Industrial Eco-efficiency in Arid Regions Based on Super-Efficiency DEA Model: A Case Study of Xinjiang (Postprint)

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Abstract

Ecological efficiency is an effective metric for circular economy and sustainable development. Investigating industrial ecological efficiency in the Xinjiang region is of significant practical importance for promoting coordinated development between the economy and ecological environment and achieving the objectives of ecological civilization construction. This paper employs Xinjiang industrial panel data from 2001–2015 as a sample, utilizes a super-efficiency DEA model to evaluate industrial ecological efficiency and its evolutionary characteristics across 14 prefecture-level cities (prefectures, regions), and conducts Tobit regression analysis on selected influencing factors of industrial ecological efficiency. The results indicate: The overall level of industrial ecological efficiency in Xinjiang is relatively low, yet the development trend is favorable, demonstrating a fluctuating upward trend from 2001–2015 with a chain growth rate of 109.8%; transitioning from an inefficient status of 0.75 during the '10th Five-Year Plan' period to 1.0 during the '11th Five-Year Plan'period when it began to remain stably above the efficient production frontier, and further to 1.08 during the '12th Five-Year Plan' period, industrial ecological efficiency has maintained steady growth momentum; Industrial ecological efficiency exhibits significant imbalance across various regions of Xinjiang, with a maximum value of 8.97 and a minimum value of 0.59, representing a 15.2-fold disparity; Industrial ecological efficiency is positively correlated with economic development level, technological innovation, industrial structure, and environmental planning, and negatively correlated with openness to the outside world and industrial agglomeration.

Full Text

Industrial Eco-Efficiency in Arid Region Based on Super-Efficiency DEA Model: A Case Study in Xinjiang

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Abstract: Eco-efficiency is an effective measurement of sustainable development. Studies on the industrial ecological efficiency of Xinjiang, an ecologically fragile arid region in China, are of important practical significance to promote the coordinated development of industry and ecological environment and achieve the goal of ecological civilization construction. In this study, the industrial panel data of Xinjiang from 2001 to 2015 were taken as the samples, the super-efficiency DEA model was used to evaluate the ecological efficiency and its changes in 14 prefectures, autonomous prefectures and cities in Xinjiang Uyghur Autonomous Region, and the Tobit regression model was used to analyze the factors affecting the industrial ecological efficiency. The results showed that: The overall level of industrial ecological efficiency in Xinjiang was not high, but the development trend was good. The industrial ecological efficiency was increased in a fluctuation way, and its comparative growth was 109.8%. It was increased from 0.75 during the Tenth Five-year Plan period to 1.0 during the Eleventh Five-year Plan period and further to 1.08 during the Twelfth Five-year Plan period; The industrial eco-efficiency in Xinjiang was imbalanced, the highest and lowest values were 8.97 and 0.59, respectively, and their difference was 15.2 times; The industrial eco-efficiency was positively correlated with the industrial development level, scientific and technological innovation, industrial structure and environmental planning, but negatively correlated with opening to the outside world and industrial agglomeration.

Keywords: industrial eco-efficiency; super-efficiency DEA model; Tobit regression; Xinjiang

2 Methodology and Data Analysis

This study employed DEAP 2.1 and DEA-Solver Professional software to conduct the DEA analysis. The super-efficiency DEA model was used to evaluate industrial eco-efficiency, while the CCR model served as a benchmark for comparison. Panel data from 14 prefectures, autonomous prefectures, and cities in Xinjiang during 2001–2015 were analyzed.

presents the industrial eco-efficiency values for Xinjiang from 2001 to 2015. The super-efficiency DEA model shows that efficiency values exhibited fluctuating growth, reaching 109.8% comparative growth over the study period. Notably, the values achieved 1.00 in 2008, 2011, and 2015, indicating periods of optimal efficiency. In contrast, the CCR model results demonstrate that most years

remained at or near the 1.00 efficiency frontier, with only slight deviations in certain years. This difference occurs because the CCR model identifies multiple decision-making units (DMUs) as efficient (value = 1.00) when they lie on the production frontier, whereas the super-efficiency DEA model can differentiate among these efficient units by calculating values greater than 1.00.

[Figure 2: see original paper] illustrates the industrial eco-efficiency patterns across Xinjiang' s 14 administrative regions from 2001 to 2015. The super-efficiency DEA results reveal significant spatial variation, with efficiency values ranging from 0.59 to 8.97—a 15.2-fold difference between the highest and lowest performers. This substantial disparity underscores the regional imbalance in industrial eco-efficiency across Xinjiang.

The analysis identifies several key patterns. First, regions such as ¿cq, GoK, t?>, (cid:128)(cid:247)q, r2sq, ¿lmno+¿l, and hij exhibited relatively high efficiency values, clustering between 0.9 and 1.0. These areas represent the more industrially developed and environmentally efficient zones within Xinjiang. Conversely, regions including ···N, ···(cid:139), (cid:223)!(cid:153), kde, tmuoK, and (cid:253)voK demonstrated lower efficiency values below 0.9, accounting for approximately 42.8% of the studied regions.

Second, the temporal analysis reveals that during 2010–2015, the CCR model showed a declining trend, while the super-efficiency DEA model displayed more nuanced fluctuations. This pattern suggests that while conventional efficiency remained stable, the relative super-efficiency among regions varied more dynamically, reflecting differential progress in industrial ecological performance.

3 Tobit Regression Analysis of Influencing Factors

To identify the determinants of industrial eco-efficiency, this study employed a Tobit regression model. Based on existing literature and the specific context of Xinjiang' s industrial development, six influencing factors were selected: industrial development level, scientific and technological innovation, industrial structure, environmental planning, degree of opening-up, and industrial agglomeration.

The regression model was specified as follows:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + \varepsilon_i$$

where Y_i represents industrial eco-efficiency, X_{1i} through X_{6i} denote the six influencing factors, β_0 is the constant term, β_1 to β_6 are coefficients, and ε_i is the error term with $\varepsilon_i \sim N(0, \sigma^2)$.

The specific variable definitions are: 1. **Industrial Development Level (PGDP)**: Per capita GDP, reflecting the economic development stage (ratio 0.82:70.83:28.35) 2. **Industrial Structure (FIr)**: Proportion of secondary

industry, indicating the industrialization degree 3. **Environmental Regulation (EIr)**: Investment in industrial pollution control, representing environmental policy stringency 4. **Scientific and Technological Innovation (RDr)**: R&D expenditure intensity, measuring innovation capacity 5. **Human Capital (HIr)**: Investment in education and healthcare 6. **Industrial Agglomeration (IGr)**: Concentration of industrial output

The regression results demonstrate that industrial eco-efficiency is positively correlated with industrial development level, scientific and technological innovation, industrial structure optimization, and environmental planning. However, it shows negative correlations with the degree of opening to the outside world and industrial agglomeration. These findings suggest that while economic development and technological progress enhance eco-efficiency, excessive industrial concentration and certain aspects of external openness may pose challenges to environmental performance in Xinjiang' s context.

4 Conclusions

This study reveals that Xinjiang's industrial eco-efficiency, while starting from a relatively low baseline, demonstrated a positive growth trajectory during 2001–2015. The super-efficiency DEA model provides a more discriminative assessment than conventional DEA models, enabling better differentiation among regions on the efficiency frontier. The substantial regional disparities in eco-efficiency—exceeding 15-fold between highest and lowest performers—highlight the need for targeted policies that account for local industrial and environmental conditions. The identified influencing factors offer policy insights for promoting sustainable industrial development in arid regions.

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Note: Figure translations are in progress. See original paper for figures.