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Evaluation and Comparison of Environmental Regulation Efficiency in China's Urban Agglomerations: A Spatial-temporal Dynamic Perspective

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Abstract

Given the increasing emphasis on sustainable development, nations across the globe are working towards simultaneous regional economic development and ecological and environmental governance, which has become a shared objective. This article evaluates and compares environmental regulation efficiency using panel data from 2011 to 2021 for the Yangtze River Delta urban agglomeration and the Chengdu-Chongqing urban agglomeration in China. The study focuses on comparisons at the temporal and spatial dimensions. The research findings indicate that the two urban agglomerations' environmental regulation efficiency has been significantly improved. The increase of environmental regulation efficiency in the Yangtze River Delta urban agglomeration is faster than that in the Chengdu-Chongqing urban agglomeration. The Chengdu-Chongqing urban agglomeration shows a "high on both sides, low in the middle" spatial pattern. In contrast, the Yangtze River Delta urban agglomeration shows a "high in the middle, low on both sides" spatial pattern. The research findings provide policy insights for strengthening the agglomeration effect of urban agglomeration with different development levels. It also provides practical value for better and faster realization of regional equitable development.

Keywords: Environmental Regulation, Urban Agglomeration, Two-stage DEA, Comparative Analysis, Sustainable Development

Introduction

The deceleration of economic development, rising inflation, unsustainable production and consumption practices, and the escalating global grain crisis are exacerbating environmental risks, posing a significant challenge to the attainment of the United Nations Sustainable Development Goals (SDGs) by 2023 (Filho et al., 2023). Although there have been significant breakthroughs in industrialization and informatization, China has not fully transitioned away from the inefficient production processes that result in excessive energy consumption and pollution. The presence of public goods characteristics in natural resources and the existence of negative externalities from environmental contamination have resulted in inadequate market regulation. Hence, government intervention in environmental regulation (ER) is essential. China has prioritized green development since 2011. The enactment of the new Environmental Protection Law, the Environmental Protection Tax Law and the Measures for Interviews by the Ministry of Ecology and Environment, along with other relevant environmental protection policies, demonstrate that ER is now a crucial assurance for the high-quality advancement (Li and Liu, 2023). ER is a system or consciousness that exists to achieve sustainable economic and social growth by protecting the environment (Yu et al., 2009). ER is an essential tool for managing pollution and decreasing emissions. It enforces restrictions on energy consumption and emissions by implementing market entry requirements and technical standards. Common methodologies employed by scholars to quantify the level of ER include laws and regulations, data envelopment analysis (DEA), and the entropy method (Antweiler et al., 2001; Pan et al., 2024; Zou and Zhang, 2022). ER facilitates the advancement of power transformation, structural upgrading, and the shift in development mode, leading to a mutually beneficial outcome of enhancing the caliber of economic expansion and safeguarding the environment, finally attaining sustainable development.

In the advanced period of urban development, urban agglomeration is the apogee of spatial organization. Urban agglomeration refers to a closely-knit cluster of economically interlinked cities through advanced infrastructure networks, including transportation and communications. Over time, these cities become highly integrated and closely located to one another. Research has indicated that environmental policies tend to yield better results in regions with higher economic development (Hui-zhong and Yuan-gang, 2021). Both the Yangtze River Delta urban agglomeration (YRDUA) and the Chengdu-Chongqing urban agglomeration (CCUA) are situated inside China's Yangtze River Economic Belt (YREB). The YRDUA is situated in the downstream of the YREB, within the well-developed eastern coastal region of China (Dong et al., 2021). The CCUA is situated in the upstream of the YREB, which is an underdeveloped region in western China (Lu et al., 2022). The economic development of the CCUA falls behind that of the YRDUA. Due to the early exposure to the global market, certain cities in the YRDUA have attracted pollution-intensive industries from developed nations. The CCUA is characterized by its strong emphasis on industrial development, with Chongqing specifically focusing on heavy industry during its early stages. The issues of industrial pollution and energy consumption in the two urban agglomerations continue to be serious. The Government has implemented various environmental protection measures, including the Plan for the Joint Protection of the Ecological Environment in the Yangtze River Delta Region and the Plan for the Ecological and Environmental Protection of the Chengdu-Chongqing Twin Cities Economic Circle. So, in the YRDUA and the CCUA, how effective are ERs? Are the two urban agglomerations significantly different in environmental regulation efficiency (ERE)? Exploration of the two questions can enrich the theoretical and practical value of environmental governance for coordinated regional development.

According to this, this study puts forward hypotheses

Hypothesis 1: From a temporal perspective, the ERE of the YRDUA and the CCUA increases annually. However, there are significant differences among the cities.

Hypothesis 2: From a spatial perspective, the ERE of the YRDUA and the CCUA display different spatial characteristics. However, there are significant differences among the cities.

Research is scarce on the comparative of ERE among urban agglomerations. Most extant studies focus on national, provincial, and city evaluations. Simultaneously, limited research is available on spatial and temporal comparisons of ERE. This study uses panel data from 27 cities in the YRDUA and 16 cities in the CCUA from 2011 to 2021 to evaluate and compare the ERE. There are two novelties in this study. First, it examines the disparities in the impacts of ERs in urban agglomerations. Second, it highlights the importance of rational urban environmental regulation in driving sustainable development within the context of regional integration development. The study aims to provide valuable policy insights for narrowing the development gap between developed and underdeveloped regions and achieving balanced growth with economic agglomeration.

Methodology

Study Areas and Data Sources

The study areas are the YRDUA in eastern China and the CCUA in western China. According to the CCUA Development Plan released in 2016, this urban agglomeration includes 16 cities. According to the YRDUA development plan released in 2016, this urban agglomeration includes 27 cities. The selection of eastern urban agglomeration and western urban agglomeration for the study area can better compare the similarities and differences in ER between east and west China. It inspires regional coordinated development.

In 2011, China embarked on its 12th Five-Year Plan, marking a crucial phase in the transformation of its development model. In 2021, China has commenced the initial year of its 14th Five-Year Plan and focused on achieving high-quality development. Therefore, considering the data availability, this study utilizes panel data from two urban agglomerations spanning the period from 2011 to 2021 to compare and analyze the ERE. The data are from the China Urban Statistical Yearbook, China Environmental Statistical Yearbook and the Statistical Yearbooks of Shanghai, Jiangsu, Zhejiang, Anhui, Sichuan, and Chongqing.

Comparative Model and Variable Selection

Comparison of the Environmental Regulation Efficiency

DEA is based on the relative efficiency measurement criterion, which can ensure that the measurement results are objective and effective, and has become the most commonly used research method to measure the efficiency of environmental regulation (Cheng et al., 2016). With the development of the DEA, the extended two-stage network structures DEA model proposed by Li et al (2012) can obtain global optimal efficiency. The recently evolved model is better suited for the Chinese case. The DEA model is currently applied in diverse contexts, including evaluations of bank, production, hospital, military, agriculture, airports, energy, environment, innovation, and research and development (R&D) (Chen et al., 2021; Chu et al., 2022; Kottas et al., 2020; Liu et al., 2020; Qu et al., 2022; Stichhauerova and Pelloneova, 2019; Sueyoshi et al., 2017; Zhang and Chen, 2022). Therefore, this article combines the environmental protection and pollution control of urban agglomeration, constructs network structures DEA model from the perspective of output-input, and establishes the ERE index system in line with the characteristics of urban agglomeration. Data collation from DEARUN software.

Because factor endowments vary from region, this article refers to the studies of Tenaw and Beyene (2021) and Li et al. (2022) and constructs the evaluation system from the perspective of material and non-material factor transformations. The ERE can be categorized into the stages of material factors and non-material factors. The first stage is the Material Factor Environmental Regulation stage, which reflects the efficiency of environmental regulation indicators linked to material factors. The input stage of material factors selects ERE indicators related to urban, industrial and residential life. The output stage of the material factor selects the efficiency indicators of ER related to the treatment of environmental protection technologies. The second stage is the non-material factor environmental regulation stage. The non-material factor input stage includes the technology factor indicators of the material factor output stage, supplemented by environmental regulation indicators related to the labor and capital factors. Gross domestic product (GDP) and green development were selected for the non-material factor output stage. At first, the two-stage DEA model assesses the efficiency of environmental measures related to urban, industrial and life to be transformed into environmentally friendly technological outputs and then assesses the efficiency of environmental measures related to technological, labour and capital factors to be transformed into the promotion of economic development that is environmentally friendly. Table 1 shows the indicators of ER.

Table 1
Evaluation Index of ERE

Stage	Vector	Indicators	
Material factors environmental regulation stage	Inputs	Urban	Ratio of urban domestic sewage purification
		Industry	Ratio of comprehensive use of industrial solid waste
		Life	Ratio of harmless treatment for domestic refuse
	Outputs	Technology	Industrial wastewater discharge reaches standard level (IWD)
			Volume of Industrial Sulphur Dioxide Removed (VISDR)
			Volume of Industrial Soot Removed (VISR)
Non-material factors environmental regulation stage	Inputs	Technology	IWD
			VISDR
			VISR
		Labor force	Practitioners in environment management
		Capital	Fixed asset investment
	Outputs	Economic development	GDP
		Green development	Green area

Comparison of Spatial-Temporal Distribution

The spatial-temporal data is analyzed using ArcGIS 10.2 software. ArcGIS, known as Arc Geographic Information System, is a software for analyzing and managing geographic information designed by Environmental Systems Research Institute, Inc. It provides powerful spatial data processing and map-making functions (Johnston et al., 2001; Scott and Janikas, 2009). This study begins with grading the clustering results of ERE through the Natural Break method (Jenks and Caspall, 1971). Then, the spatial-temporal data are visualized using the map-making function to compare the similarities and differences between the two urban agglomerations in terms of ER more clearly.

From the time dimension, this study compares the dynamics of ERE in the two urban agglomerations from 2011 to 2021. From the spatial dimension, this study compares the annual average performance of the two urban agglomerations regarding ERE. This section aims to uncover the deeper reasons for the differences between the two urban agglomerations through comparative analysis.

Results and Discussions

Temporal Dynamic Analysis and Compare of Environmental Regulation Efficiency

Based on the results of the two-stage network DEA model of the two urban agglomerations from 2011 to 2021, this study finds out the temporal trend of the ERE, the transformation efficiency of material factors and the transformation efficiency of immaterial factors in the two urban agglomerations. This article selects the annual average of all cities in the two urban agglomerations that shows in Table 2. Then, this article produces line graphs reflecting the ER and two-stage time dynamic changes in the two urban agglomerations. The details can be seen in Figures 1 to 3, and this section further analyses the specific reasons for the variability of the two urban agglomerations at different times.

Table 2
Annual average of ERE and two-stage efficiency

	YRDUA			CCUA		
YEAR	ERE	Material factor stage	Non-material factor stage	ERE	Material factor stage	Non-material factor stage
2011	0.3031	0.4426	0.6811	0.4043	0.4588	0.8757
2012	0.2882	0.4241	0.6749	0.3610	0.4194	0.8690
2013	0.2797	0.4115	0.6811	0.3416	0.4188	0.8369
2014	0.2836	0.4263	0.6700	0.3128	0.3900	0.8270
2015	0.2944	0.4370	0.6777	0.3111	0.3925	0.8205
2016	0.2911	0.4144	0.6973	0.3037	0.3850	0.8122
2017	0.3049	0.4204	0.7260	0.3082	0.3888	0.8152
2018	0.3193	0.4174	0.7629	0.3119	0.3844	0.8255
2019	0.3204	0.4226	0.7666	0.3230	0.3869	0.8368
2020	0.3803	0.5007	0.7560	0.3252	0.3838	0.8425
2021	0.3432	0.4244	0.8192	0.3326	0.3856	0.8580

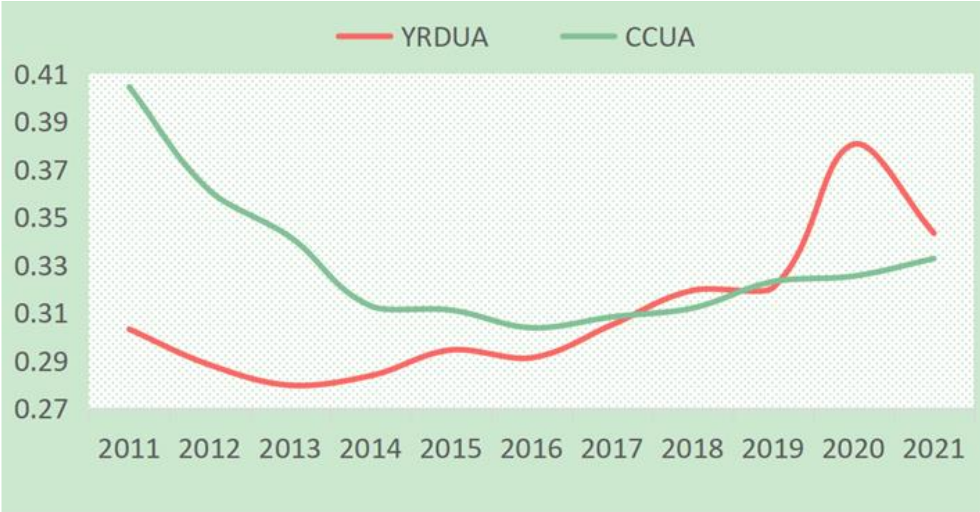

Figure 1. Temporal dynamic comparison of the ERE.

Table 3
Results of the ANOVA (ERE)

ANOVA—ERE of the YRDUA						
Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-value	*p*-value	F crit
City	7.8132	26	0.3005	81.4599	0.0000	1.5383
Year	0.2433	10	0.0243	6.5963	0.0000	1.8672
ANOVA—ERE of the CCUA						
Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-value	*p*-value	F crit
City	6.5149	15	0.4343	127.4043	0.0000	1.7335
Year	0.1415	10	0.0141	4.1497	0.0000	1.8943

Regarding the time trend, the ERE is below 0.41, which indicates ineffectiveness. The performance of the two urban agglomerations is significantly different. The study verified the significant differences by Analysis of Variance (ANOVA). Table 3 shows a statistically significant difference in ERE among different years and cities in the two urban agglomerations because the P-value is 0.0000. The ERE of the YRDUA has consistently increased, while in the CCUA, it initially decreased and then gradually improved. *Hypothesis 1* can be confirmed that ERE in the two urban agglomerations increases, but there are differences among cities. The reason is that the YRDUA prioritizes economic growth throughout the initial period. Nevertheless, the ERE has increased due to the long-term benefits of economic development and geographical location. The ERE has been consistently increasing in the YRDUA in recent years due to the strong awareness of environmental protection among the populace, a reasonable industrial structure, and an advanced ecological civilization. The primary emphasis of the CCUA is the production of secondary industries. The industrial structure has been significantly modified and progressively optimized during the study period. However, the industry is responsible for a substantial portion of energy consumption, which resulted in the failure of ER to achieve the desired outcome within a brief period.

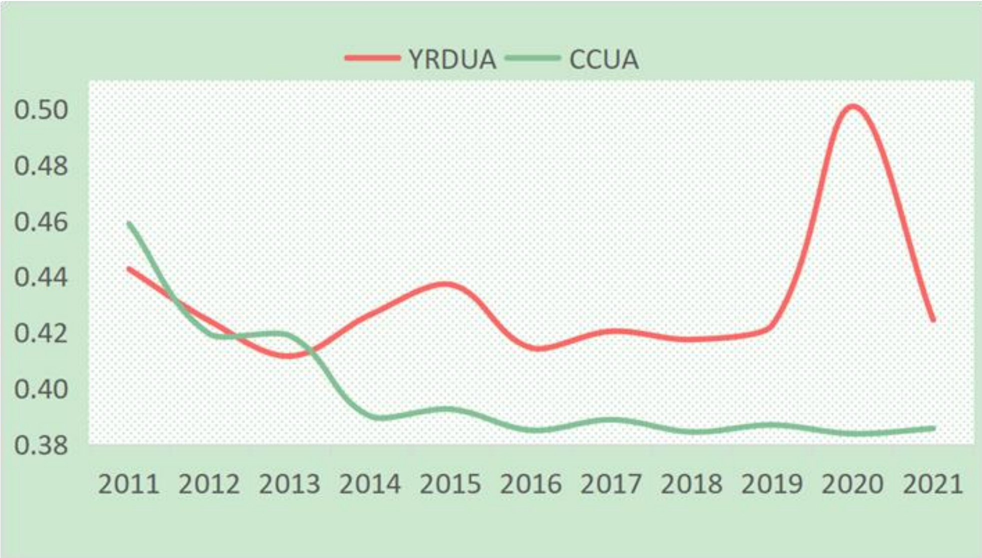

Figure 2. Temporal dynamic comparison of material factor transformation efficiency.

Table 4
Results of the ANOVA (Material factor stage)

ANOVA—Material factor stage ERE of the YRDUA						
Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-value	*p*-value	F crit
City	7.9597	26	0.3061	57.0482	0.0000	1.5383
Year	0.6701	10	0.0670	12.4868	0.0000	1.8672
ANOVA—Material factor stage ERE of the CCUA						
Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-value	*p*-value	F crit
City	10.0879	15	0.6725	217.8258	0.0000	1.7335
Year	0.0891	10	0.0089	2.8865	0.0025	1.8943

From the time trend, the transformation efficiency of material factors in ER is low, below 0.5, and the performance of the two urban agglomerations differs. According to ANOVA in Table 4, there are statistically significant differences in material factor stage ERE among different years and cities in the two urban agglomerations because the P-value is less than 0.05. From the whole study period, the YRDUA rises in fluctuation and then decline. The CCUA declines in fluctuation. It indicates that the efficiency of material elements in the CCUA in transforming into environmental protection and governance technologies gradually decreases, and the effectiveness is weaker. However, the efficiency of converting material elements into environmental protection governance technologies in the YRDUA is more stable. The efficiency peaks in 2020, indicating that the "Yangtze River Delta Eco-Green Integrated Development Demonstration Area" proposed in 2019 is effective.

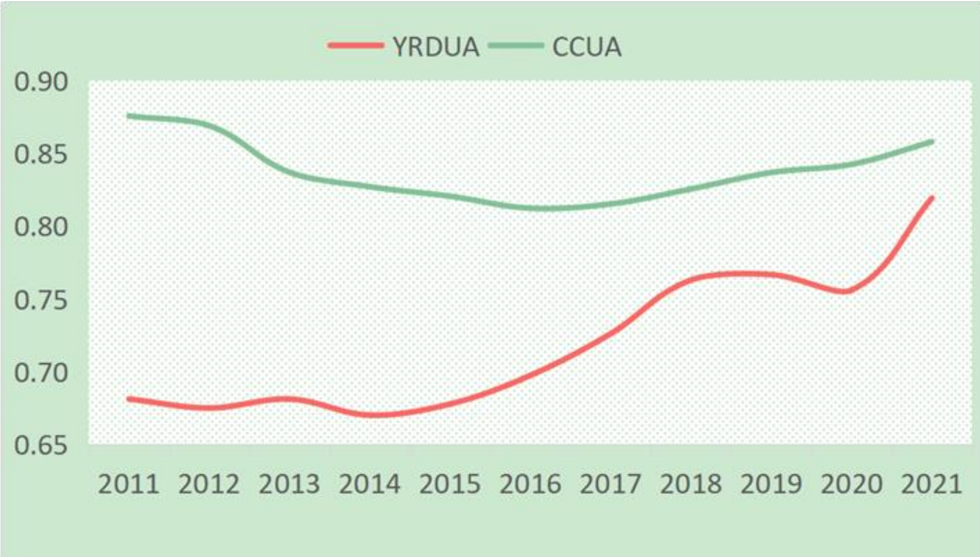

Figure 3. Time dynamic comparison of non-material factor transformation efficiency.

Table 5
Results of the ANOVA (Non-material factor stage)

ANOVA—Non-material factor stage ERE of the YRDUA						
Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-value	*p*-value	F crit
City	3.1807	26	0.1223	36.4889	0.0000	1.5383
Year	0.6765	10	0.0677	20.1785	0.0000	1.8672
ANOVA—Non-material factor stage ERE of the CCUA						
Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-value	*p*-value	F crit
City	0.7615	15	0.0508	15.7995	0.0000	1.7335
Year	0.0731	10	0.0073	2.2738	0.0166	1.8943

From the time trend, the transformation efficiency of non-physical factors in ER is high, which is higher than 0.65. According to ANOVA in Table 5, statistically significant differences in non-material factor stage ERE among different years and cities in the two urban agglomerations because the P-value is less than 0.05. The CCUA is more efficient than the YRDUA, but the two urban agglomerations gradually converge with time. Over the whole study period, the efficiency of non-material factor transformation of the YRDUA rises in fluctuation, and the CCUA remains stable in fluctuation. This indicates that the efficiency of transforming non-material factors into economic development in the YRDUA has gradually increased with apparent outcomes. In the CCUA, the efficiency of transforming non-material factors into economic development is more stable. This can prove that after adding the inputs of technology, labor, and capital factors, the role of ER is more significant, and its promotion effect on economic development is more prominent.

Spatial Distribution Analysis and Compare of Environmental Regulation Efficiency

This article uses ArcGIS 10.2 software to compare the spatial distribution of ERE, material factor transformation efficiency and non-material factor transformation efficiency in two urban agglomerations. This article selects the city average of all years in the two urban agglomerations that shows in Table 6. Through the Natural Break method, the two urban agglomerations are classified into four categories, reflecting the spatial distribution of ER and the two stages of the two urban agglomerations. The spatial distribution is shown in Figures 4 to 6.

Table 6
City average of ERE and two-stage efficiency

YRDUA				CCUA			
CITY	ERE	Material factor stage	Non-material factor stage	CITY	ERE	Material factor stage	Non-material factor stage
Anqing	0.2474	0.4082	0.6020	Chengdu	0.3157	0.3382	0.9352
Changzhou	0.2886	0.3909	0.7295	Dazhou	0.5773	0.7009	0.8239
Chizhou	0.1860	0.2900	0.6380	Deyang	0.1782	0.2082	0.8560
Chuzhou	0.1469	0.2345	0.6351	Guang'an	0.2900	0.4082	0.7113
Hangzhou	0.3396	0.5055	0.6723	Leshan	0.2530	0.3118	0.8081
Hefei	0.3570	0.5000	0.7209	Luzhou	0.4027	0.4645	0.8604
Huzhou	0.2719	0.4309	0.6311	Meishan	0.2156	0.3064	0.7001
Jiaxing	0.1995	0.3118	0.6436	Mianyang	0.3302	0.3782	0.8753
Jinhua	0.1890	0.3409	0.5557	Nanchong	0.1558	0.1818	0.8564
Ma'anshan	0.4719	0.7900	0.6021	Neijiang	0.2413	0.2855	0.8442
Nanjing	0.7648	0.7755	0.9856	Suining	0.2063	0.2300	0.9013
Nantong	0.3068	0.4155	0.7296	Ya'an	0.2974	0.3591	0.8279
Ningbo	0.4510	0.6827	0.6621	Yibin	0.6619	0.8618	0.7680
Shanghai	0.2802	0.2936	0.9530	Chongqing	0.8384	1.0000	0.8384
Shaoxing	0.1594	0.2064	0.7906	Ziyang	0.1280	0.1491	0.8573
Suzhou	0.6575	0.7827	0.8375	Zigong	0.1961	0.2073	0.9458
Taizhou 1	0.1833	0.2555	0.7121				
Taizhou 2	0.1594	0.2000	0.8016				
Tongling	0.5469	0.8327	0.6627				
Wenzhou	0.2109	0.2491	0.8456				
Wuxi	0.4971	0.5873	0.8442				
Wuhu	0.4551	0.7200	0.6404				
Xuancheng	0.1671	0.2418	0.6916				
Yancheng	0.2082	0.3100	0.6786				
Yangzhou	0.2040	0.2736	0.7443				
Zhenjiang	0.2852	0.4373	0.6505				
Zhoushan	0.1313	0.1718	0.7617				

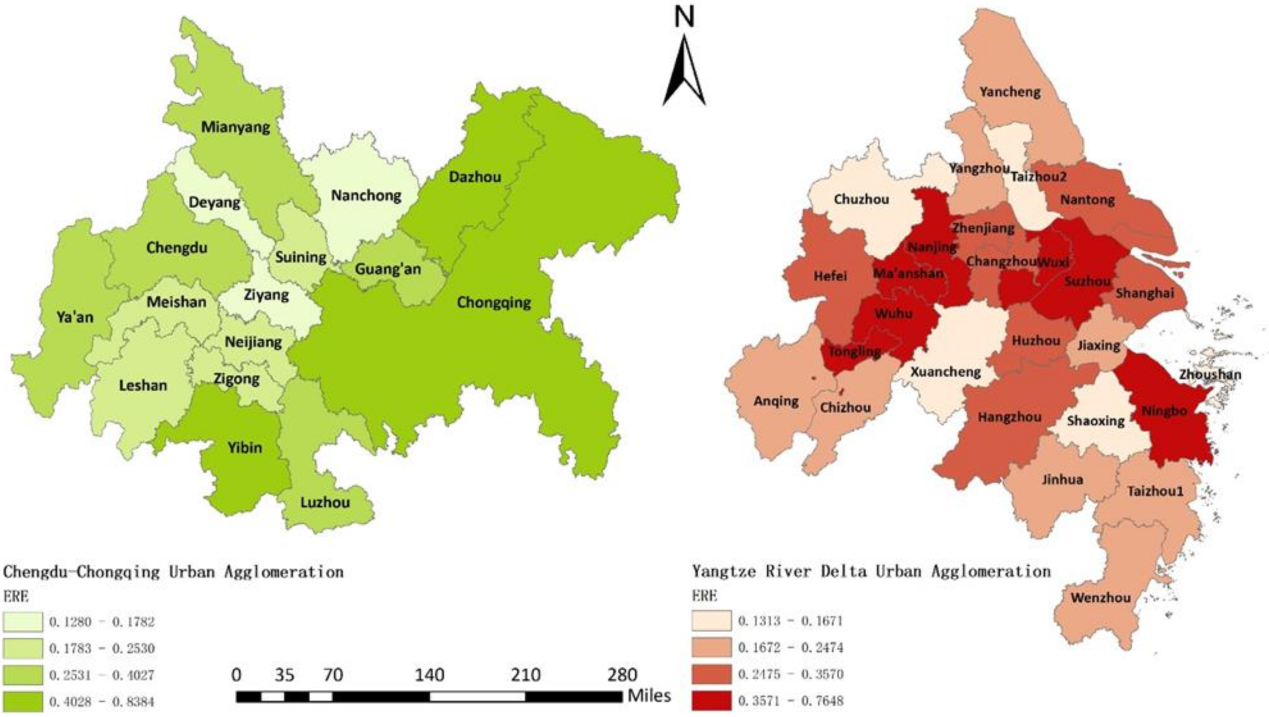

Figure 4. Spatial distribution comparison of ERE.

Notes: Taizhou1 is in Zhejiang Province. Taizhou2 is in Jiangsu Province.

Regarding the spatial distribution, the cities with higher ERE in the CCUA are scattered around the urban agglomeration, including Chongqing, Dazhou, Yibin, Luzhou, Guang'an, Chengdu, Mianyang and Ya'an. Chongqing, Chengdu, Mianyang and Yibin rank top in economic development. Dazhou, Luzhou and Guang'an have specialty industries. Ya'an has rich natural resources. On the contrary, in the YRDUA, cities with higher ERE are concentrated in the center of the urban agglomeration, including Shanghai, Nanjing, Wuxi, Hangzhou, Hefei, Suzhou, Ma'anshan, Wuhu, Zhenjiang, Tongling, Changzhou, Nantong, Huzhou and the coastal city of Ningbo. Shanghai, Hefei, Wuxi, Suzhou, Nanjing, Hangzhou, Zhenjiang, Changzhou and Ningbo are all more economically developed regions. Ma'anshan, Wuhu, Tongling, Huzhou and Nantong are all industrial cities that have focused on innovation-driven high-quality development in recent years. Shanghai, Suzhou, Nantong and Ningbo are coastal cities with an extensive degree of receptivity to the external environment. The other cities in the two urban agglomerations are less efficient in ER. Therefore, *Hypothesis 2* can be reconfirmed, from a spatial perspective, the ERE of the YRDUA and the CCUA display different spatial characteristics. However, there are significant differences among the cities. The main reasons are economic development, industrial structure and geographic location. In summary, the ERE of the CCUA shows a spatial pattern of "high on both sides and low in the middle". The ERE of the YRDUA presents a spatial pattern of "high in the middle and low on both sides".

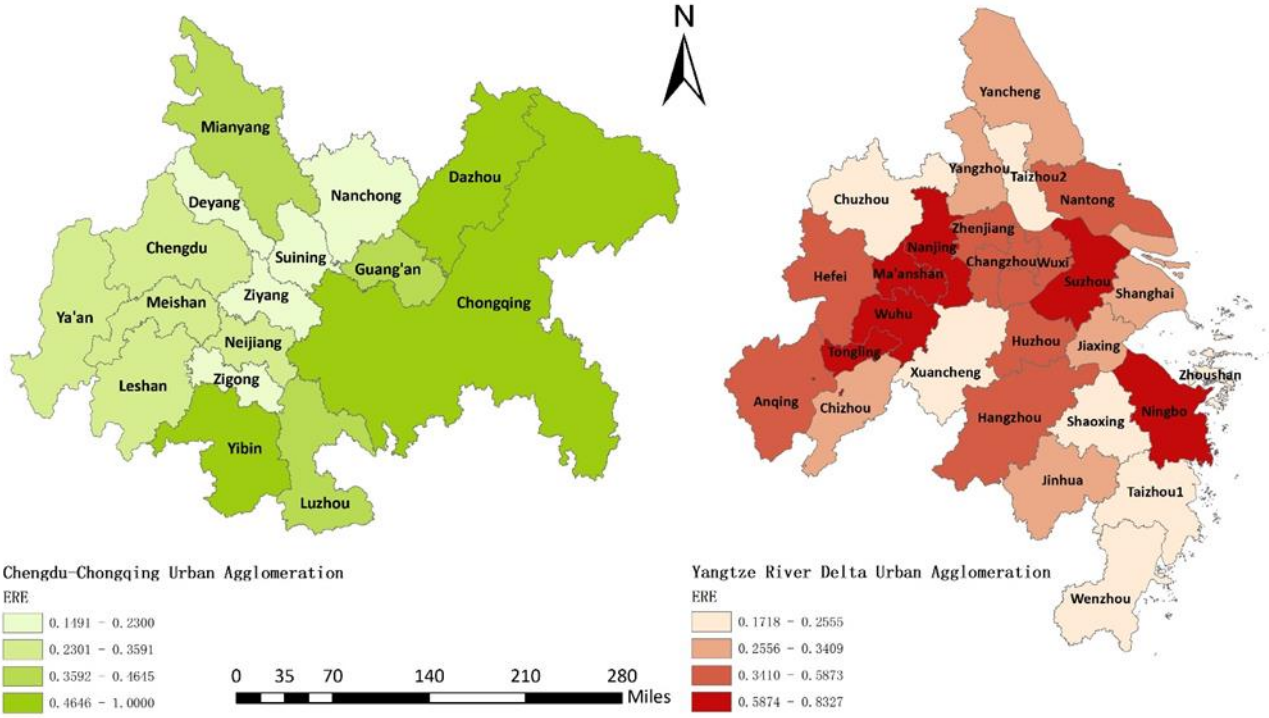

Figure 5. Spatial distribution comparison of material factor transformation efficiency.

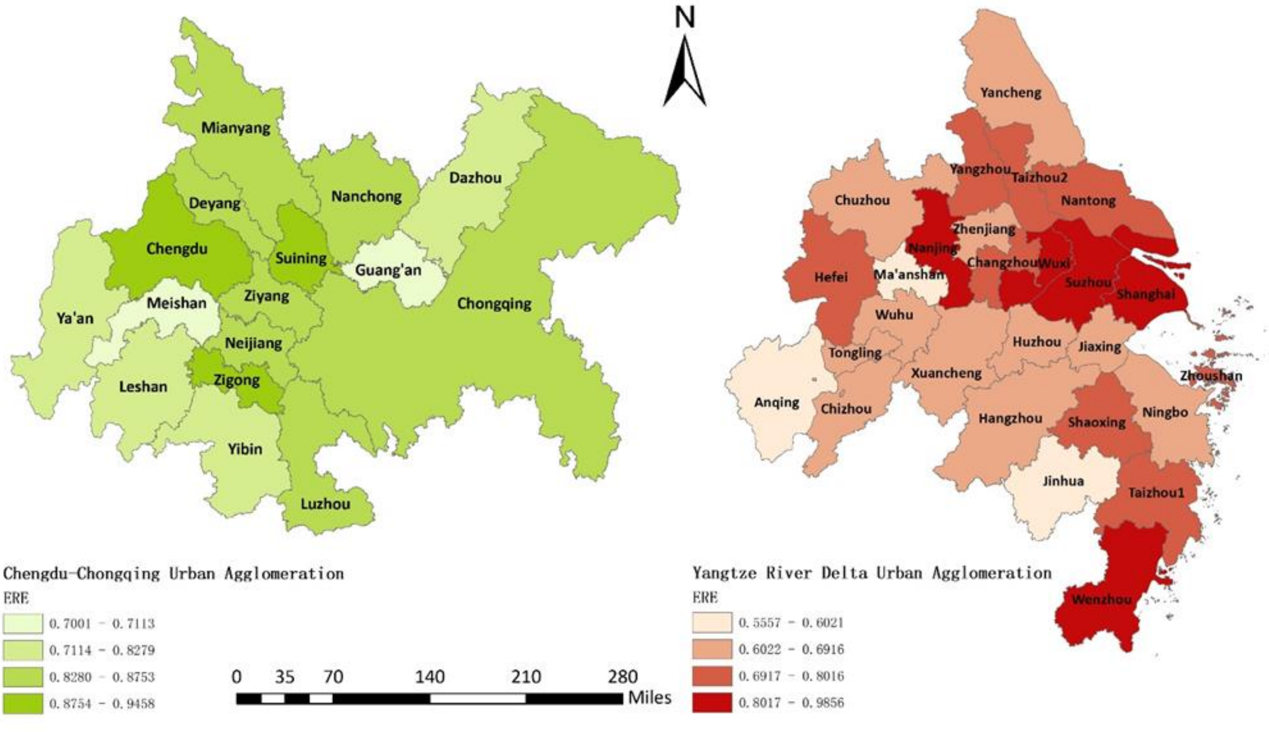

Figure 6. Spatial distribution comparison of non-material factor transformation efficiency.

The spatial distribution of the two-stage efficiency can be seen in Figures 5 and 6. In the CCUA, the cities with higher efficiency of material factor transformation of ER are in the southeast, and the cities in the center are less efficient. Cities with higher efficiency of transformation of non-physical factors are concentrated in the north, center, and southeast, while cities in the southwest and Guang'an are less efficient. In the YRDUA, the cities with higher transformation efficiency of material factors in ER are located in the west and the center. Conversely, the south and north cities are less efficient. Cities with higher efficiency of transformation of non-physical factors are concentrated in the northeast and south, and cities in the southwest are less efficient. The spatial distribution of material factors and the non-material factors of all cities jointly contribute to the spatial composition of total ERE. Generally, ERE is higher in relatively economically developed areas, cities with a rational industrial structure and geographic agglomeration.

Discussions

In the new era, China's economic development is currently focused on sustainable development and high-quality development. Urban agglomeration, a critical component of China's future regional economic and social development, is confronted with the inflexible limitations imposed by resources and the environment. Enhancing ER is the necessary and fundamental prerequisite for expediting the high-quality advancement of Chinese urban agglomeration.

This study explores ERE and conducts the spatial and temporal dynamic comparison between the CCUA and the YRDUA. This study further analyses the two stages of ERE. The results are presented in Table 7. This study's findings can support two hypotheses. *Hypothesis 1 and 2 propose that the ERE of the YRDUA and the CCUA increase yearly and display different spatial characteristics. However, there are significant differences among the cities.* The results of the previous study can prove hypotheses as well. By analyzing the word frequency data of "environmental protection" in the Government Work Report, it can be found that the government is paying more attention to environmental issues (Shiyi and Dengke, 2018), which reflects the increasing intensity of ER. Eastern China is economically developed and has the advantage of coastal openness, so the overall and two-stage efficiency of environmental regulation grows faster. Western China is economically backward, and the inland area is restricted in opening up to the outside world. The western region is rich in natural resources and the environment is of high quality, so the overall and two-stage efficiency of environmental regulation has a higher starting point, but the growth rate is slower and most time in a declining trend. Moreover, small cities are more likely than large cities to exert ER through administrative orders (Shiyi and Dengke, 2018). The YRDUA and the CCUA encompass cities of various sizes, resulting in noticeable disparities in the economic ripple effects across different city scales.

Table 7
Results of the Study

Variables	CCUA		YDRUA	
	Temporal trend	Spatial distribution	Temporal trend	Spatial distribution
ERE	Down, then up	High on both sides Low in the middle	Up	High in the middle Low on both sides
MERE	Down	High in the southeast Low in the middle	Up, then down	High in the west and the middle Low in the north and south
NMERE	Down, then up	High in the north, middle and southeast Low in the southwest	Up	High in the northeast and south Low in the southwest

Notes: ERE represents environmental regulation efficiency. MERE represents material factors environmental regulation stage efficiency. NMERE represents non-material factors environmental regulation stage.

Conclusions and Recommendations

Conclusions

Governments have the dual goals of economic development and environmental governance in sustainable development. The following conclusions can be drawn from this study:

1. ERE, the transformation efficiency of material factors in ER and the transformation efficiency of non-material factors in ER are below 0.41, which indicates low effectiveness.

2. From the time trend, the ERE of the YRDUA has consistently increased, while in the CCUA, it initially decreased and then gradually improved. In the material factor stage, the YRDUA rises in fluctuation and then declines. The CCUA declines in fluctuation. In the non-material factor stage, the YRDUA rises in fluctuation, and the CCUA remains stable in fluctuation. Hypothesis 1 can be confirmed that ERE in the two urban agglomerations increases, but there are differences among cities.

3. Regarding the spatial distribution, the cities with higher ERE in the CCUA are scattered around the urban agglomeration. On the contrary, in the YRDUA, cities with higher ERE are concentrated in the centre of the urban agglomeration. The spatial distribution of the two-stage efficiency shows different characteristics. Hypothesis 2 can be confirmed that from a spatial perspective, the ERE of the YRDUA and the CCUA display different spatial characteristics. However, there are significant differences among the cities.

Recommendations

First, since environment regulation in two urban agglomerations is less efficient, the government should focus on the optimization of environmental regulatory tools. Initially, the Government can implement measures such as increasing environmental protection requirements and intensifying law enforcement to compel enterprises to undergo transformation and upgrading.

Furthermore, the Government should actively endorse environment policies that aim to decrease taxes and fees. In the CCUA, ERE has decreased for a long time. In the material factor stage, the YRDUA's ERE decreased. These imply that it is important to reduce policy costs at the material transformation stage. This will effectively reduce the costs associated with ecological regulations and incentivize businesses to embrace more sustainable production practices and technological breakthroughs.

Moreover, it is imperative to incorporate ERs tailored to specific regions. From a spatial distribution perspective, there is a clear disparity in the distribution of ERE between the two urban agglomerations. The beneficial resources are predominantly concentrated in the more developed areas and cities. Therefore, the developed eastern urban agglomeration should promote novel environmental techniques and prioritize enhancing business profitability. The government should provide guidance to firms in order to transform the burden of ER into a catalyst for technological innovation. In the underdeveloped western urban agglomeration, the primary emphasis should be enhancing environmental control and alleviating the burden on industrial companies. Governments should develop ERs based on the available resources in cities.

Declaration of Competing Interest

None.

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