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Measurement and Spatio-Temporal Characteristics of High-Quality Development Efficiency in Metropolitan Areas: A Case Study of the Changchun Metropolitan Area

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Abstract: The concept of high-quality development (HQD) is characterized by its emphasis on efficiency, equity, and environmental sustainability. In the context of China's new urbanization development, the metropolitan area plays a crucial role in facilitating and sustaining HQD. This study focuses on the Changchun Metropolitan Area (CCMA) as a case study to measure the efficiency of high-quality development (HQDE) at the county level using the super-efficiency SBM model and spatial autocorrelation model. Additionally, we examine the spatio-temporal distribution characteristics of HQDE in terms of economy, innovation, coordination, greenness, openness, and sharing (EICGOS). The main findings are as follows: (1) The HQDE of the CCMA ranges from 0.7 to 0.8 with an initial rapid increase followed by a gradual decline; however, there are notable variations among different counties. (2) Regarding spatial structure within the metropolitan area, highest efficiency is observed in the half-hour living circle followed by the 2-h accessibility circle while lowest efficiency is found in the 1-h commuting circle. Over time, there is a declining trend in efficiency within core leading areas. (3) In terms of dimensions, CCMA demonstrates the highest level of economic development efficiency (EDE), whereas green development efficiency (GDE) exhibits lower levels compared to other dimensions. Furthermore, development efficiencies across all dimensions show a decline over time. (4) Spatially distributed patterns reveal significant agglomeration areas for HQDE within the CCMA region. High-high agglomeration areas are predominantly concentrated in the central region of Changchun and southern region of Liaoyuan while low-low agglomeration areas primarily exist in northwest Songyuan and specific counties within Changchun. To attain HQD of the CCMA, it is advisable to bolster the economic scale of the central city, mitigate developmental disparities between counties and cities, and expedite green transformations in old industrial cities. These findings offer a valuable point of reference for optimizing resource allocation at the metropolitan level and devising strategies to foster regional HQD.

Keywords: high-quality development; super-SBM model; spatio-temporal characteristics; Changchun Metropolitan Area

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1. Introduction

1.1. Background

The model of development at the expense of resource consumption has led to three major crises: climate change, biodiversity loss, and pollution and waste [1]. The Sustainable Development Goals (SDGs) framework, which comprehensively considers economic development, environmental protection, and human well-being, is widely recognized as an effective way to improve the situation [2]. Achieving the SDGs is a shared responsibility of all sectors of every nation state and government, and they are united about the urgent need for bold policies and immediate actions to enable a sustainable future [3]. In this regard, each country develops its own plans according to its own needs, resources and socio-cultural aspirations: the EU proposed a package of circular economy plans and announced the European Green Deal at the end of 2019, with the realization of carbon neutrality in 2050 as the core strategic goal, aiming to build a modern economic system in which economic growth is decoupled from resource consumption [4]. The United States adopted the America 2050 Strategy in 2006, which provides a guiding framework for promoting economic and environmental development [5]. Since 2000, China has been dedicated to reconciling environmental concerns with economic growth [6]. In 2017, China proposed high-quality development (HQD). Its essence lies in putting quality first, achieving high efficiency, fairness, and environmentally-friendly sustainable growth to meet people's increasing aspirations for a better life [7]. HQD emphasizes innovation as the primary driving force while also embodying coordination as an inherent feature; green principles are embraced universally; openness is seen as essential; sharing becomes fundamental. In short, high-quality development is an efficient, fair, and sustainable mode of development, which can stimulate social creativity and activate social vitality.

HQD marks a new era for China's development, indicating that previous models of economic growth centered around "scale expansion" and "factor-driven" approaches should gradually transition towards "high efficiency", "fairness", and "sustainability" [8]. Consequently, efficiency emerges as an inherent requirement for achieving HQD while also serving as a crucial benchmark for evaluating the level of development.

Against the background of economic globalization, the economic competition of a country or region is accelerating into a competitive pattern dominated by urban agglomerations [9]. Metropolitan areas, city clusters, and metropolitan belts are the growth poles and power sources of high-quality development [10]. Urban agglomeration has become a central focus in China's new urbanization strategy, with an emphasis on achieving HQD [11]. However, it should be noticed that the increasing concentration on urban agglomeration has given rise to a development gap between core cities and the other smaller secondary cities within urban agglomerations, which is detrimental to HQD of regions [12]. The metropolitan area has emerged as a distinct geospatial unit, acting as the core hub for population concentration, economic activities, and service clustering within the urban agglomeration [13]. The spatial scale of a metropolitan area is smaller than that of an urban agglomeration, and it encompasses a core city and several second-level cities simultaneously, presenting a novel perspective to addressing the unevenness between cities. Thus, the metropolitan area plays a crucial role in supporting HQD [14]. Additionally, it serves as a driving force and a leading example in promoting HQD [15].

Northeast China, being a well-established industrial base in China, has played a significant role in the country's efforts towards modernization because of the past planned economy system, similarly to the phenomenon in the German Ruhr industrial zone. However, with the implementation of economic reforms and the transition to a new normal economy, the region has experienced a decline in economic performance and a long-term downturn. Consequently, there has been a growing focus on revitalizing Northeast China in the field of regional development research. The primary task and crucial opportunity lie in exploring strategies for achieving HQD that can propel comprehensive revitalization to a new stage. The Changchun modern metropolitan area plays a crucial role in facilitating the rejuvenation and HQD of northeastern China. It functions as a central hub for population, economy, and resources, despite its spatial coverage being less than half of the total geographical area of Jilin Province. However, the urban center of Changchun is confronted with various challenges, including a sluggish rate of economic growth and a dearth of impetus for development [16]. In terms of economic aggregate, Changchun was ranked 12th among China's 15 sub-provincial cities in 2020, positioning it in the fourth echelon. The Gross Domestic Product (GDP) output value of Changchun in 2020 was approximately twice as high as that of other cities. The increasing gap between population distribution has led to a persistent concentration of residents in the central city, impeding the integration of various regions within the metropolitan area and hindering the establishment of a cohesive spatial framework for urban development. As the pursuit of HQD has shifted from a focus on quantity to quality, efficiency has become a key aspect of HQD. Therefore, evaluating the level of HQD in the CCMA from an efficiency perspective aligns more closely with the concept of HQD.

1.2. Literature Review

The proposal of the 17 Sustainable Development Goals (SDGs) by the United Nations in 2015 has offered a comprehensive framework for developed and developing nations to prioritize the harmonious coordination of economy, ecology, and society [17]. Its purpose is to accelerate mutual coordination and common development in terms of population, resources, and environment [18]. HQD builds upon the fundamental principles of sustainable development ideology, including green development, coordinated development, and shared development, which are closely related to the environment, regional coordination, and human welfare in sustainable development. Despite the notion of HQD originating from Chinese discourse, it is also mentioned in international academic research through various related terms such as growth [19], sustainable development [20], innovative development, and innovative growth [21]. These concepts are essential components of the connotation of HQD, as they align with its underlying principles. In a word, HQD is not only a long-term strategy to drive China's modernization process but also a localizing plan to facilitate global SDGs [22].

Since its introduction, scholars have engaged in extensive discussions on the meaning of HQD. Pan et al. believed that HQD is an efficient, fair, and sustainable development that stimulates the creativity and vitality of the whole society [23]. Hu et al. and Li et al. considered that HQD is multi-dimensional and part of a complex organic whole involving the economy, society, culture, and ecology [24,25]. Zhang argued that HQD entails satisfying the growing demands of individuals for an improved standard of living through enhancements in productivity and socio-economic advancement [26]. An & Li define HQD in the Yellow River Basin as prioritizing ecology while emphasizing market efficiency, energy transformation, industrial support, regional coordination, and people-oriented growth [27]. Although the connotation of HQD has been widely discussed, there is still a lack of consistency in academic evaluations regarding the definition of HQD. In addition, it is worth noting that efficiency is mentioned several times.

The concept of HQD encompasses a comprehensive and intricate framework, suggesting that the creation of evaluation index systems for HQD is multifaceted and intricate. Several studies have been conducted to evaluate the extent of HQD in various regions according to new development concepts and its own actual situation. Chen et al. and Ma & Xu evaluated the HQD level of the Chengdu-Chongqing metropolitan area and the Yellow River Basin based on innovation, coordination, openness, sustainability, and sharing [28,29]. Wang et al. [30] and Chen et al. (2023) [31] have identified imbalanced and insufficient development in central China and Northeast China; they devised an HQD evaluation index system that encompasses effectiveness, coordination, innovation, sustainability, sharing, and stability. Xu et al. proposed an HQD evaluation index system in the Yellow River Basin [32] which took into account ecological security, economic growth driven by innovation, enhancement of people's livelihoods, and environmental and ecological conditions. Pan et al. proposed a comprehensive five-dimensional index system to assess the level of HQD in prefecture-level cities in China [23], including economic development, innovation impact, environmental influence, ecological services, and the well-being of the population. Mai et al. constructed an evaluation index system to assess the economic and social development of 31 provinces in China from five perspectives: economic dynamics, innovation capability, people's welfare, green ecology, and security [33].

While the index systems of these studies are based on the connotation of HQD, they all evaluate HQD at a general level. This approach only scratches the surface of HQD and fails to explain its internal mechanism. It also lacks a specific perspective for evaluating certain aspects such as efficiency. Hua et al. were the first to study HQD efficiency and TFP of regional economies in China in terms of the five development concepts [34]. Zhang et al. introduced the efficiency perspective and constructed the ICGOS model to evaluate the HQD level of the Yangtze River Economic Belt [35]. Tian et al. evaluated the efficiency of green development in Chinese cities by considering unexpected output [36]. These studies make a valuable contribution to the enrichment of evaluation methods and perspectives in the assessment of HQD. However, the scale of the research is macro rather than micro, and primarily focuses on singular aspects of HQD.

As for research content, the evaluation of HQD has been involved in multiple industries, such as agriculture [37], logistics industry [38], tourism [39], with a significant focus on the economy [40], environmental constraints [41], and resources [42]. However, there is seldom a thorough attempt to estimate HQD.

Existing research on the scale of HQD mainly focused on the whole country [23], regional areas [30,32,43], or basin economic belt [35]. The assessment of HQD levels within urban agglomerations and metropolitan areas is in its nascent phase, with some insightful analyses having been conducted. For instance, Li et al. proposed connotation of HQD of city clusters based on the basic comprehension of Chinese-style modernization and measured the HQD of 19 city clusters by using the entropy weight CRITIC method [9]. Xie et al. uses the entropy weight TOPSIS method to build an urban HQD level indicator system, comprehensively measuring the high-quality development level of 31 cities in the middle reaches of the Yangtze River and analyzing the evolution of spatial distribution and autocorrelation [44]. Tu et al. assessed the HQD level of the Chengdu-Chongqing urban agglomeration from the perspective of spatial structure, scale, and urban connection [45]. Recommendations have been proposed to promote HQD in specific urban agglomerations, such as the Beijing-Tianjin-Hebei urban agglomeration [46]. In terms of metropolitan areas, the green development level has been examined, taking into account factors such as "double polarization", plateau type, valley type, and vulnerability [47]. Sustainability assessments have been conducted using the Sustainable Development Solutions Network (SDSN) framework [48]. Transportation system developments and challenges in specific metropolitan areas, such as the Jakarta metropolitan area in Indonesia, have been reviewed, with recommendations for optimization [49]. Qiu et al. analyzed the spatial-temporal heterogeneity of green development efficiency and its influencing factors in the growing Xuzhou Metropolitan Area [50]. However, the majority of studies concentrate on the economy and green development of urban agglomerations [51,52], with limited research dedicated specifically to the high-quality development of urban agglomerations and metropolitan areas, and even fewer evaluations of efficiency. Additionally, when assessing the development level of both metropolitan areas and urban agglomerations, the entropy weight method is predominantly used, while other methods are rarely employed.

Data envelopment analysis (DEA) has gained popularity among scholars due to its non-parametric calculation method and unrestricted production function. Researches primarily focused on the efficiency of resource utilization, including water [53], land [54], energy [55], carbon emission [56,57], and multi-resource systems like water-energy-food systems [58,59]. The DEA model for efficiency measurement has undergone several developmental processes. Initially, the basic DEA models solely permitted proportional enhancements in both input and output. However, the introduction of slackness variables in the non-radial SBM model enabled improvements beyond proportionality [60]. To address the issue of multiple decision-making units which are effective simultaneously, the Super-DEA model was introduced [61]. Panel data models, such as window-DEA and Malmquist index [62], have been developed to ensure comparability over time. Overall, the models used in the field of DEA have witnessed significant advancements in terms of comprehensiveness and accuracy in measuring efficiency, while also effectively tackling practical challenges.

In summary, the current literature on metropolitan areas and urban agglomerations is extensive and insightful, offering valuable research findings that are highly relevant for studying the HQD of the CCMA. However, there are still some limitations to consider. Firstly, most studies primarily focus on qualitatively describing the positive impact of metropolitan areas on the development of urban agglomerations, without specifically addressing the topic of HQD within metropolitan areas. Secondly, while many studies evaluate the level of HQD from a macro perspective, such as the new development concept, they often fail to delve into its core meaning or establish an evaluation framework focused on a specific aspect. When it comes to evaluating the efficiency of HQD, few studies specifically combine efficiency with an input-output perspective. Furthermore, there is a limited number of rigorous evaluations of development conducted at the metropolitan level. The majority of research on urban development primarily concentrates on the city scale, with less emphasis placed on the county level. Therefore, the objective of this paper is to address the actual needs and connotations related to the HQD of the CCMA. To achieve this goal, a comprehensive evaluation index system will be constructed from an input-output perspective. This system incorporates the new concept of development and considers the development of regional economies, which encompasses six dimensions: economy, innovation, coordination, greenness, openness, and sharing. The super-efficiency SBM model is used to analyze the level of HQD in the CCMA. Subsequently, a spatio-temporal difference analysis is conducted to explore its evolutionary characteristics.

2. Materials and Methods

2.1. Research Framework

This study aims to examine the level of high-quality development in the Changchun Metropolitan Area (CCMA). The study is organized into several parts. Firstly, it provides an understanding of the concept of HQD and metropolitan area development, analyzing the mechanism of HQD in the metropolitan area from the perspective of input and output. The evaluation dimensions of HQD at the metropolitan area level are also explained. Secondly, an evaluation index system for the level of HQD in the metropolitan area is constructed based on an input-output perspective. By employing the DEA model and spatial autocorrelation model, this study quantifies and examines the level and spatial distribution characteristics of HQD in the CCMA from 2010 to 2020. Finally, drawing upon the findings, the authors offer recommendations aimed at fostering HQD in the CCMA (Figure 1).

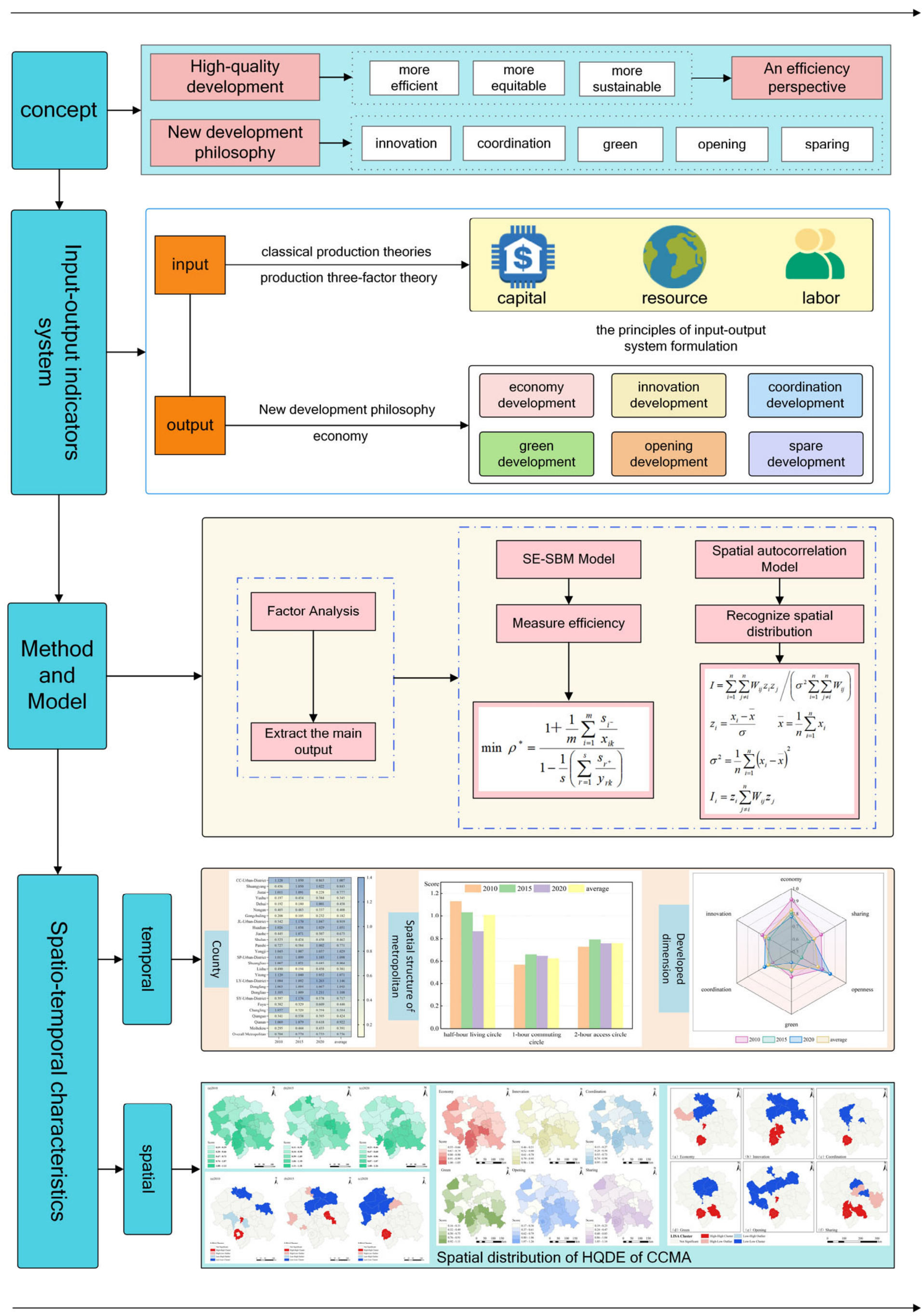

Figure 1. Research framework.

2.2. Theoretical Logic of Constructing the Evaluation Index System

HQD entails the endeavor to enhance efficiency and progress to a more advanced stage. Efficiency is a crucial prerequisite for attaining development of superior quality, and it is evaluated by assessing both input and output. The development concepts of innovation, coordination, greenness, opening and sharing offer precise guidance for each region to attain HQD and delineate the trajectory of growth. Metropolitan areas are regarded as cyber space regions in which core cities assume a prominent position in terms of radiation and driving forces. They aim to achieve integrated economic, social, and ecological advancements by leveraging spatial synergy, collaborative service construction and sharing, infrastructure enhancement, and enhanced connectivity. Metropolitan areas serve as essential support systems for urban agglomerations and play a pivotal role in fostering regional development as part of new urbanization initiatives. Therefore, the objective of this paper is to develop an evaluation index system at the metropolitan area level, with a specific focus on six key aspects: economy, innovation, coordination, greenness, openness, and sharing. This approach seeks to identify challenges and shortcomings in promoting HQD in metropolitan areas using the “five developmental concepts” framework.

The study has constructed an evaluation index system (Table 1 and Figure 2) consisting of two main dimensions: input and output. Within the input dimension, indicators such as capital, labor, and resources have been selected based on the theoretical framework of the three factors of production. In terms of the output dimension, the study has identified six distinct criteria layers: economic development, innovative development, coordinated development, green development, open development, and shared development. Economic development, being one of the fundamental components, plays a crucial role in facilitating the growth of metropolitan areas by serving as the material basis for their expansion. It encompasses the measurement of the overall economic aggregate and scale, thereby contributing to the attainment of high-quality urban development. In contrast, innovative development serves as a catalyst for the growth of high-quality metropolitan areas by quantifying the outputs of innovation. Coordinated development emphasizes the need to address imbalances and evaluates the degree of coordination within a metropolitan area from perspectives such as the urban-rural gap and industrial structure. Green development aims to establish a balanced and symbiotic relationship between human beings and the natural environment, while evaluating the effectiveness of environmental governance and the provision of ecological services. Open development is considered essential for high-quality progress in a metropolitan area, and can be measured through indicators such as foreign trade levels and an open environment assessment. Lastly, shared development aims to ensure wider benefits to people, reflecting a people-oriented concept that takes into account public services and social security when constructing shared indicators.

Table 1. The input-output indicators system of HQDE.

Type		Indicators	Necessity	References
Input	Capital	Fixed asset investments	Reflect capital input	[58]
	Labor	Number of employees in the secondary and tertiary industries Rural practitioners	Reflect labor input	
	Resource	Construction land area Total energy consumption Total water supply	Reflect resources inputs	 [58] [58]
Output	Economy	GDP	Reflect economic aggregate	[58]
	Innovation	Annual number of patent grants	Reflect innovation level	[35]
	Coordination	Per capita disposable income ratio between urban and rural areas	Reflect urban-rural differences	[29], [35]
		Industrial structure advanced index	Reflect industry coordination	[28], [31]
	Green	Treatment rate of domestic sewage	Reflect environmental quality	[28], [29]

	Harmless treatment rate of domestic waste		[28], [29]
	Per capita green park area	Reflect environmental services	[31]
Open	Total exports/GDP Total number of tourists	Reflect economic dynamism	[29]
Shared	Number of full-time teachers per 10,000 people	Reflect infrastructure construction and services	[31], [35]
	Beds of medical institutions per 10,000 people		[28], [31]
	Per capita highway mileage		[31]

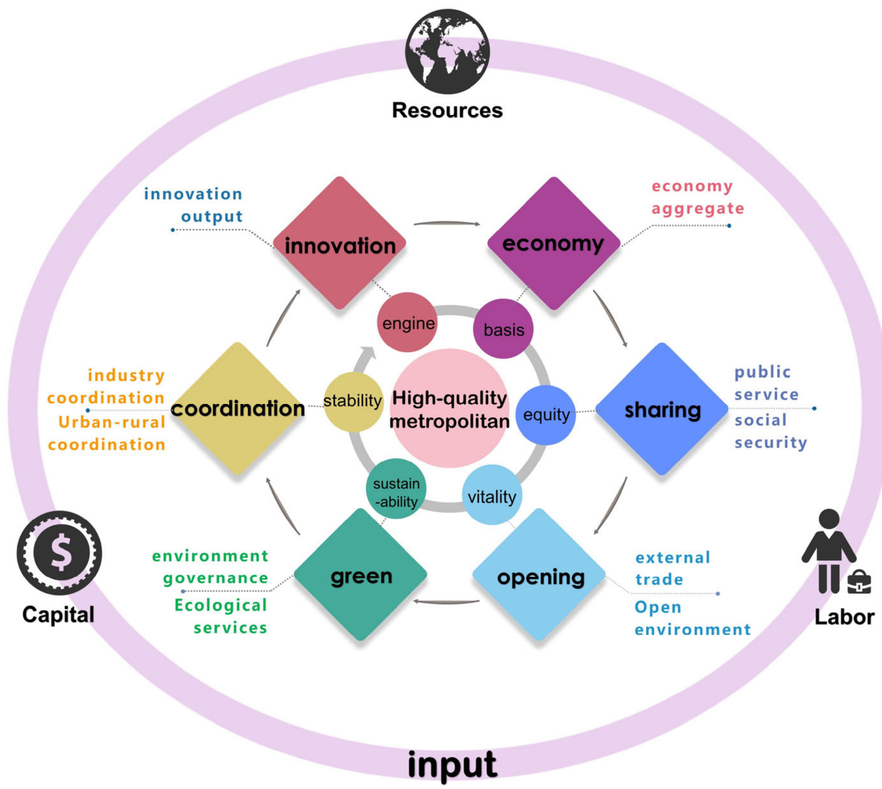

Figure 2. Efficiency measurement mechanism of HQD in CCMA.

2.3. Research Area

The Changchun Metropolitan area (CCMA) is situated in the central region of Jilin Province. The Changchun Modern Metropolitan Area Development Plan (2021–2035) is the governing framework that falls under Jilin Province's "one main six double" HQD strategy. The region encompasses a combined land area of 91,000 square kilometers and comprises six cities, namely Changchun, Jilin, Siping, Liaoyuan, Songyuan, and Meihekou. As of the end of 2020, the CCMA had a resident population of 18.26 million and a total GDP of CNY 1001.7 billion [63].

The central and eastern regions of the CCMA are located in the central agricultural belt of Jilin Province. This area serves as the distribution hub for the highly productive golden corn belt. The northwest region, in contrast, is situated on the eastern periphery of a vulnerable ecological zone for agriculture and animal husbandry in northern China. This particular region exhibits a fragile ecological backdrop that is prone to wind erosion and sandstorms. Significant challenges, including soil erosion, land degradation, wetland shrinkage, and land salinization, have emerged in the northwestern area of the CCMA, thereby impeding sustainable agricultural development [64].

In recent years, significant advancements have been made in the CCMA to promote the seamless integration of science and the economy. This progress has been accomplished by expediting the processes of technology transfer and establishing a contemporary industrial system. However, there are still practical limitations that need to be addressed in the field of scientific innovation. These limitations include the dispersion of resources, the inadequate transformation of technological achievements into tangible outcomes, and the lack of sufficient economic growth momentum [65]. The development of the CCMA is currently undergoing rapid growth, shifting from gradual expansion to the exploration of its full potential. However, there are still prominent issues such as unbalanced spatial allocation of resources, insufficient division of labor and cooperation, intense competition at a low level of homogenization, and an imperfect system and mechanism of coordinated development [66]. Figure 3 presents a graphical depiction of the geographical position of the research area and the architectural layout of the CCMA.

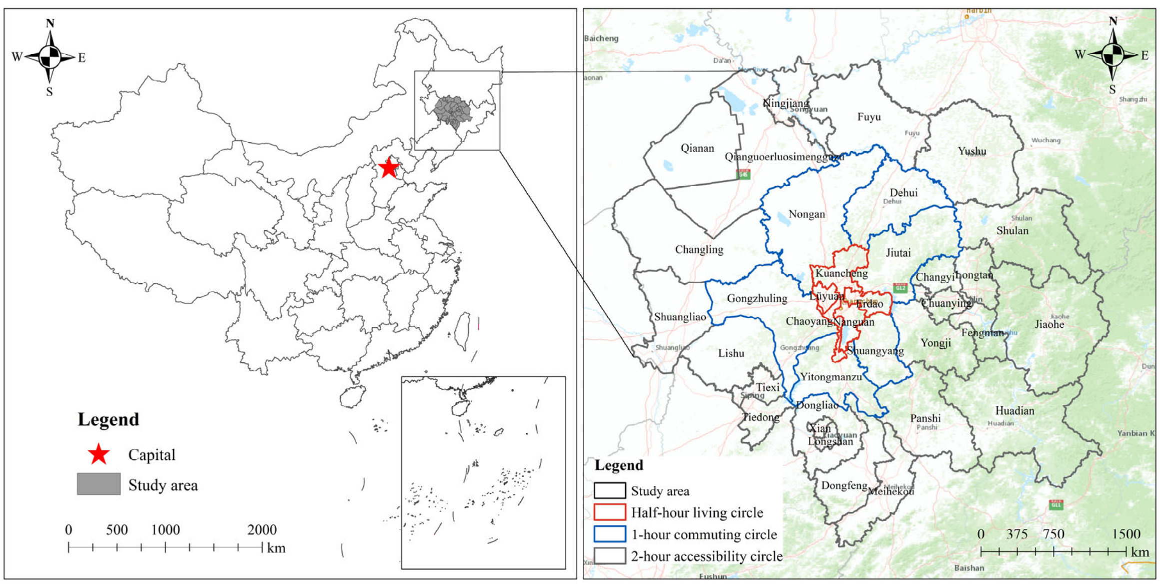

Figure 3. The study area (approval number GS(2020)4619).

2.4. Research Methods

2.4.1. Factor Analysis

Factor analysis is a statistical method that was developed by C.E. Spearman, a renowned British psychologist, who developed a theoretical framework aimed at identifying underlying factors within a specific set of variables. The primary objective is to identify the underlying factors that can categorize variables with similar attributes, thereby reducing the complexity of the variables. Additionally, factor analysis allows for the testing of hypotheses pertaining to the relationships between variables [67,68].

2.4.2. Super Efficiency SBM Model

The traditional DEA model does not take into account the slack of input and output variables. In response to this limitation, Tone proposed a method to evaluate the efficiency of decision-making units (DMUs) using non-radial measurement and slack-based measure (SBM) [60]. This led to the development of the SBM model for non-expected output. However, the SBM model's values are restricted to a range of 0 to 1, which presents a challenge when multiple DMUs can be efficient simultaneously. To address this issue, Tone introduced the super-efficiency SBM model, which assesses DMUs using effective

SBMs and allows for comparison among multiple effective DMUs [51]. By integrating the SBM model with the concept of super-efficiency, the super-efficiency SBM model facilitates the computation of efficiency scores for all Decision Making Units (DMUs), taking into account unexpected outputs. This effectively overcomes the limitations of standard efficiency models. In the assessment of super-efficient SBM, the SBM model is first employed to assess the decision-making unit (DMU), followed by the evaluation of the efficient DMU utilizing the super-efficient model [69]. Therefore, this study employs the super-efficiency SBM model to assess the efficiency of high-quality development in the CCMA.

Assuming n decision-making units (DMUs) are being measured for their efficiency, each having m types of inputs denoted as $x_i(i = 1,2,\cdots,m)$, q items of outputs denoted as $y_r(r = 1,2,\cdots,q)$, and considering a specific DMUk under evaluation; then, according to the super-efficiency SBM model, the measurement of each DMU's efficiency is as follows:

$$\rho^* = \min\rho = \min\frac{1-\left(\frac{1}{M}\sum_{m=1}^{M}\frac{s_m^x}{x_m^{k'}}\right)}{1+\left[\frac{1}{1+Q}\left(\sum_{q=1}^{Q}\frac{s_q^y}{y_q^{k'}}\right)\right]}$$
$$\sum_{k=1}^{K} z_k^y y_q^k - s_q^y = y_q^{k'}, q = 1\cdots, Q;$$
$$\sum_{k=1}^{K} z_k^y y_m^k - s_m^x = y_m^{k'}, m = 1\cdots, M;$$
$$s_q^y \geq 0, s_m^x \geq 0 \tag{1}$$

In the formula: ρ^* indicates the efficiency value of HQD of DMU, which can exceed 1, the larger the value, the higher the efficiency level of HQD; M and Q represent input and output variables; s_m^x and s_q^y represent input and output slack variables; z_k^y represents weight variables. All calculations were developed using Max DEA 8 Ultra.

2.4.3. Spatial Autocorrelation Model

The spatial autocorrelation model utilizes the global Moran index and local Moran index to analyze the spatial discrepancies in measured outcomes and reveal the spatial clustering patterns of efficiency values. The global Moran index I, which is a commonly used and effective measure for illustrating the spatial autocorrelation within the study area [70], is calculated using the following equation:

$$I = \sum_{i=1}^{n}\sum_{j\neq i}^{n} W_{ij} z_i z_j \Bigg/ \left(\sigma^2 \sum_{i=1}^{n}\sum_{j\neq i}^{n} W_{ij}\right)$$
$$z_i = \frac{x_i - \bar{x}}{\sigma} \qquad \bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{2}$$
$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2$$

where I is the global Moran index; n is the number of observations; x_i is the observed value at position i; and z_i is the normalized transformation of x_i. The expected value and expected variance of the global Moran index can be calculated from the assumed spatial data distribution.

The global Moran index ranges from [−1, 0) and (0, 1], which represent spatial negative correlation, spatial uncorrelation, and spatial positive correlation, respectively. Compared with the global Moran index, the local Moran Index I_i is used to verify whether the research object has the phenomenon of outlier agglomeration [70]. Its calculation formula is as follows:

$$I_i = z_i \sum_{j \neq i}^{n} W_{ij} z_j \tag{3}$$

If the calculated local Moran index is positive, it indicates that the autocorrelation type of HQDE is either high-high clustering or low-low clustering, with adjacent values of the same type being close together. If the local Moran index is negative, it means that different types of attribute values (high-low clustering or low-high clustering) are adjacent. Z statistics is used to test the significance of the local Moran index. This article uses the global Moran index to describe the spatial correlation degree of HQDE values, and the local Moran index is used to describe its spatial clustering characteristics in CCMA.

2.5. Data Source

A total of 26 counties and districts within the CCMA were selected as subjects for investigation. Each district within a prefecture-level city served as an evaluation unit. The sample years encompassed 2010, 2015, and 2020. Data primarily originated from reputable sources including the "Jilin Statistical Yearbook" (http://tjj.jl.gov.cn (http://tjj.jl.gov.cn (accessed on 26 May 2023)), "China County Statistical Yearbook", "China Urban Statistical Yearbook", "China Urban Construction Statistical Yearbook", and "China County Construction Statistical Yearbook" (https://www.stats.gov.cn (http://tjj.jl.gov.cn (accessed on 26 May 2023)). Furthermore, statistical yearbooks, statistical bulletins, and government work reports for each prefecture-level city and county were consulted to ensure comprehensive information gathering. Moreover, the land use data in this study was obtained from Wuhan University's CLCD database, which offers a spatial resolution of 30 m (http://irsip.whu.edu.cn/resources/CLCD.php (accessed on 18 April 2023)). The energy consumption data were extracted from the night light data of China from 2010 to 2020 by referring to the night light value estimation method developed by Wu Jiansheng [71]. Missing data were addressed through interpolation techniques or substitution with nearby values. Additionally, the collected information underwent preprocessing procedures that utilized factor analysis to identify five common factors out of twelve output indicators for DEA analysis. The MaxDEA Ultra8.0.0 software facilitated super-efficiency SBM analysis. Overall, these rigorous methods ensure the accuracy and reliability of our findings.

3. Results

3.1. Time Variation Characteristics of HQDE

3.1.1. HQDE of County and District Areas

Based on the established evaluation indicators system mentioned earlier, the input-output efficiency values of HQD in the CCMA were calculated for the years 2010, 2015, and 2020 using the MaxDEA Ultra8.0.0 super-efficiency SBM model, as illustrated in Figure 4. The findings indicate that the average HQDE of the CCMA during the study period was 0.736, suggesting that it has not yet achieved an effective state and there is still a gap to be bridged. The averages for the years 2010, 2015, and 2020 were recorded as 0.704, 0.770, and 0.733, respectively, revealing a temporal pattern characterized by rapid growth followed by gradual decline, resembling an inverted U-shape. Notably, the efficiency value for the year 2020 slightly decreased compared to that of 2015, which could be attributed to the impact of the COVID-19 pandemic on the economy; for example, the suppression of supply and demand, resulting in a decline in efficiency [72].

There are significant disparities in the HQDE within the CCMA, particularly among its counties and cities. Roughly one-third of the counties in this region demonstrate effective levels of development, as indicated by efficiency values in 2010, 2015, and 2020. Among these counties, Changchun Urban District, Huadian, Yongji, Siping, Yitong, and Liaoyuan Urban District exhibit relatively high levels of HQDE, with average efficiency values exceeding 1 (indicating an effective state). Notably, the Liaoyuan urban district stands out with a high efficiency value of 1.146. This phenomenon is attributed to the comparatively lower levels of labor force, land, and water resources input in the Liaoyuan urban area in comparison to other counties. That is to say, less resource input has created a good output. In contrast to other counties within the metropolitan region, Liaoyuan city's land area comprises a mere 2.8% of the overall land area of Jilin Province, resulting in diminished investment in land resources. Moreover, this can be attributed to Liaoyuan's designation as a pioneering city for the economic transformation of resource-depleted urban areas since 2008. The government has facilitated this transformation and upgrading through the optimization of the business environment, the development of emerging industries, and the formation of a cluster effect for economic transformation and industrial structure optimization and upgrading [73]. On the other hand, Yushu, Dehui, Gongzhuling, and Lishu lag behind in terms of HQDE. These areas are primarily focused on agricultural development, with a higher input of rural labor and agricultural water compared to the average of the whole metropolitan area. However, the industrialization of agricultural products is limited, resulting in inadequate agricultural value output and low agricultural management efficiency [74,75]. When considering different years, Changchun Urban District had the highest overall efficiency value (1.128) in 2010, while Dehui had the lowest efficiency value—below 0.2. In 2015, Songyuan Urban District exhibited the highest level of efficiency (1.176), whereas Gongzhuling was found to be the least efficient (0.105). In 2020, Liaoyuan Urban District and Jiutai were identified as the highest and lowest performing areas, respectively, with efficiency values of 1.263 and 0.228. Over time, both the maximum and minimum values for HQDE have increased, indicating a gradual shift towards an effective state within the CCMA and a positive trend in terms of HQD level.

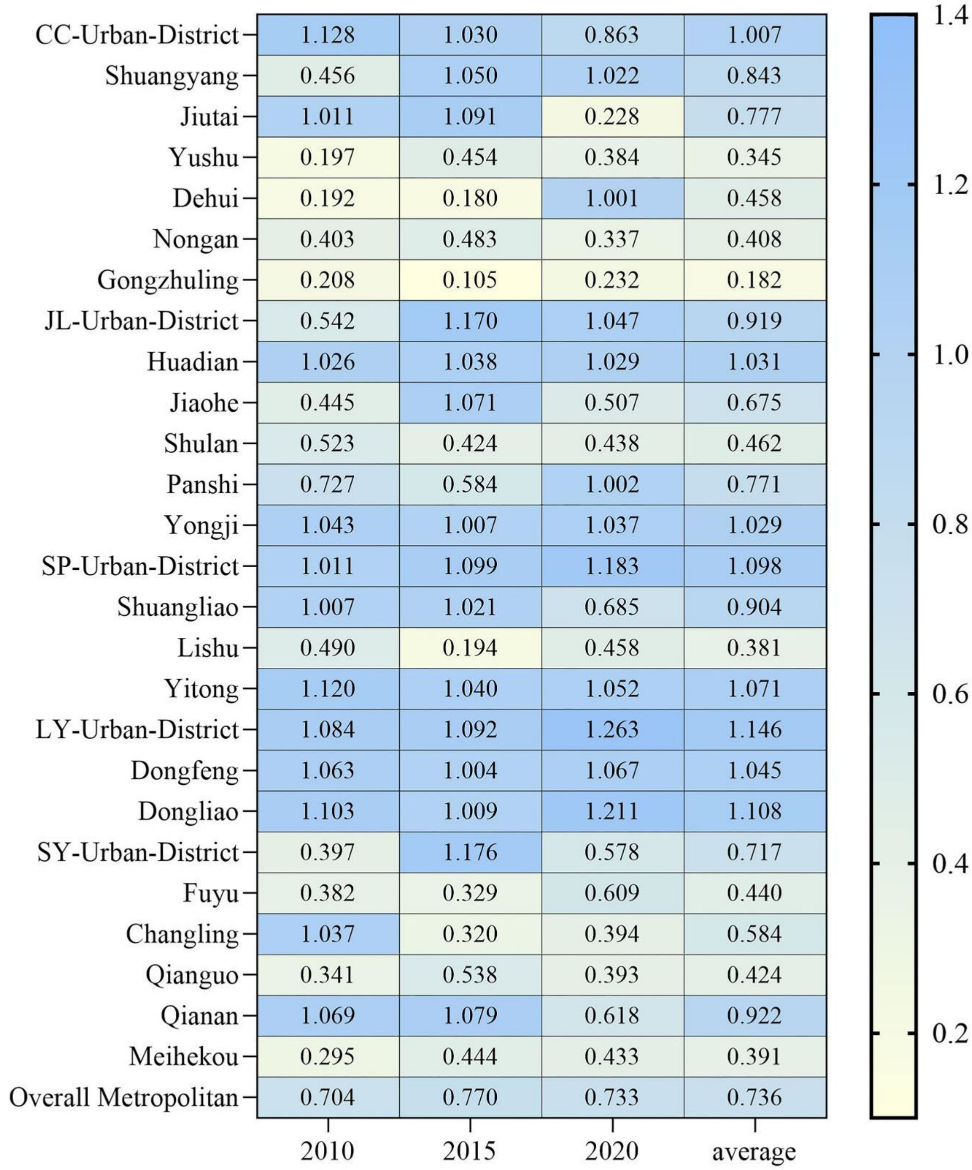

Figure 4. HQDE of 26 counties and districts from 2010 to 2020.

3.1.2. HQDE of the Spatial Structure at the Metropolitan Scale

The metropolitan area is a spatially structured region characterized by hierarchical layering. In the Jilin Province's strategic planning for the HQD of CCMA, it has been divided into three concentric circles: the half-hour living circle (the core leading area of the metropolitan area), the 1-h commuting circle (the primary carrying area of the metropolitan area), and the 2-h accessibility circle (the radiation and cooperation area of the metropolitan area). These circles represent different areas within the metropolitan region, each with varying levels of efficiency in terms of overall HQD.

Upon analyzing the data for each circle, it is evident that the average values for overall HQDE are 1.007, 0.623, and 0.757 for the half-hour living circle, 1-h commuting circle, and 2-h accessibility circle, respectively (Figure 5a). The half-hour living circle stands out with the highest efficiency value, indicating successful achievement in HQD. However, the 1-h commuting circle lags significantly behind both the half-hour living circle and the 2-h accessibility circle. This discrepancy may be attributed to its proximity to the central city of the metropolitan area, which leads to the concentration of population, resources, and technical talents in the central city, resulting in inefficiency within the 1-h commuting circle [62,65].

Furthermore, the temporal trends of the three circles exhibit distinct patterns. HQDE in the half-hour living circle shows a decline over time, suggesting a weakening radiation and driving effect of the central city of the CCMA, as well as insufficient sustainability in its development. This finding is consistent with previous research conducted by Yao et al. [54,76] and Ding et al. [63,66]. On the other hand, the changing trends in both the 1-h commuting circle and the 2-h accessibility circle align with those of the entire metropolitan area. This indicates that these two circles play a significant role in determining the overall efficiency value of the metropolitan area as a whole.

3.1.3. HQDE of Development Dimensions

The comprehensive development of the metropolitan area encompasses various dimensions, including economy, innovation, coordination, greenness, openness, and sharing. The following section aims to measure and analyze the efficiency values of these dimensions in order to promote HQD.

As depicted in Figure 5b, the efficiency level of economic development is at its peak, with an efficiency value surpassing 0.8, indicating proximity to the optimal state. The efficiency values of the other dimensions exhibit minimal variation and a significant difference from the optimal state. Notably, the efficiency value for green development is the lowest at 0.646, indicating a relatively low level of green development in the CCMA. This finding aligns with the research conducted by Sun et al. [77]. Northeast China is China's old industrial base where heavy industry has long been the focus of industrial development. The current energy consumption structure heavily relies on thermal power, which is difficult to change in the short term [78]. The historical environmental pollution caused by the long-term resource development process poses challenges for Northeast China in achieving high-level green development [79]. The seasonal air pollution problem is prominent due to the large-scale open burning of agricultural straw before spring ploughing in the main grain-producing areas. This practice significantly worsens local and regional air quality, with the average daily concentration of PM2.5 reaching 807 μg/m^3, which is 32 times higher than the concentration standard (https://www.mee.gov.cn/ywgz/dqhjbh/dqhjzlgl/202004/t20200419_775251.shtml (accessed on 25 April 2024)). Furthermore, the efficiency of shared development and coordinated development is relatively low at 0.710, indicating suboptimal levels in the region. This may be attributed to the industrial structure of the metropolitan area, which prioritizes the industrial economy as the primary "growth pole", thereby impeding the coordinated development of the region. This is consistent with the findings of Wang et al. [30] and Chen et al. [80]. Additionally, the insufficient construction of regional transportation infrastructure [81] contributes to the limited progress in shared development. Between 2020 and 2022, the average density of Changchun's urban road infrastructure is projected to be 5.5 km/km^2, which is lower than the national average (6.4 km/km^2) [82].

From a temporal perspective, the overall efficiency value of the six dimensions gradually decreases over time, with the most significant decline observed in 2015. Specifically, the efficiency value of economic development and green development tends to be low, while the efficiency value of coordinated development shows an increasing trend. The open development dimension exhibits noticeable fluctuations, with an average fluctuation rate of 34%. The introduction and implementation of the Northeast Revitalization Strategy has led to some economic development in Northeast China. However, since 2013, China's economy has entered a new normal phase, resulting in a decline in the economy of Northeast China and the emergence of the "new Northeast phenomenon" stage in the revitalization efforts [83]. Based on the above analysis, it is evident that prioritizing green development and coordinated development is crucial for the future HQD of the CCMA.

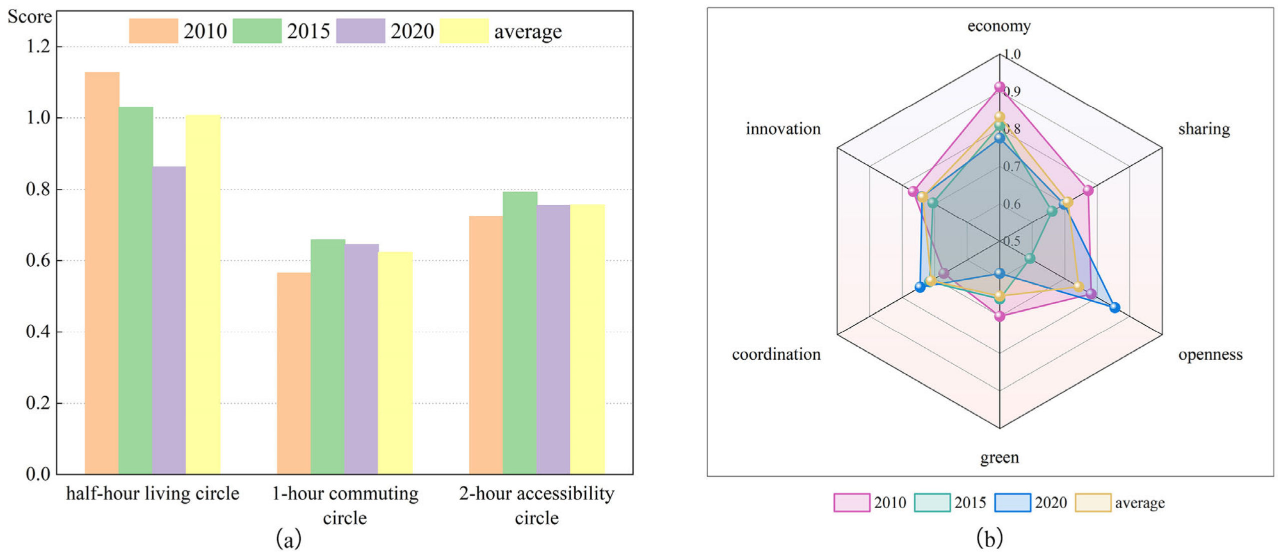

Figure 5. (**a**) Efficiency values for spatial circles from 2010 to 2020 and (**b**) efficiency values for development dimensions from 2010 to 2020.

3.2. Spatial Distribution Pattern and Evolution of HQDE

3.2.1. Spatial Distribution of HQDE at the Overall and County Scales

In order to conduct a comprehensive analysis of the spatial distribution pattern of HQD in the CCMA, this study presents a spatial distribution map illustrating HQDE in the years 2010, 2015, and 2020 (Figure 6). The findings reveal that the central, southeastern, and southern counties and cities within the CCMA exhibit higher levels of HQDE, while lower levels are observed in the western and northern regions. Over time, there has been a declining trend in efficiency values for the western region. This has resulted in a spatial evolution pattern within the CCMA, characterized by dispersion towards the southeast and northwest directions. Consequently, a spatial differentiation pattern emerges, with higher efficiency observed in the southeast and lower efficiency observed in the northwest. This spatial differentiation can be attributed to various factors, including the concentration of resource elements and technologies within the central city, as well as the reliance on agricultural production and petroleum resource extraction industries that are prevalent in the western and northern areas. These industries often require substantial material inputs to achieve greater economic benefits, which can result in lower overall efficiency [65].

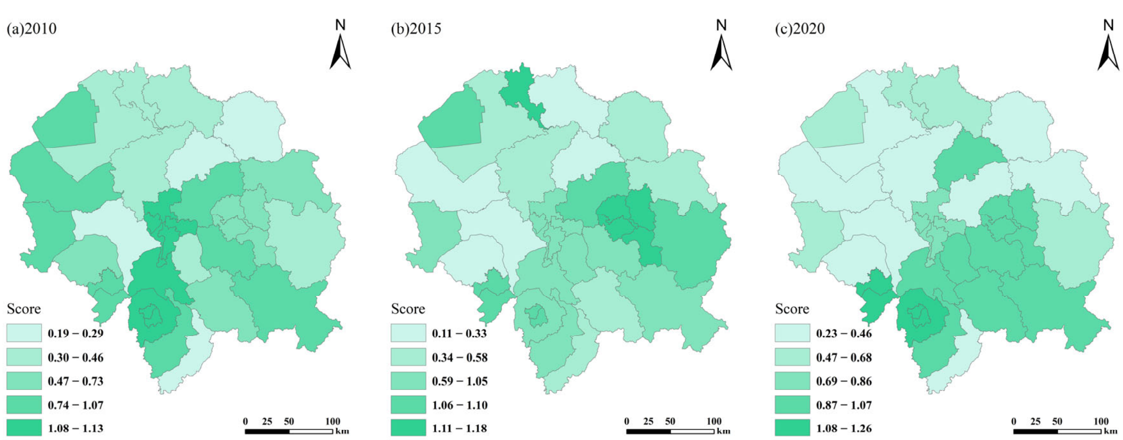

Figure 6. Spatial distribution of HQDE in the CCMA from 2010 to 2020.

3.2.2. Spatial Distribution of HQDE by Development Dimensions

There are notable variations in the spatial distribution pattern of efficiency values across different dimensions of development. Figure 7 illustrates that regions with high efficiency values in economic development, innovative development, and open development are concentrated in the central, southern, and southeastern areas of the CCMA. Conversely, areas with high efficiency values in coordinated development are found in the northwestern and southern parts, while the southern, southeastern, and western regions exhibit higher levels of green development. The southeastern region demonstrates the highest level of shared development, followed by the central region.

This analysis demonstrates that the central region of the metropolitan area exhibits a notable degree of economic development, innovation, and openness. However, it falls short in terms of green development and coordinated development, particularly in the urban areas of Changchun and Jilin. The findings presented here contradict the conclusions drawn by Sun et al. [79], as this study employed an input-output perspective to assess efficiency. The central urban area in question has a significantly higher input compared to the surrounding counties, but its output may not reach a level that corresponds to the input, resulting in low efficiency. The rapid urbanization and expansion of the central region have exacerbated the human–land conflict, widening the gap between urban and rural areas. Additionally, it is worth noting that the industrial structure in this particular region is predominantly focused on heavy industry, and this concentration has not had any noticeable impact on the process of upgrading [76].

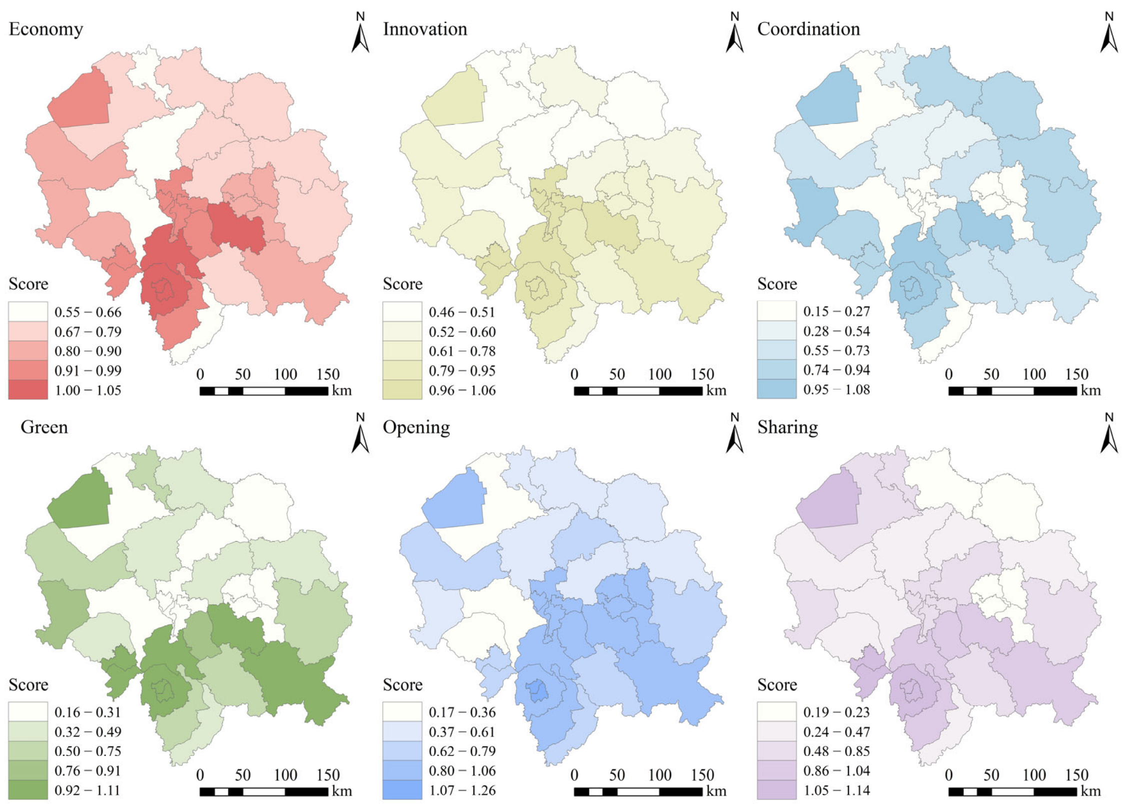

Figure 7. Spatial distribution of HQDE in six development dimensions.

3.3. Spatial Correlation Characteristics of HQDE

3.3.1. Overall Scale of Metropolitan Area

In order to further investigate the spatial distribution characteristics of HQDE in the CCMA, a global autocorrelation test was conducted on the corresponding values (as shown in Table 2). The results revealed that the Moran's I index for HQDE in 2010, 2015, and 2020 was positive. Additionally, the *p*-value passed the significance level test of 0.05, and the z-value exceeded the critical value of 1.96. Furthermore, a significant positive correlation was observed at a 99% confidence level in 2020, indicating a notable spatial clustering phenomenon. From a temporal perspective, the Moran's I index exhibited a fluctuating and increasing trend, indicating that the spatial agglomeration of HQDE in the CCMA is strengthening over time.

Table 2. Global spatial autocorrelation index of HQDE from 2010 to 2020.

Year	Moran's I	z-Score	*p*-Value	State
2010	0.241792	2.475049	0.013322	Cluster
2015	0.216676	2.275849	0.022855	Cluster
2020	0.375573	3.715415	0.000203	Cluster

Based on the aforementioned research on global spatial autocorrelation, it has been found that the HQDE demonstrates significant spatial agglomeration in the CCMA. However, the specific locations of this agglomeration have not been provided. To address this gap, the present study conducts a Local Indicators of Spatial Association (LISA) analysis to calculate the local Moran's I index. A LISA cluster map is then generated to identify the locations of spatial agglomeration with HQDE (refer to Figure 8). The HQDE in the CCMA is primarily characterized by two types of agglomeration: H-H agglomeration and L-L agglomeration. The H-H agglomeration is concentrated in the southern and central areas, while the L-L agglomeration is located in the north, with a trend of shifting westward. From the perspective of agglomeration types, the spatial distribution of HQDE in the CCMA exhibits significant instability. In 2010, the H-H agglomeration was primarily concentrated in the southern and central urban areas, while L-H agglomerations were found to the south of the central area. L-L concentrations were predominantly observed in the northern and northeastern regions. No H-L agglomerations were identified in any other areas. By 2015, the H-H agglomeration zone had shifted from the southeast to the east within the central area, while the L-L concentration had expanded towards the eastern and southern directions. Meanwhile, there were no L-H aggregation zones present, but the emergence of H-L aggregations was observed around both L-L concentration areas and the western parts of the CCMA. In 2020, there was a further enhancement in the spatial spillover effects for L-L concentrations, which extended to cover the northwest regions within the CCMA. The H-H agglomeration zone has returned to its previous location in the southern region of Liaoyuan City, while still maintaining its proximity to both L-L concentration areas. It is located north of the central part of the metropolitan area, without an L-H aggregation zone.

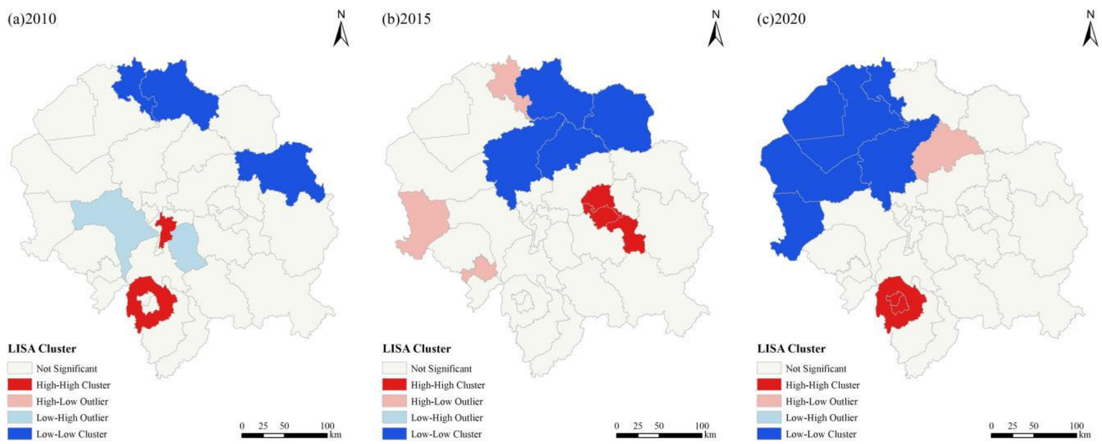

Figure 8. Local spatial autocorrelation clustering diagram of HQDE in the CCMA from 2010 to 2020.

3.3.2. Development Dimensions of Metropolitan Area

In order to further investigate the spatial distribution characteristics of HQDE in each dimension, this study computed the global Moran's I index for the annual average efficiency values of three sample years across six development dimensions. A significance test was then conducted on the index. The results, presented in Table 3, reveal that the Moran's I index for the efficiency values in all six dimensions is positive. Furthermore, the p-values for all dimensions pass the significance test at the 1% level. This suggests that there is a significant positive correlation between the efficiency values in the economy, innovation, coordination, greenness, opening, and sharing dimensions of the CCMA in terms of spatial agglomeration.

Table 3. Global autocorrelation index of high quality development efficiency of different dimensions.

Dimension	ED	ID	CD	GD	OD	SD
Moran's I	0.367161	0.477825	0.295692	0.382472	0.49928	0.36494
z-score	3.673058	4.635451	2.968478	3.763144	4.906871	3.612385
p-value	0.00024	0.000004	0.002993	0.000168	0.000001	0.000303
state	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster

The phenomenon of local spatial agglomeration is depicted in Figure 9, and the efficiency values of the six dimensions demonstrate a significant spatial polarization effect in terms of local spatial autocorrelation. The concentration of the high-high (H-H) agglomeration area is primarily observed in the southern part of the CCMA, while the low-low (L-L) agglomeration area is predominantly concentrated in the northern part. When examining each dimension individually, it becomes apparent that innovative development, coordinated development, green development, and open development all exhibit distinct spatial polarization effects on their respective efficiency values. The extent of L-L agglomeration is larger than that of H-H agglomeration, indicating a strong spatial spillover effect and correlation effect for innovative development, coordinated development, green development, and open development within the CCMA. Notably, the largest L-L agglomeration area corresponds to the dimension of open development, suggesting its relatively lower level compared to other dimensions in this region. In addition to high-high (H-H) and low-low (L-L) aggregations, there are also high-low (H-L) aggregation areas distributed around the L-L aggregation zone. The local spatial Local Indicators of Spatial Association (LISA) map reveals interdependencies and restrictive relationships among six development dimensions in space. A low level of development in one particular dimension within an area may have an impact on developments across other dimensions, emphasizing the importance of comprehensive progress encompassing multiple facets [35].

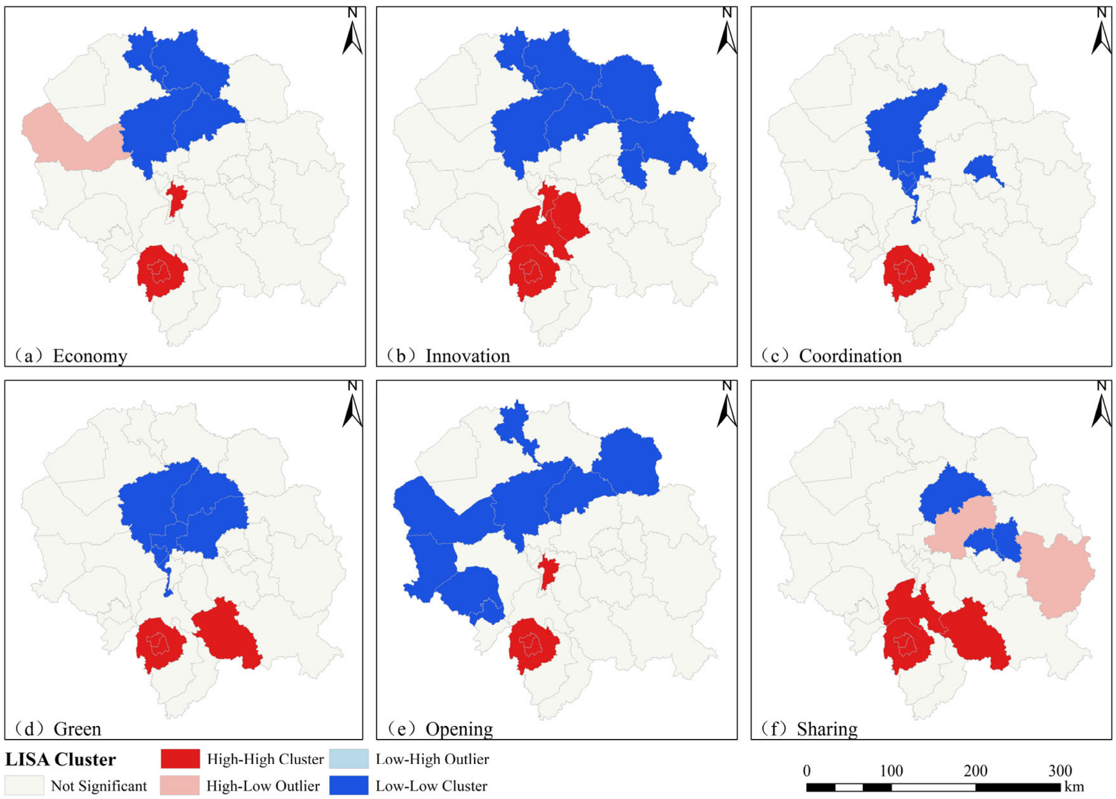

Figure 9. LISA cluster graph of HQDE in six development dimensions.

4. Discussion

4.1. In Terms of the Different Circular Structures within the CCMA, It Has Been Observed That the HQDE in the Main Bearing Area Is Comparatively Lower Than That in the Radiation Cooperation Area

According to the aforementioned research, the HQDE within the 1-h commuting circle in the CCMA is lower than that of the 2-h accessibility circle and the half-hour living circle. This finding contradicts our previous understanding. It is commonly believed that the transfer of resources, talents, and industries to the core city's carrying area would result in a slightly higher level of development in that area compared to the more peripheral cities. This belief is based on the spatial spillover and distance attenuation effects. A research study on the rural-urban interface in Chicago and Atlanta noted that whether an urban fringe in the United States directly benefits from urbanization is an empirical question, especially if it is constructed in a multidimensional way, taking into account housing quality and cost, ethnic diversity and conflict, and quality of life (e.g., congestion, air and noise pollution, or higher taxes). The study findings indicate that the rural-urban interface near core cities remains predominantly rural [84]. The CCMA is characterized as a polar-core cultivation-start-up metropolitan area with a relatively loose layer structure. It is currently in the stage of single-core agglomeration, with population, resources, and factors being concentrated and transferred to the central city. The siphon effect of the core city is much stronger than the diffusion effect. This means that the radiation driving effect on the surrounding cities is weaker compared to the siphon effect and the effect of space deprivation [85]. Consequently, talents and technologies in the main bearing areas of the central city may be transferred due to the siphon effect, while the outermost areas are weakened by the influence of the central city's deprivation effect, in accordance with the principle of distance attenuation. As a result, the HQDE of the main bearing area is lower than that of the radiation cooperation area and the core leading area.

4.2. The Efficiency of Green Development in Central Urban Areas Is Relatively Low when Considering Multiple Dimensions of Development

This can be attributed to the current stage of development in the CCMA, where the central city experiences a high population density and inadequate service capacity. As a result, there is an excessive ecological burden, which leads to a lower level of green development compared to the surrounding areas [77]. While the central urban area may have a more advanced economic development and technological innovation capability compared to the surrounding counties, the natural resource endowment and level of green development in the surrounding counties, particularly the western region, surpass that of the central urban area. Achieving HQD entails comprehensive progress, encompassing not only high-quality economic development but also green and sustainable development [35]. Consequently, the level of green development in central urban areas is relatively low. In terms of input and output perspective, the central urban area invests more resources, population, and capital in sewage treatment, garbage treatment, and park green area development compared to the surrounding counties. However, the output of these high inputs is not as extensive as that of the surrounding counties, resulting in lower relative efficiency.

4.3. Insights from Other Metropolitan Areas to Enhance the Level of HQD for the CCMA

Currently, there are noticeable disparities in the level of development among metropolitan areas. Some metropolitan areas have reached a mature stage of development, while others are still in the early stages of growth. Although it is a growing metropolitan area, the CCMA falls significantly behind more established metropolitan areas. However, this presents an opportunity for it to learn from other metropolitan areas and promote HQD. In comparison to mature metropolitan areas, the CCMA can learn from the Beijing-Tianjin-Hebei metropolitan area. By creating new districts, it can help distribute some of the functions of the central urban area, thus reducing the strain on population resources and the environment in the central urban area. In terms of innovation-driven development of core cities, the CCMA can learn from the Guangzhou-Shenzhen metropolitan area. In this area, core cities leverage innovative industries to create agglomeration effects [86]. In contrast to the capital city metropolitan area, the CCMA should draw inspiration from the Hangzhou metropolitan area and the Xi'an metropolitan area. The Hangzhou metropolitan area vigorously develops the internet and digital economy, which possess strong communication capabilities and contribute to improving the level of internal integration within the region [87]. The Xi'an metropolitan area excels in combining its unique regional characteristics with a wealth of historical and cultural heritage. Therefore, the development of the CCMA should be based on the revitalization of Northeast China and the regional characteristics of the Northeast's old industrial base. It should fully leverage the advantages of biological resources and industrial location. Considering the current stage of development in the CCMA, achieving HQD requires a dual approach that involves both poly core and radiation drive simultaneously. Core cities should provide impetus for HQD through scientific and technological innovation. They should also strengthen the integration of science, education, and industry, and establish industrial parks and innovation clusters to promote innovation agglomeration within the core area. Simultaneously, the surrounding counties should improve the equalization of basic public services in order to reduce the service gap. They should also focus on developing industries that are different from those in the core circle, and establish an industrial chain that can attract and retain residents while providing employment opportunities. Furthermore, the CCMA as a whole should establish an efficient and comfortable transportation network to facilitate urbanization and integration.

4.4. Limitations and Prospects

This study assesses the level of HQD in county-level cities by focusing on efficiency. This approach is novel in terms of both research perspective and scale, although there are still some limitations that require further exploration. Firstly, the absence of a standardized evaluation system for the HQD index introduces subjectivity in the selection of indicators. Additionally, the requirements of the DEA method for input-output indicators raise the question of how to enhance the representativeness of indicators without increasing their quantity. Secondly, this study does not investigate the spatial spillover effect and the factors that influence efficiency, which could be a potential avenue for future research. Lastly, the small scale of the study presents challenges in collecting data, and the alternative processing of certain data may affect the accuracy of the research findings. Furthermore, the adoption of a relatively simple efficiency measurement method suggests the need to consider integrating multiple methods in future studies.

5. Conclusions and Policy Recommendations

5.1. Conclusions

From an efficiency perspective, this study aims to establish a comprehensive evaluation system that encompasses multiple dimensions, including economy, innovation, coordination, greenness, openness, and sharing. The purpose is to assess the level of HQD in the CCMA, considering the three levels of county, metropolitan spatial structure, and development dimensions. The main outcomes of this research are outlined below:

(1) The level of HQD in the CCMA has not reached an optimal level, as evidenced by the consistent efficiency value observed between 2010 and 2020, which ranged from 0.7 to 0.8. This observation indicates a disparity between the present condition and the intended level of efficiency. Additionally, there exists notable disparity in the level of efficiency in HQD across various county units within the CCMA, thereby emphasizing the occurrence of a polarization phenomenon. The most significant discrepancy was observed in 2015, where there was a notable difference of 1.07 between the highest and lowest values, accompanied by a variance of 0.13.

(2) From the perspective of metropolitan area development, the half-hour living circle has the highest efficiency, while the 1-h commuting circle has the lowest efficiency. This discrepancy can be attributed to the phenomenon of "space deprivation". The efficiency difference between the primary bearing area and the radiation cooperation area of the metropolitan area is not significant, but it differs greatly from that of the core leading area. Over time, the efficiency of the core leading area shows a declining trend, indicating a weakening of the driving effect of radiation.

(3) From the perspective of six dimensions of development, the CCMA exhibits the highest level of economic development efficiency, although it has not yet reached an optimal state. Conversely, the efficiency of green development is the least optimal, with shared development and coordinated development following in terms of efficiency. Over the course of time, there has been a noticeable decrease in the efficiency of development across various dimensions.

(4) The central, southern, and southeastern regions of the CCMA, specifically the counties and cities near the Harbin-Dalian transportation corridor, exhibit a high level of comprehensive efficiency in terms of HQD. The spatial distribution of economic development, innovation, and openness exhibits a pattern of concentrated high values within the core circle, with lower values dispersed throughout the outer circle. On

the contrary, the concepts of green development and coordinated development exhibit a decentralized pattern, characterized by lower values in the central areas and higher values in the peripheral regions.

5.2. Policy Recommendation

(1) It is of the utmost importance for the government to prioritize the implementation of coordinated development strategies within the metropolitan area. This objective can be attained through the implementation of regional coordination strategies that facilitate the rational allocation of resource factors. Additionally, the development of differentiated and specialized industries, leveraging the distinctive advantages of each county, can contribute to the achievement of this goal. This approach aims to promote dislocation and foster complementary development, while also fostering the establishment of industrial linkages among counties, cities, and central cities. Additionally, it is imperative for the government to assume a prominent role in enhancing transportation networks and environmental governance. By incorporating public services and making investments in transportation infrastructure, it is possible to establish the essential prerequisites for facilitating the seamless flow of resources and personnel between urban and rural regions, as well as between different counties and cities. Public service institutions, such as medical and educational facilities, have the potential to bridge the urban-rural divide by establishing branches and satellite locations in surrounding counties and cities. This expansion allows them to extend their reach and provide essential services to a wider population.

(2) The CCMA is still in its early stages of development, and the concentration of resources and population has not yet reached a level that produces a spillover effect. In the later stages, it is necessary to continue strengthening agglomeration, accelerate the construction of the economic growth pole of the core city, improve the level of agglomeration and economies of scale in Changchun, transition from a siphon effect to a diffusion effect, and strategically plan for future economic development through scientific and technological innovation and industrial upgrading. This includes expediting the transformation of scientific and technological resources into productive forces, aligning innovation resources with regional needs, promoting the implementation of scientific and technological achievements based on actual conditions, and enhancing the driving role of central cities through their influence. This objective can be realized by implementing infill development strategies within central urban areas, such as new development of vacant, abandoned, planned, and smaller plots in built-up areas of indirect communities where infrastructure already exists to limit urban land use sprawl. This method has demonstrated efficacy in addressing the challenges of rapid urbanization and promoting sustainable urban growth, as exemplified by its successful implementation in the city of Ardabil, Iran [88].

(3) In order to address these issues, the CCMA should prioritize the transition towards green industrial cities while simultaneously promoting economic development. The government has the ability to allocate funds towards green technology and energy by implementing financial and taxation measures. This approach can effectively accelerate research and development efforts as well as the industrialization of associated technologies. This will facilitate the growth and upgrading of green industries, as well as the enhancement of the environmental supervision system. It is widely acknowledged that integrating environmental considerations into development strategies and enforcing environmental policies and regulations are crucial for fostering sustainable urban development and economic progress [89]. In the case of developing countries, the main obstacles are the capacity to implement environment-related policies, institutional and legal frameworks, and the ability to regulate and implement environmentally sound policies through good governance. Enhancing governance practices, in conjunction with robust legal frameworks and operational procedures, can serve as a potent mechanism for advancing sustainable development

goals [90]. The recent City Assessment of Cairo, Egypt, indicates that there is a requirement to combine various policies and plans in order to advance the city's green development [91]. Additionally, it is imperative to implement environmental protection awareness campaigns and educational initiatives in order to augment public and corporate awareness and commitment to environmental preservation. Peripheral enterprises should focus on improving their pollution prevention and control capabilities while undertaking industrial transfers, thereby increasing green output and alleviating pressure on the ecological environment in the central urban area. An effective illustration is the suggestion of creating an industrial city that emphasizes "prioritization", "ecosystem identification", and "Platform-based digital and green transformation" as part of a shared approach to green transformation. This involves initially concentrating on key industry sectors, then pinpointing the ecosystem and platform for transformation, and finally connecting ecosystem priorities with platform-based innovation. The practicality and effectiveness of this concept have been proven through implementations in Greece and Cyprus [92]. These measures will ultimately enhance the overall level of green development in the CCMA.

(4) The findings of the spatial distribution analysis suggest that the presence of a transportation corridor has a substantial impact on the efficiency of regional development. Consequently, it is imperative for the CCMA to expedite the construction of a comprehensive transportation system for external communication. The proposed initiative aims to elevate the agglomeration level of the central city by integrating transportation and industrial chains, while also enhancing the development framework of both the core and periphery of the CCMA. For instance, improving the development of high-speed rail systems can increase connectivity within urban areas, boost the importance of main cities, and maintain the overall layout of metropolitan regions [93].

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