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# Spatial-temporal evolution of industrial land transformation effect in eastern China

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The study of industrial land transformation effect is of great significance for promoting the sustainable and healthy development of the industrial economy. This paper adopts panel data of 10 provinces in eastern China from 2008 to 2020, constructs an indicator system including five dimensions on the premise of clarifying industrial land transformation and applies the comprehensive evaluation method of gray relational theory to measure its effect. The results show that: 1) overall, industrial land transformation effect in the eastern region shows a good development trend but there are gaps between different provinces, which have been expanding over time in the extreme values. 2) At the provincial level, in terms of industrial land transformation effect, Beijing, Shanghai, Guangdong, and Jiangsu are in the leading positions; Zhejiang, Fujian, and Hebei are in the middle positions; and Tianjin, Hainan and Shandong are slightly behind. 3) At the dimensional level, Industrial land development dimension and industrial land employment dimension generally show a good trend; the spatial pattern of industrial land optimization dimension and environmental pollution control dimension does not change significantly with most provinces at a low level; development conditions support dimension shows a positive spatial trend, indicating that each province attach importance to infrastructure construction and scientific technological progress, creating positive conditions for industrial land transformation. Overall, the results identify whether industrial land in eastern China is being used rationally, which has practical implications for promoting industrial structure upgrading, scientific and technological progress and ecological environment improvement.

KEYWORDS

**industrial land, transformation effect, spatial-temporal evolution, eastern region, China**

# 1 Introduction

Industrialization is a key driver of economic growth and urbanization and the rapid development of industry in China has helped to accelerate the country's modernization and to become a major force in driving global economic growth. As industrialization progresses, a continued supply of large areas of industrial land will be required to further support industrial economic output (Wang et al., 2018; Liu R. et al., 2022). In the early land finance model, local governments advocated investment in land and many industrial parks or development zones were built, making industrial land occupy a larger proportion of urban construction land (Chen et al., 2018; Liu et al., 2018; Wang Q. et al., 2021). However, despite the positive impact of industrial land expansion on the development of urban economic benefits, the one-sided pursuit of total crossover has led to inefficient use of industrial land, idle waste, environmental pollution and other problems (Chen et al., 2020; Li et al., 2021; Li K. et al., 2022), which also makes the mismatch between land supply and demand increasingly serious (Cheng et al., 2021). Currently, China's economic development model is changing from high quantity to high quality and industry is also beginning to change from traditional sloppy development to intensive development. The traditional model of expanding industrial land area to increase economic output is unsustainable and the intrinsic value of industrial land must be tapped through resource optimization to improve the quality of industrial land (Gao et al., 2018; Gao et al., 2021; Yang et al., 2022). The eastern region of China with its early start and high level of industrialization is the "leading goose" of China's industrial economic development but it is also facing the pressure of rapidly rising factor costs, relatively insufficient resource endowments, and the expansion of industrial relocation (Li et al., 2019; Liu et al., 2021). Considering the government's emphasis on strengthening the planning and intensive use of industrial land stock, some industrial land is still allocated to low-capacity, low-efficiency, high-pollution, high-energy-consumption projects; therefore, land efficiency needs to be improved and transformation and development is urgent.

"Transformation" refers to the transition process of changing from one movement form to another by changing the intrinsic nature or external form of things to promote their development in a better direction. In recent years, economic transformation, mainly the transformation of development subject, model and structure, has been the focus of scholars' attention (Ma et al., 2018; Yang et al., 2018; Dong Y. et al., 2020; Kurnia et al., 2022). Around the development concept of innovation, coordination, greenness, openness, and sharing in the new era, industrial land transformation needs to balance economic, social and ecological benefits (Wu et al., 2020; Wang J.-C. et al., 2021; Pu et al., 2021). Due to the scarcity of urban land resources, industrial land transformation relies more on the tapping of existing land through the transformation of traditional industries and the development of new industries to adjust the industrial structure and improve land efficiency (Zhang et al., 2018; Jiang, 2021). Based on this, this study considers that the "transformation" of industrial land is a kind of gradual structural transformation of industrial land development with the fundamental goal of improving its comprehensive utilization efficiency, guided by the upgrading of industrial structure and effective management of industrial pollution. It can promote the efficiency of industrial land, accelerate the structural adjustment of industrial development factors, improve the level of industrial labor force knowledge and the industrial land infrastructure system, and finally promote high-quality industrial development. Industrial land transformation development is an effective means to promote intensive land use (Chen and Wang, 2022; Cheng, 2022). In this context, has industrial land transformation achieved the expected effect? What are the spatial-temporal characteristics of the industrial land transformation effect? Answering the above questions has a guiding role in promoting the sustainable and healthy development of the industrial economy.

To rationalize the use of land resources and promote industrial land transformation and development, scholars in China and globally have conducted extensive research (Ahmad et al., 2019; Gao et al., 2021). In some developed countries, such as the United States and those within the European Union, research mainly focuses on industrial land redevelopment and remediation and has accumulated relatively rich research results (Green, 2018; Martinat et al., 2018; Ustaoglu et al., 2020). Through the renovation of old industrial areas, developed countries have gradually explored a path that suits their economic development and environmental protection to achieve the goals of revitalizing regional economies and improving land use efficiency and environmental quality. However, considering the rapid industrialization of developing countries, especially China, scholars have increasingly focused their attention on China (Pan and Song, 2017; Dong L. et al., 2020; Li L. et al., 2022; He and Tang, 2022), the world's second largest economy. China's industrial land area has expanded massively in recent decades and industrial development has accomplished a series of important achievements but the problems caused by the uncontrolled expansion of industrial land have also had certain negative effects (Song et al., 2018; Sun et al., 2020). Therefore, relevant studies are devoted to exploring the aspects of industrial land transformation to optimize the quality of land use. Specifically, scholars mainly evaluate the efficiency of industrial land use in the context of transformation (Chen et al., 2019, 2022; Yan et al., 2020), focusing on industrial green development, land use evaluation and industrial land efficiency. To discover which factors play a driving role in the process of transformation, scholars also analyze the dynamics driving industrial land transformation (Shu et al., 2018; Xia et al., 2020; Yue et al., 2022), involving economics, policy, and environmental protection. In addition, some studies have attempted to clarify the game relationships among various interests such as government, enterprises, and residents in the process of industrial land transformation to achieve a balance of interests among different property rights subjects (Gao and Chen, 2020; Lai et al., 2020; Wu et al., 2020).

In conclusion, academic research into industrial land transformation has increased (Arabsheibani et al., 2016; Chan et al., 2019; Hu et al., 2019), which has laid a good research foundation for this paper. However, most of the above studies emphasize the economic benefits of transformation and pay less attention to its non-economic benefits, which makes it difficult to identify whether it meets the requirements of intensive and sustainable use. Therefore, this study innovatively constructs a multi-dimensional evaluation indicator system that integrates economic, social and ecological benefits to measure the industrial land transformation effect in 10 provinces in eastern China. The objectives of this study are as follows: 1) to obtain the industrial land transformation scores of each province by constructing an indicator system and weighting them. 2) To apply kernel density estimation to analyze the evolutionary trend of the overall industrial land transformation effect. 3) To explore the spatial-temporal evolution characteristics of industrial land transformation effect in each province based on ArcGIS spatial analysis technology and provide references and suggestions for the subsequent guidance of healthy and sustainable development of industrial economy in each province. The rest of the paper is structured as follows: the second part explains the selection of indicators and the research methodology and the regression results are given in the third part. Then, we discuss the mechanism of industrial land transformation, propose the transformation development, and give the prospect of future research in the fourth part. Finally, the full text is summarized in the fifth part.

# 2 Materials and methods

## 2.1 Indicator selection

Industrial land transformation effect refers to the expected effect obtained by the industrial industry in changing the original development model and progressive adjustment and reform. The expected effect of transformation contains several aspects such as industrial structure, development conditions, employment status, resource utilization, and ecological environment (Sun and Yuan, 2015; Tang and Hu, 2021; Tian et al., 2021). In the "Proposal of the Central Committee of the Communist Party of China on Formulating the Thirteenth Five-Year Plan for National Economic and Social Development", innovative development, green development, coordinated development, open development, and shared development centrally reflect the laws of economic and social development, which is a major innovation of China's development theory. By linking industrial land transformation and new development theories, we believe that industrial land transformation should focus on systematic development and different measurement perspectives exist. On this basis, this study proposes five dimensions and 17 quantitative indicators (Table 1) to measure industrial land transformation effect by drawing on existing literature (Chen and Zhou, 2017; Liu H. et al., 2022; Li Q. et al., 2022; Pu and Zhang, 2022) and the actual development of industrial land in China.

1) Industrial land development dimension. Reflecting the scale of economic development of industrial land in a region, it mainly highlights the total amount of its economy and the degree of its contribution to regional development.
2) Industrial land optimization dimension. Reflecting the characteristics of industrial land industrial structure upgrading in the process of transformation, it mainly highlights its technicalization, coordination, low energy consumption and higher management level.
3) Industrial land employment dimension. Reflecting the social drive of industrial land transformation, combining the mutual influence of industrial land transformation and industrial employment, it mainly highlights the prospect of industrial employment and the degree of specialization in the transformation process.
4) Development conditions support dimension. This reflects two aspects that support the industrial land transformation, in which research and technology are the driving force for the transformation and upgrading of industrial land and infrastructure is the condition for the development of modern industrial industry.
5) Environmental pollution control dimension. This reflects the impact of industrial land transformation on the ecological environment and the importance of green development of industrial land by the emission of the three types of industrial waste (waste gas, waste water, and industrial residue).

## 2.2 Methods

### 2.2.1 Gray relational analysis

Gray relational analysis can find the numerical relationship between factors and the application of this theory to assign weights to the indicator system of industrial land transformation effect has no special requirements on the number and category of samples. Moreover, the calculation is convenient and the quantitative results are reliable.

**Step 1.** Average the data to make it dimensionless.

$$X_i'(k) = X_i(k) \Big/ \frac{1}{n}\sum_{k=0}^{n} X_i(k)_i, \mathrm{i} = 1, 2, \cdots, \mathrm{m}; \mathrm{k} = 0, 1, \cdots, \mathrm{n} \tag{1}$$

TABLE 1 Indicator system for measuring industrial land transformation effect.

| | Dimension | Indicator | Indicator calculation |
|---|---|---|---|
| Indicator system for measuring industrial land transformation effect in the eastern province | Industrial land development dimension | Industrial land economic density $X_1$ | Total industrial assets/industrial land area |
| | | Industrial land growth density $X_2$ | Gross industrial product/industrial land area |
| | | Industrial industry contribution $X_3$ | Gross industrial product/regional gross domestic product (GDP) |
| | Industrial land optimization dimension | Proportion of industrial technology $X_4$ | High-tech industry main business income/ industrial enterprises main business income |
| | | Comprehensive industrial energy consumption $X_5$ | Total energy consumption/gross industrial product |
| | | Industry comparative labor productivity $X_6$ | Proportion of gross industrial product/ proportion of industrial labor force |
| | | Proportion of output value of foreign-invested enterprises (including Hong Kong, Macao and Taiwan-invested) $X_7$ | Total industrial assets of foreign-invested enterprises/total industrial assets |
| | Industrial land employment dimension | Industrial land employment density $X_8$ | Number of industrial employees/industrial land area |
| | | Industrial employment specialization $X_9$ | Number of personnel in R&D institutions of industrial enterprises/number of industrial employees |
| | | Industrial industry employment elasticity $X_{10}$ | Employment growth rate/production value growth rate |
| | Development conditions support dimension | Industrial land infrastructure investment $X_{11}$ | Industrial fixed assets investment/industrial land area |
| | | Industrial technology R&D investment $X_{12}$ | Expenditure on R&D institutions of industrial enterprises/main business income of industrial enterprises |
| | | Density of scientific research institutions in industrial land $X_{13}$ | Number of R&D institutions in industrial enterprises/industrial land area |
| | | Quality of industrial science and technology personnel $X_{14}$ | Proportion of industrial enterprises with master's degree or above in scientific research institutions |
| | Environmental pollution control dimension | Industrial wastewater emissions $X_{15}$ | Industrial wastewater emissions/industrial land area |
| | | Industrial smoke (dust) emissions $X_{16}$ | Industrial smoke (dust) emissions/ industrial land area |
| | | Industrial sulfur dioxide emissions $X_{17}$ | Industrial sulfur dioxide emissions/ industrial land area |

**Step 2.** Calculate the absolute difference between the comparison series and the reference series.

$$\Delta i(k) = |X_i(k) - X_i(0)| \tag{2}$$

**Step 3.** Calculate the bipolar minimum difference and maximum difference.

$$\Delta_{\max} = \max_i \max_k \Delta i(k), \ \cdot \Delta_{\min} = \min_i \min_k \Delta i(k) \tag{3}$$

**Step 4.** Calculate the correlation coefficient.

$$r_i(j) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta i(k) + \zeta\Delta_{\max}} \tag{4}$$

Where $\zeta$ is the resolution coefficient, usually taken as 0.5.

**Step 5.** Find the correlation degree.

$$R(k) = \frac{1}{n}\sum_{i=1}^{m} r_i(k) \tag{5}$$

Calculate the factor correlation degree of each indicator and obtain the gray correlation weight value $w_i$ for each indicator after normalization.

### 2.2.2 Linear weighting method

On the basis of obtaining the weight $w_i$ of each indicator, the study uses linear weighting method to obtain the industrial land transformation score and sub-dimensional transformation score to measure the transformation effect and variability of different provinces.

We first normalized the data. Different evaluation indicators often have different scales, and the values differ greatly from each other, which will affect the results of data analysis if they are not processed. In order to eliminate differences in magnitude and range of values between indicators, standardization is needed to scale the data to fall into a specific region for comprehensive analysis. The study was processed using the minimum-maximum normalization method with the following equation.

$$y* = \frac{y - \min}{\max - \min} \tag{6}$$

where y* is the data normalized value corresponding to the index, y is the original data value corresponding to the index, min is the minimum value of the original data value of each index, and max is the maximum value of the original data value of each index. After the minimum-maximum normalization method is processed, the data normalized values are mapped within 0–1.

Then, we used the linear weighting method to calculate the industrial land transformation effect score and the sub-dimension transformation effect score based on the weights of each indicator and the standardized values of the data.

$$Z_j = \sum_{i=1}^{n} W_i y_i \tag{7}$$

Where $i$ is the value of all indicators, $Z_j$ is the comprehensive score of industrial land transformation effect of the $j$ province; the value of $i$ is the dimensional indicator, $Z_j$ is the dimensional transformation score of the $j$ province; and $y_i$ is the data standardized value corresponding to the indicators. In addition, since the standardized values of the data mapped within 0–1, the linearly weighted data results had small values, making it difficult to identify their differences, so a 10-fold value was assigned to the industrial land transformation effectiveness score to better compare the transformation effectiveness of different provinces.

### 2.2.3 Kernel density estimation

Kernel density estimation is a common method to study the characteristics of data distribution and is generally compared with the help of graphs. Its estimation takes the following form.

$$f(x) = \frac{1}{hN} \sum_{i=1}^{N} \eta \left( \frac{X_i - \bar{X}}{h} \right) \tag{8}$$

Where $h$ is the bandwidth; $\bar{X}$ is the mean value; and $\eta$ is the kernel function. With the help of Stata 14.0 software, a two-dimensional plot of the kernel density curve is drawn with the sample points of the composite score of industrial land transformation effect to analyze the evolution pattern of industrial land transformation effect.

## 2.3 Study area

Facing the transformation of China's economic development mode from high growth to high quality, the Chinese government emphasizes that the eastern region should take advantage of its strong basic conditions and concentration of innovation factors to accelerate the cultivation of world-class advanced manufacturing clusters in order to help enhance economic output efficiency, innovation capacity and growth capacity. From the perspective of industrial development, the eastern region is facing the pressure of industrial relocation, structural upgrading and land efficiency, but also has the elemental conditions to better support the transformation of industrial land, and the implementation of industrial land transformation is of practical significance. With the implementation of the transformation of industrial land in the eastern region, this study can test whether the level of regional transformation development has achieved the expected effect and provide experience for the subsequent transformation development of other regions. This study takes 10 provinces (cities) in the eastern region (excluding Hong Kong, Macao, and Taiwan), namely Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan, as the research sample (Figure 1) and adopts 2008–2020 as the research interval to establish an indicator system to measure industrial land transformation effect. The data come from the *China Statistical Yearbook* (2009–2021), the *China City Statistical Yearbook* (2009–2021), and the *China Industrial Statistical Yearbook* (2009–2021).

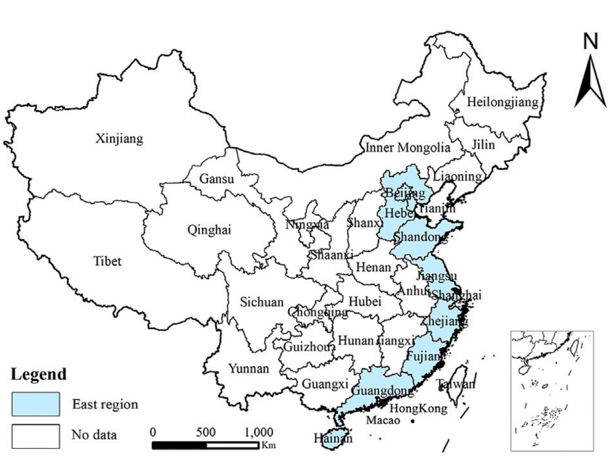


FIGURE 1
The location of study area.

# 3 Results

## 3.1 Scores of industrial land transformation effect

Scores of industrial land transformation effect in 10 provinces were calculated by using the weighted linear law

TABLE 2 Scores of Industrial land transformation effect in eastern provinces (2008–2020).

| Province | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beijing | 2.42 | 2.46 | 2.58 | 2.71 | 2.74 | 2.75 | 2.97 | 3.19 | 3.39 | 4.04 | 4.38 | 4.61 | 4.87 |
| Tianjin | 2.89 | 2.79 | 2.91 | 3.08 | 3.23 | 3.32 | 3.17 | 3.13 | 2.93 | 2.44 | 2.49 | 2.77 | 2.91 |
| Hebei | 2.51 | 2.47 | 2.53 | 2.81 | 3.22 | 3.44 | 3.53 | 3.20 | 3.08 | 3.37 | 3.10 | 3.43 | 3.62 |
| Shanghai | 3.04 | 2.81 | 2.86 | 2.79 | 2.79 | 2.84 | 2.75 | 2.86 | 2.97 | 2.30 | 3.54 | 3.66 | 4.37 |
| Jiangsu | 2.89 | 2.92 | 3.00 | 3.10 | 3.69 | 3.71 | 3.72 | 3.66 | 3.75 | 3.80 | 3.87 | 4.07 | 3.86 |
| Zhejiang | 2.72 | 2.56 | 2.68 | 2.81 | 2.99 | 3.00 | 2.97 | 3.11 | 3.27 | 3.31 | 3.38 | 3.45 | 3.75 |
| Fujian | 3.15 | 3.07 | 3.10 | 3.10 | 3.25 | 3.34 | 3.35 | 3.37 | 3.54 | 3.32 | 3.39 | 3.33 | 3.44 |
| Shandong | 2.51 | 2.52 | 2.49 | 2.52 | 2.64 | 2.71 | 2.61 | 2.48 | 2.66 | 2.73 | 2.38 | 2.19 | 2.46 |
| Guangdong | 3.42 | 3.17 | 3.27 | 3.62 | 3.68 | 3.55 | 3.39 | 3.49 | 3.66 | 3.93 | 4.13 | 4.15 | 4.32 |
| Hainan | 2.79 | 2.58 | 2.71 | 2.97 | 2.99 | 3.32 | 3.30 | 2.57 | 2.66 | 2.78 | 2.91 | 2.95 | 2.69 |
| Average score | 2.84 | 2.74 | 2.81 | 2.95 | 3.12 | 3.20 | 3.18 | 3.11 | 3.19 | 3.30 | 3.36 | 3.46 | 3.63 |

TABLE 3 Scores of Industrial land transformation effect in different dimensions (2008–2020).

| | Industrial land development dimension | | Industrial land optimization dimension | | Industrial land employment dimension | | Development conditions support dimension | | Environmental pollution control dimension | |
|---|---|---|---|---|---|---|---|---|---|---|
| Province | 2008 | 2020 | 2008 | 2020 | 2008 | 2020 | 2008 | 2020 | 2008 | 2020 |
| Beijing | 0.22 | 0.60 | 0.67 | 1.13 | 0.64 | 0.89 | 0.42 | 0.88 | 0.48 | 1.37 |
| Tianjin | 0.96 | 0.58 | 0.76 | 0.71 | 0.81 | 0.68 | 0.28 | 0.53 | 0.09 | 0.41 |
| Hebei | 0.89 | 1.32 | 0.57 | 0.36 | 0.82 | 0.93 | 0.21 | 0.92 | 0.02 | 0.09 |
| Shanghai | 0.50 | 0.51 | 1.03 | 0.97 | 0.58 | 1.11 | 0.65 | 0.86 | 0.28 | 0.92 |
| Jiangsu | 0.79 | 1.02 | 0.89 | 0.83 | 0.89 | 0.97 | 0.28 | 0.90 | 0.04 | 0.13 |
| Zhejiang | 0.82 | 0.95 | 0.43 | 0.46 | 1.08 | 1.20 | 0.36 | 0.98 | 0.03 | 0.17 |
| Fujian | 0.80 | 1.32 | 0.93 | 0.50 | 1.16 | 1.08 | 0.27 | 0.52 | 0.01 | 0.02 |
| Shandong | 0.87 | 0.65 | 0.43 | 0.40 | 0.88 | 0.70 | 0.29 | 0.56 | 0.04 | 0.13 |
| Guangdong | 0.71 | 0.76 | 1.19 | 1.02 | 0.96 | 1.24 | 0.49 | 1.08 | 0.06 | 0.22 |
| Hainan | 0.29 | 0.54 | 1.10 | 0.76 | 0.60 | 0.62 | 0.19 | 0.34 | 0.60 | 0.44 |
| Average score | 0.69 | 0.83 | 0.80 | 0.71 | 0.84 | 0.94 | 0.34 | 0.76 | 0.16 | 0.39 |

with weights assigned by gray correlation theory and the scores (Table 2) and dimensional scores (Table 3) were derived to reflect the differences and specific changes in industrial land transformation effect in each province. Overall, in Beijing, Shanghai, Guangdong, and Jiangsu province, industrial land transformation is effective and in the lead; for Fujian, Hebei, and Zhejiang province, industrial land transformation is in the middle with great development potential; and in Tianjin, Shandong, and Hainan province, industrial land transformation is not significant and to be further enhanced.

As shown in Table 2, the overall trend of industrial land transformation effect in the eastern region is on the rise in terms of average scores. Since 2011, the increase in transformation effect is particularly prominent, which is attributed to the transformation of the quality-oriented economic development model and the initial establishment of a new growth model, which has promoted industrial land transformation and reflected the positive effect of national policy guidance. Among them, the score decreased briefly in 2009 and 2015. In 2009, due to the impact of the international financial crisis, the short-term industrial output capacity decreased. The reason for the decline in the effect of transformation in 2015 is that it was the great year of “de-capacity and de-inventory” for China’s centralized industrial governance. Affected by this, the improvement process of industrial land transformation effect was relatively stagnant.

In addition, in terms of the effect of transformation by dimension, there are differences in the transformation scores of industrial land under dimensions. We found that the scores of industrial land development dimension, industrial land employment dimension, development condition support dimension, and environmental pollution control dimension increased during the study period, while the scores of industrial land optimization dimension decreased. The possible reason is that, compared with the improvement of the total industrial economy, the industrial land optimization dimension reflects the characteristics of industrial structure upgrading, which requires breakthroughs in technology, energy consumption, management and other aspects in order to promote the overall industrial quality. Therefore, although local governments have made some efforts to optimize industrial land, more targeted measures are needed to achieve the transformation development of this difficult area. In terms of the sub-dimensional transformation effect of each province, the level of industrial land development in Tianjin and Shandong needs to be improved; the level of industrial land optimization in Beijing and Zhejiang is high and needs to be improved in other provinces; the level of industrial land employment in Fujian, Shandong and Tianjin needs to be improved; the level of development conditions support in each province is high; the level of environmental pollution control in Hainan needs to be improved.

## 3.2 Spatial-temporal evolution of industrial land transformation effect

### 3.2.1 Overall trends of industrial land transformation effect

Applying kernel density estimation, the distribution of industrial land transformation effect measures in 10 provinces in the eastern region for the main years 2008, 2011, 2014, 2017, and 2020 is plotted based on the composite effect score (Figure 2), with the vertical coordinate being the kernel density, reflecting the concentration of the sample points and the horizontal coordinate being the composite score of industrial land transformation effect. The study explains the evolution of industrial land transformation effect in 10 provinces in the eastern region and the analysis yields the following distinctive features.

1) According to the position, the opening and closing values of the kernel density curve show a "rightward shift" with the change of year, i.e., the overall rightward shift of the kernel density curve indicates that the transformation effect of industrial land in 10 provinces in the eastern region has gradually improved. Compared with 2008, the center of the kernel density curve shifted significantly in 2020 and the change interval of transformation effect in the horizontal axis direction increased significantly, indicating that while the overall transformation effect increased, the gap between regions also expanded.
2) According to the shape, the overall kernel density curve is a single-peaked distribution with obvious clustering, among which there is a slight bimodal distribution in 2011 and 2014, indicating that there is a slight bifurcation in 2011 and 2014.2008, 2011, and 2014 kernel density curves are steeply sloped and concentrated in the middle and low value areas of transformation effect. In 2017 and 2020, the overall distribution of kernel density curves showed a gentle slope and a significant decrease in density. The transformation effect of regional industrial land was concentrated in the middle and high value areas and the transformation effect increased significantly.
3) According to the kurtosis, the kurtosis of the kernel density curve in the study period shows a change from a "sharp" to a "broad" shape. 2008 and 2011 kurtosis curves show a spike shape and the distribution of low values of industrial land transformation effect is more concentrated, indicating that the transformation effect is low. By 2014, the height of the crest of the nuclear density curve decreases significantly. Compared with 2008 and 2011, the wave crest is relatively flat in 2014 and shows a shift to higher values, which indicates progress in the transformation of regional industrial land. By 2017 and 2020, the height of the crest further decline and the overall shape of the broad peak indicated that the overall transformation effect in each region was more balanced and the overall level was improved.

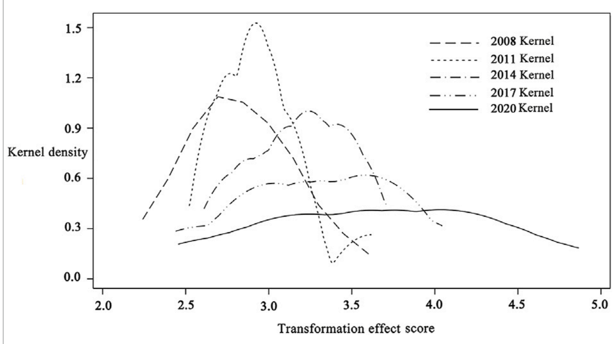


FIGURE 2
Kernel density estimation of industrial land transformation effect in major years.

### 3.2.2 Spatial-temporal evolution of industrial land transformation effect in different dimensions

Using ArcGIS spatial analysis technology, the spatial-temporal evolution of the industrial land transformation effect in each province under different dimensions was analyzed by comparing the effect score with the mean value, and the results are shown in Figures 3–7.

1) Industrial land development dimension. Combining Table 3 and Figure 3, it can be seen that there is no significant change in the spatial pattern of industrial land development dimension differences from 2008 to 2020 In the context of

transformation, the overall economic development trend of industrial land in the eastern region is better, with Hebei, Fujian, Jiangsu, and Zhejiang leading the way and regional industry, as a growth pole driving economic development, has been maintaining a better development trend. The rapid economic development of industrial land in Beijing has achieved remarkable results during the study period. The economic development of industrial land in Shandong and Tianjin has slowed down, mainly due to the new stage of regional industrial development into reduction and intensive, innovative development, industrial enterprises are influenced by the adjustment of urban function positioning to move out, and the trend of industrial land withdrawal or redevelopment is obvious. The economic development of industrial land in Shanghai and Guangdong is stable and the overall change is not significant. The economic foundation of industrial land in Hainan is relatively weak but the overall growth level of industrial land development has been maintained at a high level under the policy support. It is worth noting that the industrial land development degree of Shandong and Guangdong, from higher than the regional average in 2008 to lower than the regional average in 2020, has weakened the scale of industrial economic development in both places, which needs to draw the attention of local governments.

2) Industrial land optimization dimension. Combining Table 3 and Figure 4, it can be seen that there is no significant change in the spatial pattern of the difference in the dimension of industrial land optimization from 2008 to 2020. Beijing, Shanghai and Guangdong have higher levels of industrial land optimization dimensions. Beijing is a pioneer in the development of high-tech industries in China and as its industrial development continues to optimize its industrial structure and significantly reduce its high-energy-consuming industrial industries, industrial land transformation has been effective. Shanghai has always been the most international metropolis in China with a significantly higher foreign trade dependency than the national average and has a good foundation for industrial transformation and optimization structure. Guangdong attaches importance to the construction of strategic emerging industries and provides strong support for industrial land transformation by increasing the proportion of investment in high-tech industries. Hainan province adopts the policy of the Hainan Free Trade Zone to develop modern industry, seizes the national strategy of developing resources in the South China Sea, and vigorously develops outward-oriented industrial bases so that industrial land transformation can achieve “overtaking”. Tianjin promotes the upgrading of industrial structure to build a national advanced manufacturing research and development base and the basic conditions for industrial land transformation are better. Jiangsu and Zhejiang have fewer changes in industrial land optimization and no outstanding achievements in the process of transformation. The industrial land optimization dimension in Shandong and Hebei is at a low level and the proportion of traditional industrial enterprises remains high. The level of the optimization dimension of industrial land in Fujian is on a downward trend, and there is an urgent need to improve industrial competitiveness.

3) Industrial land employment dimension. Combining Table 3 and Figure 5, it can be seen that the differences in the industrial land employment dimension from 2008 to 2020 show significant changes in the spatial pattern. From the whole eastern region, industrial development still plays a leading role in the national economic growth and the pull for the industrial land employment dimension is very obvious. For example, the rise of strategic emerging industries can provide more jobs. However, in the process of industrial land transformation, the factor structure of industrial development has also changed with the relative content of capital and technology increasing and the relative content of labor gradually decreasing, which is reflected in the gradual transformation of labor-intensive industries to capital-intensive and technology-intensive industries and the corresponding increase in the knowledge and ability requirements for industrial employment. We found that industrial land employment dimension in Tianjin, Fujian and Shandong shows a decreasing trend, which reduces the employment elasticity of industrial industries to a certain extent. A possible explanation is the crowding-out effect of industrial upgrading on employment. Industrial upgrading and the application of high technology make the substitution advantage of technology and capital for labor obvious, which reduces the degree of employment in industry to a certain extent, and the employment dimension of industrial land thus shows a certain reverse trend.

4) Development conditions support dimension. Combining Table 3 and Figure 6, it can be seen that the differences of development conditions support dimension from 2008 to 2020 change significantly in the spatial pattern. In the context of transformation, the level of infrastructure construction and technological progress has a significant impact on the efficiency of urban industrial land use. Development conditions support dimension in Hebei and Jiangsu has shifted from a lower level in 2008 to a higher level in 2020, indicating that the regions attach importance to industrial infrastructure construction and increasing investment in industrial research and experimental development, which provides better development conditions for industrial land transformation. Beijing, Shanghai and Guangdong have been maintaining a high level of development conditions support dimension. In 2020, the quality level of Guangdong’s industrial science and technology personnel ranks first among the eastern

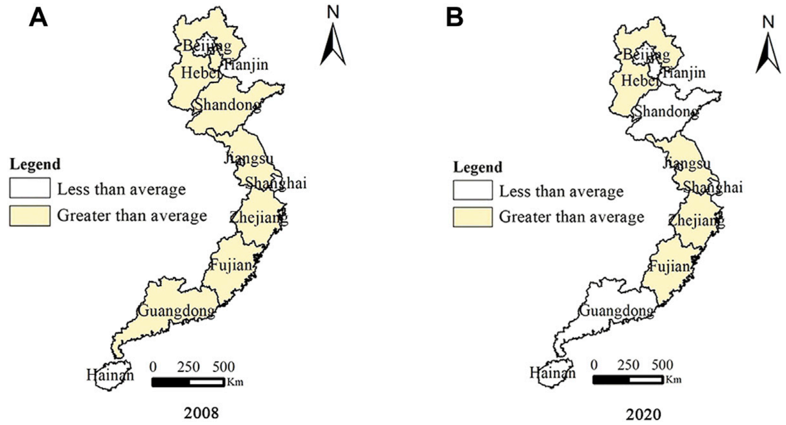


FIGURE 3
Spatial differentiation of industrial land development dimension (2008 and 2020).

provinces, with a rich talent pool; Shanghai gathered a large number of industrial enterprises R & D institutions, strong scientific, and technological power; Beijing relies on many universities, dense educational resources, industrial innovation capacity is outstanding. Zhejiang, Tianjin, and Shandong have steadily improved development conditions support dimension and have greater development potential. The development conditions of industrial land in Fujian and Hainan have been relatively slow to improve, and the transition process has been at a lower level.

5) Environmental pollution control dimension. Combining Table 3 and Figure 7, it can be seen that from 2008 to 2020, the difference in environmental pollution control dimension is constant in the spatial pattern. Although the overall level in each province has increased, the increase is small and the large inter-provincial differences indicate that the overall green development of industrial land is still in its initial stage. Beijing and Shanghai have invested most prominently in industrial land pollution control, improving the environmental quality of urban industrial land by upgrading the environmental pollution control level of industrial enterprises and strictly controlling the environmental pollution indicators of industrial enterprises: the environmental pollution control dimension is in the forefront. The environmental pollution control dimension in Guangdong, Tianjin, Jiangsu, Shandong, Zhejiang, and Hebei have been steadily improved, and industrial pollution control has been effective. Relative to other regions, Hainan has a higher score of environmental pollution control dimension, indicating that its pollution control contributes more to the development of industrial land due to the influence of industrial types with a lower degree of heavy industry but it is the only province that shows a reverse change in time, indicating that the development of regional industrial land has certain negative environmental impacts. It is worth noting that environmental pollution control dimension in Fujian was at the lowest level in 2020 with a large gap with other provinces, indicating that the development of its industrial land is facing a more serious environmental pollution problem.

# 4 Discussion

## 4.1 Industrial land transformation mechanisms and development suggestion

Improving the quality of industrial land and ensuring the stable development of urban industry have become issues of increasing concern to governments (Green, 2018; Feng and Li, 2021). On the premise of clarifying industrial land transformation, this study tries to build a multidimensional and systematic research framework to measure industrial land transformation effect based on a comprehensive indicator system, which is important for identifying and optimizing the rational use of industrial land and improving the transformation path of industrial land. Based on the analysis of the spatial-temporal evolution of the transformation effect, the study conducts a preliminary discussion on the mechanism of industrial land transformation and development proposals in China. The industrial economic system is a typical "economic-social-ecological" system and its transformation is a continuous dynamic change process, in which various driving factors play different roles (Zeng et al., 2017; Hohensinner et al., 2021).

Overall, the industrial land in each province shows a better trend of transformation but the overall gap still exists and the gap is larger in some provinces, which is mainly due to the differences in resource endowment, location conditions, industrial base, hinterland economy, and other factors. Throughout the process

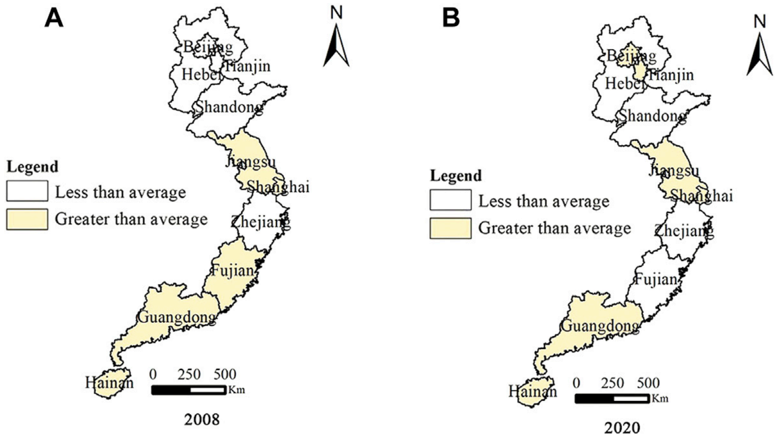


FIGURE 4
Spatial differentiation of industrial land optimization dimension (2008 and 2020).

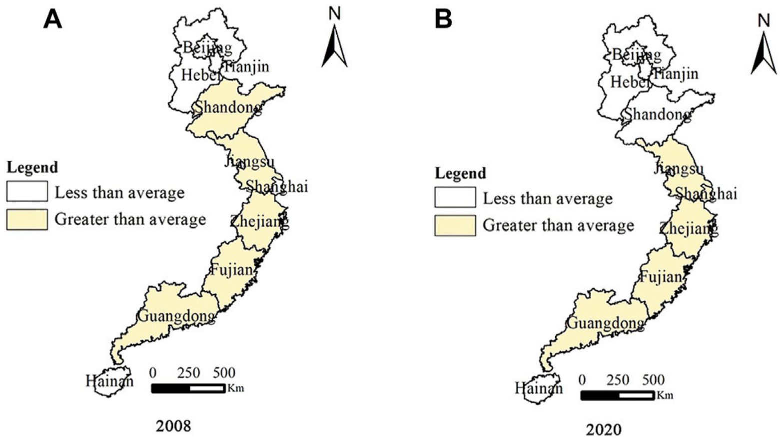


FIGURE 5
Spatial differentiation of industrial land employment dimension (2008 and 2020).

of China's industrial economy transformation, the reason is that the quality-oriented economic development shift and the initial establishment of a new growth model have forced the industrial economy to achieve transformation. First, the national policy orientation will largely influence the process of industrial economic transformation. For example, the "Opinions on Promoting Urbanization with County Cities as Important Carriers promulgated" in 2022 and the Opinions on Completely and Accurately Implementing the "New Development Concept and Doing a Good Job in Carbon Dafeng and Carbon Neutral Work promulgated" in 2021 both emphasize the importance of efficient use of industrial land and optimization of industrial structure. Second, the role of science and technology innovation cannot be ignored, once a certain industrial high-tech breakthrough brings about rapid development of industrial industries, science and technology gradually become the origin and core driving force leading industrial economy transformation. In addition, due to years of exploitation of natural resources, such as minerals, fossil fuels and other resources that provide raw materials or power for industrial production, traditional high-energy consuming industries are difficult to maintain and must take the road of transformation and upgrading.

Therefore, driven by various factors, industrial land transformation is a guarantee for healthy and sustainable development of industrial economy in the new era and the current industrial land transformation policies also focus on two aspects: energy conservation and environmental protection and technological innovation. We combine the

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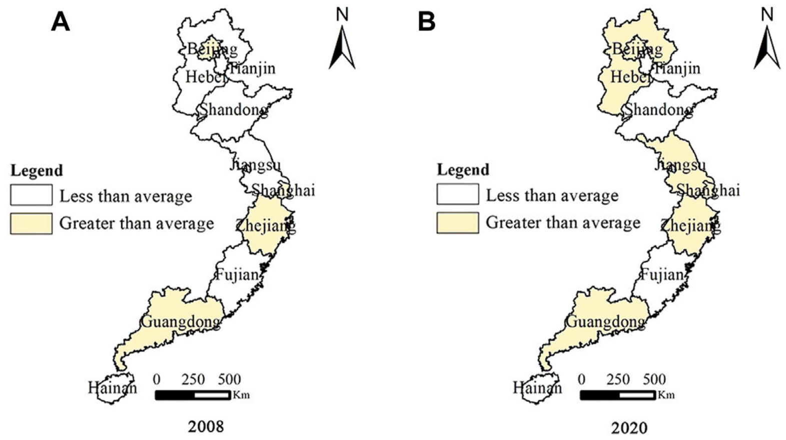


FIGURE 6
Spatial differentiation of development conditions support dimension (2008 and 2020).

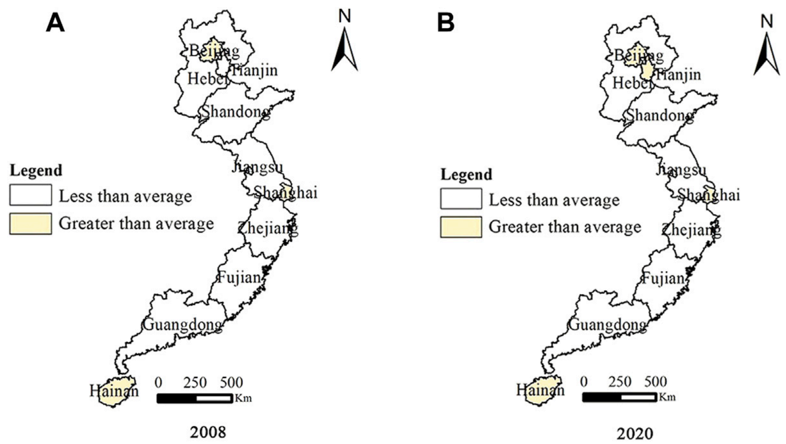


FIGURE 7
Spatial differentiation of environmental pollution control dimension (2008 and 2020).

research results and make the following recommendations. First, industrial land transformation effect in the eastern region is uneven. Different provinces should reasonably formulate industrial land transformation objectives and implement targeted transformation policies in combination with their industrial development foundation. For example, the industrial land transformation in Tianjin and Shandong has weak effects in terms of economic development and employment of residents, and there is a need to increase the support for industrial enterprises and establish advanced industrial parks; The industrial land transformation in Beijing and Shanghai should give priority to the limitation of urban land area, and on this basis actively revitalize the stock industrial land; Fujian, Hainan's industrial land transformation need to enhance government guidance, priority remediation of environmental pollution. Second, government agencies at all levels in the eastern region should realize the importance of "energy conservation and environmental protection" in the process of industrial land transformation and optimize the industrial structure to achieve green, low-carbon and circular development with fewer pollutant emissions and less energy consumption to achieve higher efficiency. Finally, the pillar position of science and technology and infrastructure must be insisted on for industrial land transformation. To realize industrial land transformation, it is necessary to improve innovation ability, cultivate, and develop strategic new industries, promote the integration of industrialization and informationization, and promote the transformation of China into a "manufacturing power" based on more advanced technology and more complete infrastructure.

## 4.2 Research limitations and prospects

This study makes a certain contribution to promoting the development of industrial land transformation but there are also the following limitations: 1) the existing studies on industrial land transformation effect focus on the economic benefits of industrial land transformation development and lack the measurement of non-economic benefits. Although this paper discusses industrial land transformation effect comprehensively from multiple dimensions and clarifies the importance of its comprehensive benefits, the concept of effect exists in multiple interpretations and we define industrial land transformation effect only from the perspective of expected effects, which requires further research and reflection. In the future, we can consider more natural and human aspects to measure industrial land transformation effect in a comprehensive and diversified way. 2) Industrial land transformation is a dynamic and complex systemic process and the influence mechanisms of the various driving factors on industrial land transformation effect are complex. This study mainly focuses on the analysis of the spatial-temporal evolution characteristics of industrial land transformation effect based on existing studies and relevant theoretical foundations and provides a simple qualitative explanation of the mechanism. Future research can collect necessary statistical data and use econometric models to quantitatively analyze the transformation mechanism to provide data support for better guidance of industrial land transformation development.

# 5 Conclusion

Based on the industrial land statistics of 10 provinces in eastern China from 2008 to 2020, this study constructs a comprehensive indicator system, adopts rough set theory and gray correlation theory to assign weights, measures industrial land transformation effect in each province, and explores the spatial-temporal evolution of industrial land transformation effect at the overall level and the sub-dimensional level. The results of the study are summarized as follows.

1) In terms of industrial land transformation effect, Beijing, Shanghai, Guangdong, and Jiangsu province are in the lead with significant industrial land transformation effect; Fujian, Hebei, and Zhejiang province have medium industrial land transformation effect and great development potential; and Tianjin, Shandong, and Hainan province are lacking industrial land transformation effect and need further improvement. From the average score, industrial land transformation effect is closely related to the national policy guidance.
2) At the level of overall spatial-temporal evolution, the industrial land transformation in the eastern region shows a better development trend and the transformation effect in each province is steadily improving but the gap has always existed and has expanded over time. By 2017, the gap in industrial land transformation effect between the two extreme regions, Beijing and Hainan province, is the most significant and is higher than the deviation level between the extreme regions in previous periods.
3) From the spatial-temporal evolution level of each dimension, Industrial land development dimension and Industrial land employment dimension show a better development trend and most provinces are at a higher level. Industrial land optimization dimension and environmental pollution control dimension does not change significantly in the spatial pattern and most provinces are at a lower level, and the industrial structure adjustment and industrial green development of regional industrial land need to be further improved. Development conditions support dimension shows an obvious positive change trend in space, and each province attach importance to infrastructure construction and scientific research and technological progress.

Based on the analysis of the research results, this paper further explores the mechanism of industrial land transformation and proposes a targeted practical path to optimize industrial land transformation. Finally, there are certain shortcomings in this study, and in the future, it is necessary to deepen the conceptual interpretation of effect, analyze the mechanism of industrial land transformation, and provide data support to better guide the development of industrial land transformation.

# Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

# Author contributions

DD designed the research framework. JY writing the original draft preparation. YR revising and editing the paper. All authors read and approved the final manuscript.

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# Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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