002\,\boldsymbol{X_6} - 0.00002\,\boldsymbol{X_7} + 0.00002\,\boldsymbol{X_8} + 0.0009\,\boldsymbol{X_9} + 0.0122\,\boldsymbol{X_{10}} \quad (7)$$

The above results showed that the use of natural capital in the Yangtze River Delta was related to the total population (X1), GDP per capita (X2), primary industry value added (X3), secondary industry value added (X4), fixed asset investment (X6), and social factors. The total retail sales of consumer goods (X7) were highly positively correlated, whereas they were negatively correlated with the added value of the tertiary industry (X5), park green area (X8), domestic sewage treatment rate (X9), and treatment rate of domestic garbage (X10). Therefore, the main reasons for the continuous increase in the use of natural capital were social and economic factors, whereas the development of the tertiary industry, increase in green area, and the treatment rate of domestic sewage and garbage were conducive to the natural capital stock.

Table 9. Spatial error model estimation results.

| | SLM | | SEM | |
|---|---|---|---|---|
| VARIABLE | COEFFICIENT | P | COEFFICIENT | P |
| W_EF | 0.1484 | 0.0055 | 0.2690 | 0.0071 |
| CONSTANT | 0.2174 | 0.0397 | 0.1884 | 0.0101 |
| X1 | -0.0049 | 0.0048 | -0.0005 | 0.0093 |
| X2 | -0.1384 | 0.0040 | -0.0945 | 0.0056 |
| X3 | -10.2928 | 0.0117 | -9.3006 | 0.0114 |
| X4 | -10.2441 | 0.0119 | -9.2353 | 0.0118 |
| X5 | 10.4258 | 0.0114 | 9.4219 | 0.0111 |
| X6 | -0.0001 | 0.0054 | -0.0002 | 0.0034 |
| X7 | -0.000005 | 0.0095 | -0.000020 | 0.0082 |
| X8 | 0.000004 | 0.0080 | 0.000020 | 0.0092 |
| X9 | 0.0051 | 0.0061 | 0.0009 | 0.0027 |
| X10 | 0.0115 | 0.0027 | 0.0122 | 0.0074 |
| λ | | | -0.4603 | 0.0038 |
| ρ | 0.0572 | 0.0032 | | |
| LogLIK | 35.4631 | | 38.3468 | |
| R2 | 0.4352 | | 0.5747 | |
| AIC | -46.9262 | | -54.6935 | |
| SC | -32.2997 | | -41.2859 | |

## Results

Natural capital originates from research on sustainable development, and is the core issue of the theory of sustainable development. The present study used a three-dimensional ecological footprint model to calculate the flow and stock capital of 25 cities in the Yangtze River Delta from 2000 to 2019, and calculated the utilization efficiency of natural resources in the Yangtze River Delta. The sustainable development of natural capital in the Yangtze River Delta region was discussed over the past 20 years. The main conclusions found were as follows:

(1) According to the evaluation of the use of natural capital in the Yangtze River Delta, with 2014 as the boundary, the development of the Yangtze River Delta from 2000 to 2019 is divided into two stages. In the early stage, the rationality of the use of natural capital was poor, especially the excessive use of natural capital flows and the excessive use of stocks, causing serious ecological deficits and stock losses. During this period, economic and social development came at the expense of ecology. In the later period, the utilization of natural capital stocks decreased, the utilization of natural capital flows stabilized, the overall utilization of natural capital stabilized, and society began to enter the stage of sustainable development. Therefore, in the 20 years of rapid social development, the economic growth of the Yangtze River Delta has begun to move towards a recyclable, sustainable and efficient development path, and it currently plays an active role in carbon neutrality.

(2) The natural capital utilization efficiency mode in the Yangtze River Delta include "rapid growth," "steady growth," "steady decline," and "rapid decline." reflected the regional economic development. From the analysis of influencing factors, the city's natural capital utilization efficiency and its changes in the past 20 years are mainly affected by four factors: resource conditions, industrial structure, regional location, and policy factors.

– Resource conditions: Resources are the prerequisite for urban development. Cities with better innate resources are basically cities above the third type (Table 7). Of course, excessive natural capital also leads to overly conservative development in their development and is easy to degenerate. There is a trap that the natural capital utilization efficiency mode will be "rapidly reduced". For cities with poor natural resources, the natural capital utilization efficiency may be low in the early stage, such as Wenzhou, but with the change of development thinking, it will reduce dependence on natural capital, and instead participate in low-investment and high-yield industries such as finance and the Internet. The natural capital utilization efficiency will increase.
– Industrial structure: The efficiency of natural capital utilization were mainly affected by the industrial structure; i.e., the more developed the tertiary industry, the higher the utilization efficiency, and vice versa. The lower the utilization efficiency, the higher the strength. This is because the primary and secondary industries require a lot of capital during the production process, and circular economy and clean energy technologies have not yet been truly popularized, resulting in a low input-output ratio during economic development. The tertiary industry uses capital and human resources as its main elements, and have advantages of low resource consumption and environmental pollution, and huge potential economic benefits. In summary, the development of the tertiary industry is an effective way to improve the efficiency of natural capital utilization, and promote regional sustainable development.
– Regional location: From 2001 to 2011, the unfairness of natural capital flows increased and the distribution was unbalanced; from 2012 to 2015, the distribution of natural capital flows was highly unbalanced and the unfairness further intensified over time. During this period, the powerful groups (like province or Integrated city) in the region used existing economic resources to obtain excess profits, resulting in the unfair allocation of natural capital, which led to the spatial flow of natural capital to the advantageous groups. Therefore, the utilization of capital in central cities (such as capital cities or transportation hub) is high and efficient. Cities adjacent to the central city have good development of natural capital utilization due to the trickle-down effect, whereas, in areas far from the central city and connected to economic regions, the utilization rate of natural capital is low and most have high strength and low efficiency. However, inter-regional economic, technological, and talent flows might contribute to regional sustainable development. With the development of the social economy, the degree of agglomeration of cities with high utilization of natural capital in the Yangtze River Delta has weakened. This conclusion is similar to the existing conclusion "East is better and North is bad", and it has strong reference value [40].

(3) The change in the use of natural capital in the Yangtze River Delta mainly benefits from the regulatory role of the government.In the past 20 years, the government has launched a number of urban integration strategies, promoted the opening of coastal cities along the Belt and Road, and built high-speed railways in cities in the Yangtze River Delta. At the same time, it also proposed strategies such as supply-side reform, green water and green mountains, and so on to aim at adjusting the economic structure, realizing the optimal allocation of factors, and improving the quality and quantity of economic growth. Recently, discussions on carbon peaking and neutrality have also been placed on the agenda, and the country's requirements for regional sustainable development have been increasing. As the development pole of China, the Yangtze River Delta region has taken the lead in responding to policies and

appropriately slowing down the development speed. Also, its own development efficiency and natural capital flow to advantageous groups have improved. Therefore, during economic development, it is necessary to strengthen policy supervision and rationally guide the healthy development of the region.

## Discussion

### Strategies and Suggestions

From the analysis of the natural capital utilization efficiency of cities in the Yangtze River Delta region from 2000 to 2019, large differences were found among cities in terms of efficiency, and there was polarization in spatial distribution, indicating that the development of the ecological environment of the region was unsustainable, and the extensive utilization of resources, unbalanced social and economic development, and rapid industrialization and urbanization had significant effects on the efficiency of natural capital utilization. As Hu said, the use of natural capital affects urban ecological welfare [41], to improve the sustainability of regional development and relieve ecological stress, the following strategies are proposed:

(1) Promoting equitable development

Everyone has an equal right to consume resources. Therefore, resources must be used to improve people's living standards, create employment opportunities, and protect the environment instead of being used in industries that cause high pollution for economic purposes [42]. For example, as high-energy-consuming industries are in the interests of the minority, unequal energy consumption will ultimately make economic growth unsustainable. Therefore, in the process of development, it is necessary to strengthen policy supervision, reduce the polarization of the use of natural capital in the Yangtze River Delta, promote the transformation of urban industries from single to multiple, and guide the sustainable development of the region.

(2) Constructing a resource-saving production system.

– Adjust and improve the agricultural structure and construct distinctive and ecological agriculture in agricultural zones. Improve agricultural labor productivity using agricultural technologies. Minimize the chemical fertilizers applied during agricultural production and reduce the dependence of rural fuels on coal, thus creating energy saving and environmentally friendly countries [43].
– Appropriately reduce the proportion of secondary industries and promote the construction of eco-industrial parks in the cities of northern Jiangsu and Zhejiang. Focus on the promotion of clean production and the development of a circular economy. Increase technological investment, and develop new resource-saving processes and technologies; driving the implementation of water-saving, energy saving, and resource recycling projects; and promoting the application of new materials to speed up the realization of low input, low energy-consuming, and low-emission economic growth of core regions in the Yangtze River Delta [44].
– Step up efforts to develop a tertiary industry. With the main element of human capital, the tertiary industry has the advantages of low resource consumption and environmental pollution, and huge potential economic benefits. Natural capital utilization efficiency can be improved by developing service industries, such as tourism, business, and education [45].

(3) Increasing investment in natural capital

In addition to regular environmental governance, forest cultivation, natural protection, farmland protection, and landscape improvement must be strengthened to contribute to the development of natural productivity. For example, improving the ability of the ecosystem to bear environmental stress via the maintenance and improvement of the wetland ecosystem and enhancement of its self-cleaning capacity. Also, the high-dimensional development of rural agriculture should be boosted basing on comprehensive and extensive investment in rural agriculture, the productivity of natural landscapes and rural scenery should be improved rapidly, and the service consumption-focused high value added industries should be developed , such as leisure, educational, and experiential agriculture.

### Deficiencies and Prospects

To fill the gap in the quantitative measure of natural capital utilization efficiency in domestic and overseas research on natural capital, the present study conducted research using an index system. We have innovatively studied the utilization efficiency of natural capital from the perspectives of flow and stock, and discover the changing law of urban natural capital utilization efficiency from the time series. This method also has certain applications in the efficiency of tourism development [46, 47]. Although the result demonstrates many opinions, due to time limitations and the author's academic level, there are many deficiencies, and further research and discussion are required.

Due to the limited data availability and quality in the natural capital evaluation analysis, the index of energy land was removed from the study; however, it is very important in the analysis, making the comprehensive evaluation of regional sustainable development imperfect.

Natural capital utilization efficiency is a variable that involves various factors, and there are many deficiencies due to index simplification. Therefore, future multi-perspective and comprehensive research is required to promote the theory of natural capital and sustainable development. It is difficult to find a suitable way to expand the analysis throughout the entire region for some ecological service indexes. Therefore, continuous attention should be applied.

## Acknowledgments

This research was supported by the National Natural Science Foundation of China. (No.41671140).

Fund: "Postgraduate Research & Practice Innovation Program of Jiangsu Province"

## Conflict of Interest

The authors declare no conflict of interest.

## References

1. ZENG M.X., RUI-JUN W.U., ZHANG S.Y. Research on New Situation of Chinese Population Redistribution and Its Socio-economic Effects Based on Analysis of Chinese Sixth Census Data [J]. Population Journal, **2013**.
2. SONG Y., CHANG R.Y., YU Z.D., WANG R.Q., LIU J. The Relationship between Ecosystem Health and Ecological Safety [J]. Applied Mechanics & Materials, 260-261: 781-785, **2013**.
3. NEWS B. China Seen Reaching Peak Carbon Emissions by 2030: Study [J]. International environment reporter, **40** (24), 1212, **2017**.
4. CHEN X., SHUAI C., WU Y., ZHANG Y. Analysis on the carbon emission peaks of China's industrial, building, transport, and agricultural sectors [J]. Science of The Total Environment, 709, 135768, **2019**.
5. PEARCE D., BARIER E., MARKANDYA A. Blueprint for a Greeen Economy: A Report for the UK Department of the Environment [M]. Earthscan Publications. London. 43, **1989**.
6. PEZZEY J. Economic Analysis of Sustainable Growth and Sudtainable Development [M]. Washington DC; World Bank. 88, **1990**.
7. DALY H.E. Beyond Growth:the Economics of Sustainable Development [M]. Boston: Beacon Press, **1996.**
8. PEARCE D. Economics, Equity and Sustainable Development [J]. Futures (RU), 20, **1988**.
9. SOLOW R.M. On the Intergenerational Allocation of Natural Resources [J]. THe Scandinavian Journal of Economics, **88** (1), 141, **1986**.
10. LIU P.Y. Alternative Study of Natural Capital [D]. Shanghai: Fudan University, **2008**.
11. QIU R., YAO J.J. Natural Capital Theory: Theory of Sustainable Development[J]. Henan Social Sciences, **10** (1), 43, **2002**.
12. ZHU D.J. C model: China's development under the scarcity of natural resources [J]. Social Watch (Shanghai), **5** (16), **2006**.
13. WEITZMAN M.L. Sustainability and Technical Progress [J]. Scandinavian Journal of Economics, **99** (1), 1, **1997**.
14. VITOUSEK P.M., EHRLICH P.R., EHRLICH A.H., MATSON P.A. Human appropriation of the products of photosynthesis.[J]. **36** (6), 368, **1986**.
15. EHRLICH P.R. Human carrying capacity, extinction, and nature reserves [J]. Bioscience, **32** (5), 331, **1982**.
16. ODUM H.T. Self-organization, transformity, and information [J]. Science, **242** (4882), 1132, **1988**.
17. REES W.E. Ecological footprint and appropriated carrying capacity: What urban economics leaves out [J]. Environment and Urbanization, **4** (2), 121, **1992**.
18. WACKERNAGEL M., ONISTO L., BELLO. National natural capital accounting with the ecological footprint concept [J]. Ecological Economics, **29** (3), 375, **1999**.
19. FANG K. With the depth and breadth of ecological footprint: a new index for constructing three-dimensional model [J]. Journal of Ecology, **33** (1), 267, **2013**.
20. FANG K., GAO K., LI H.C. Analysis of Natural Capital Utilization Based on Three-dimensional Ecological Footprint Model Optimization [J]. Geographical Research, **32** (9), 1657, **2013**.
21. FANG K., LI H.Cg. Under the Construction of Natural Capital Utilization in China Based on the Depth and breadth of Ecological Footprint [J]. Journal of Natural Resources, **27** (12), 1995, **2012**.
22. FANG K. Spatial pattern change of natural capital utilization in G20 countries from 1999 to 2008 [J]. Resource Science, **36** (4), 793, **2014**.
23. JIN X., LI X., FENG Z., WU J., WU K. Linking ecological efficiency and the economic agglomeration of China based on the ecological footprint and nighttime light data [J]. Ecological Indicators, **111**, 106035, **2020**.
24. ZHANG X., SUN D., ZHANG X., YAN H. Regional ecological efficiency and future sustainable development of marine ranch in China: An empirical research using DEA and system dynamics [J]. Aquaculture, 736339, **2021**.
25. WU F., YANG X., SHEN Z., BIAN D., BABUNA P. Exploring sustainability and decoupling effects of natural capital utilization in China: Evidence from a provincial three-dimensional ecological footprint [J]. Journal of Cleaner Production, **295** (2), 126486, **2021**.
26. WU C.Y., WEI Y.H., HUANG X.J., DENNIS WEI, XIANJIN Economic transition, spatial development and urban land use efficiency in the Yangtze River Delta, China [J]. Habitat International, **63**, 67, **2017**.
27. SU X.U., ZHANG Y., DOU M., HUA R., ZHOU Y. Spatial distribution of land use change in the Yangtze River Basin and the impact on runoff [J]. Progress in geography, **36** (4), **2017**.
28. FANG Y.L., HUANG Z.F., YU F.L. Evaluation of relative efficiency of inter-provincial tourism resources[J]. Geographical Science, **33** (11), 1354, **2013**.
29. TAO X.M. A Study on City Efficiency Based on the Resources View: A Case of 16 Cities of Yangtze River Delta [J]. China Population, Resources and Environment, **2013**.
30. CHEN C.Z., LIN Z.S. Changes of per capita ecological footprint in China from 1961 to 2005 [J]. Journal of Ecology, **28** (1), 338, **2008**.
31. CASTELLANI V., SALA S. Ecological Footprint and Life Cycle Assessment in the sustainability assessment of tourism activities [J]. Ecological Indicators, **16**, 135, **2012**.
32. NICCOLUCI V., BASTIANONI S., TIEZZI E., WACKERNAGEL M., MARCHETTINI N. How deep is the footprint? A 3D representation [J]. Ecological Modelling, **220** (20), 2819, **2009**.
33. YANG Q.K., DUAN X.J., WANG L. Mechanism of interaction between urban land expansion and ecological environment effects in the Yangtze River Delta [J]. Progress in Geography, **40** (2), 220, **2021**.
34. LI P.X. Investigation of spatial pattern and influencing factors of carbon ecological efficiency in Pan-Yangtze

River Delta [J]. Acta Ecologica Sinica, **38** (23), 8500, **2018**.
35. SUN G.N., KANG G.D. A spatial dislocation analysis of natural capital, human capital and economic capital in the mainland China [J]. Studies in Science of Science, **27** (01), 59, **2009**.
36. ZANG Y.Z., PENG H., ZHOU S.L., et al. Evaluation on the spatial differentiation of land ecological quality and its coordination with economic development in south Jiangsu [J]. Research of Soil and Water Conservation, **22** (03), 188, **2015**.
37. ZHANG Y.J., MA J. Research on coordination development of ecological-environment and economy in north Jiangsu based on coupling degree model [J]. Environmental Science and Technology, **29** (03), 11, **2016**.
38. WANG H.F., LI J.L., TIAN P., et al. Spatial and temporal evolution of natural capital in typical island cities and driving force [J]. Marine Science Bulletin, **39** (05), 521, **2020**.
39. CARLISLE B.H. Modelling the spatial distribution of DEM error [J]. Transactions in Gis, **9** (4), 521, **2010**.
40. YANG T.B., ZHU Y.M., WANG N., et al. Regional differences and spatial convergence of urban ecological efficiency in the Yangtze River Delta [J]. East China Economic Management, **34** (7), 28, **2020**.
41. WEI H., MENG N., LE L.I. China's Strategies and Policies for Regional Development During the Period of the 14th Five-Year Plan [J]. Chinese Journal of Urban and Environmental Studies: 2050008, **2020**.
42. HU M.J., LI Z.J., DING Z.S., et al. Urban ecological well-being intensity and driving mode based on three-dimensional well-being: Taking the Yangtze Delta as an example [J]. Journal of Natural Resources, **36** (2), 327, **2021**.
43. WANG Y., LIN W., QIAN W. Green Growth: Constructing a Resource-Saving and Environment-Friendly Production Pattern [M]. Springer Berlin Heidelberg, **2012**.
44. YUAN Y., JIN M., REN J., et al. The Dynamic Coordinated Development of a Regional Environment-Tourism-Economy System: A Case Study from Western Hunan Province, China [J]. Sustainability, **6** (8), 5231, **2014**.
45. FANG J., CHAO Y. Empirical Research on the Contribution of Human Capital to the Development of Tertiary Industry in Shandong Province [J]. **2015**.
46. GUO X.Y., MU X.Q., MING Q.Z. Spatio-temporal coupling evolution of regional tourism development efficiency and tourism development intensity – a case study of Yangtze River Economic Belt [J]. Journal of Yunnan Normal University, **37** (6), 65, **2017**.
47. LU B.Y., MING Q.Z., Spatio-temporal coupling evolution o tourism development efficiency and tourism development intensity: a case study of Yunnan Province [J]. Ecological Economy, **35** (1), 131, **2019**.