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Measuring Green Divide:Evaluation System for Spatial Justice of China's Green Transition - The Case of Guangdong Province

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CONTENTS

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LISTS OF FIGURES AND TABLES

List of Figures

List of Tables

LISTS OF ACRONYMS

AQI Air Quality Index

CBAs Community Benefits Agreements

DEA Data Envelopment Analysis

ERDF European Regional Development Fund

EU European Union

GDP Gross Domestic Product

GIS Geographic Information System

IAM Integrated Assessment Model

MCDA multi-criteria decision analysis

MCDM multi-criteria decision making

NWD Northwest Guangdong

OECD Organization for Economic Co-Operation and Development

PRD Pearl River Delta

UNDP United Nations Development Program

UNEP United Nations Environment Programme

ABSTRACT

This research explores the spatial justice issues in China's green transition in the context of global climate change and the growing environmental crisis. Green transition involves energy structure adjustment, industrial upgrading and fair distribution of social resources, and is an important way to achieve sustainable development. However, in the process of green transition, the unbalanced and insufficient development between urban and rural areas and regions has become an important factor constraining China's green transition, especially in the areas of resource allocation, fair participation and environmental protection.

This paper constructs a spatial justice evaluation system to assess the spatial equity in the process of green transformation in Guangdong Province. The study first describes the theoretical framework of green transition and spatial justice and its practices globally and in China through literature review and policy analysis. Next, based on the five-level and three-category system of China's territorial spatial planning, it explores the embodiment of green transition and spatial justice in different levels of planning. Combining quantitative and qualitative analysis methods, this paper selects Guangdong Province as a case study to assess the development level of spatial justice in the process of green transformation in Guangdong Province in 2022, and reveals the pattern of its spatial and temporal evolution through spatial autocorrelation analysis.

The results of the study show that Guangdong Province exhibits significant regional imbalances in the process of green transformation, and there are large gaps between some urban agglomerations and regions in the development of green industries, resource use efficiency, and the equalisation of public services. Through the constructed evaluation system, this paper reveals the key factors affecting spatial justice in Guangdong Province, and proposes improvement strategies based on the framework of territorial spatial planning, aiming to promote fair and inclusive development in the process of green transformation in

Guangdong Province.

The research in this paper provides a theoretical basis for the formulation of more scientific and reasonable policies, as well as a useful reference for the practice of spatial justice in green transformation in other regions.

Key Words: Green Transition, Spatial Justice, China's Territorial Space Planning, Evaluation System, Spatial Analysis

INTRODUCTION

1. INTRODUCTION

1.1 Research Background and Significant

Against the background of global climate change and the worsening environmental crisis, green transition has become an important strategy for countries to achieve sustainable development. Green transition not only involves energy restructuring, industrial upgrading and technological innovation, but also encompasses the issues of social justice and equitable distribution of resources.[1] The concept of spatial justice, emerging from critiques of urban and governance crises in Western developed countries, focuses on achieving balanced, harmonious, and sustainable development across regions and generations.[2] European countries have accumulated rich experience in green transition and spatial justice, and have formulated a series of policies and regulations to promote low-carbon economy and ecological protection, as well as focusing on fairness and inclusiveness in the process of policy implementation[3]. Examples include the European Green Deal, which integrates spatial justice by addressing energy poverty and regional disparities.[4] These experiences highlight the importance of coordinated planning and equitable resource distribution in achieving sustainable development goals.

China has made remarkable economic achievements in the process of rapid industrialisation and urbanisation, but it also faces serious problems of environmental pollution and over-consumption of resources.[5] In order to respond to these challenges and achieve sustainable economic development, the Chinese Government has put forward the strategic goal of green transition and formulated a series of policies and plans, such as the Outline of the Fourteenth Five-Year Plan(2021-2025), which specifies the goals of achieving carbon peak by 2030 and carbon neutrality by 2060.[6]

Space, as the basic form of existence of material movement, is "the element of all production and all human activities"[7] . Spatial justice is a theoretical structure of social justice based on spatial form in the reflection and critique of urban crisis and national governance crisis in western developed countries. Its core content and central task is to meet the balanced, harmonious and sustainable development between the present generation and all generations, emphasising the balance between efficiency and equity in the process of urban planning and resource allocation, and ensuring that different regions and social groups have fair access to development opportunities and ecological welfare. Currently in China's spatial production practices such as green construction of urban and rural spaces, coordinated and linked development of regional spaces, and spatial protection of the ecological environment, unbalanced and insufficient development has become the main factor restricting the spatial production practices of China's green transition, and spatial justice has become an important consideration for achieving the green transition.[8]

Territorial Space Planning framework in China, as an important tool for national governance, is an essential driving force for promoting the green transition and achieving spatial justice. The formulation and implementation of Territorial Space Planning at all levels has provided a fundamental spatial layout and resource allocation framework for the green transition, rationalising the layout of production, living and ecological space, optimising resource allocation and promoting coordinated regional development.[9] For example, the National Outline for Territorial Planning emphasises the principles of ecological priority and green development, providing guidance for green transition in all regions.

However, China's green transition faces multiple spatial justice challenges in its progress. First, development imbalances between urban and rural areas and regions have led to an unfair distribution of resources and environmental benefits, with rural and less developed areas in a weaker position in the development of green transition.[10] Second, the implementation of industrial structure adjustment and environmental protection measures has been uneven in different regions, and some regions may face greater economic and social pressures in the transition process. [11]Finally, insufficient public participation and lack of transparency in policy implementation also affect the achievement of spatial justice.[12]

The research on spatial justice in China's green transition is of great theoretical and practical significance. On the one hand, it helps to enrich the theory of spatial justice and explore the paths and strategies to realise spatial justice in the context of China's actual situation. On the other hand, this research helps to provide scientific basis for policy formulation and promote fair and inclusive development in the process of green transition. In this context, it is particularly important to construct a comprehensive spatial justice evaluation system for green transition and study its spatial evolution pattern. This can not only systematically assess the level of spatial justice in the process of green transition, but also reveal the key factors and mechanisms affecting spatial justice, providing a basis for policy optimisation and practice improvement. By analysing specific cases and data under the framework of territorial space planning, the dynamics of spatial justice in green transition can be better understood, and theoretical innovation and policy progress can be promoted.

1.2 Research Contents and Method

This study begins with a theoretical section that provides a basic understanding of the development of green transition and spatial justice globally and in China through literature review and policy analysis. It then explores the embodiment of green transition and spatial justice in Territorial Space Planning frameworks in China, and summarises the planning focuses related to green transition and spatial justice at all levels of territorial planning in the process of urban development in China. In order to evaluate the effectiveness of the development of spatial justice for green transition in China, an evaluation system is constructed based on the analysis of the theoretical part, using a combination of qualitative and quantitative analyses. Then the practical application is carried out, with Guangdong Province as the case, to evaluate the effectiveness of the development of spatial justice for its green transition in 2022, and the spatial stratified heterogeneity of the evaluation results is analysed through Spatial Autocorrelation Analysis, and the results of the analysis are used to reveal the spatial and temporal evolution pattern of the development of spatial justice for green transition and to judge whether the development is balanced or not in Guangdong Province. Futhermore, Analysis of the degree of coupling coordination is used to measure the interaction and co-ordination between different systems. Finally, the results are used to summarise the current situation of spatial justice development in green transition in Guangdong Province and to propose improvement strategies based on the provincial territorial space planning framework, with reference to the development experience of developed regions. (See figure 1.1 for specific technical approach to the research methods.)

1.2.1 Literature Reviews

To collate global and Chinese research findings related to green transition and spatial justice, to clarify the real meaning of green transition and spatial justice, and to collate and analyse the literature on the evaluation system of the development of spatial justice for green transition, so as to provide the theoretical basis and reference for the establishment of the evaluation system in the present research. All of the above analyses lay the theoretical foundation for the evaluation system of spatial justice for green transition.

1.2.2 Green Transition and Spatial Justice in China's Territorial Space Planning

Based on the five-level and three-type framework of territorial spatial planning in China, planning focuses at all levels of Territorial Space Planning related to the green transition and spatial justice are summarised. Among them, national-level planning is the overall planning; at the provincial planning level, the planning documents of representative provinces in each region are selected according to the regional division of China's seven geographic regions; and municipal, county and township levels are combined, and based on provincial planning documents, representative city planning documents are selected according to different city functions. Finally, the planning focuses related to green transition and spatial justice collated from all levels of planning are summarised and thematically classified , so as to provide a realistic reference for the construction of the evaluation system. It is worth noting that all of the above references are to municipal public documents in Guangdong Province, the names of which are translated into English in the list of bibliography.

1.2.3 Construction of Evaluation System of Spatial Justice for Green Transition

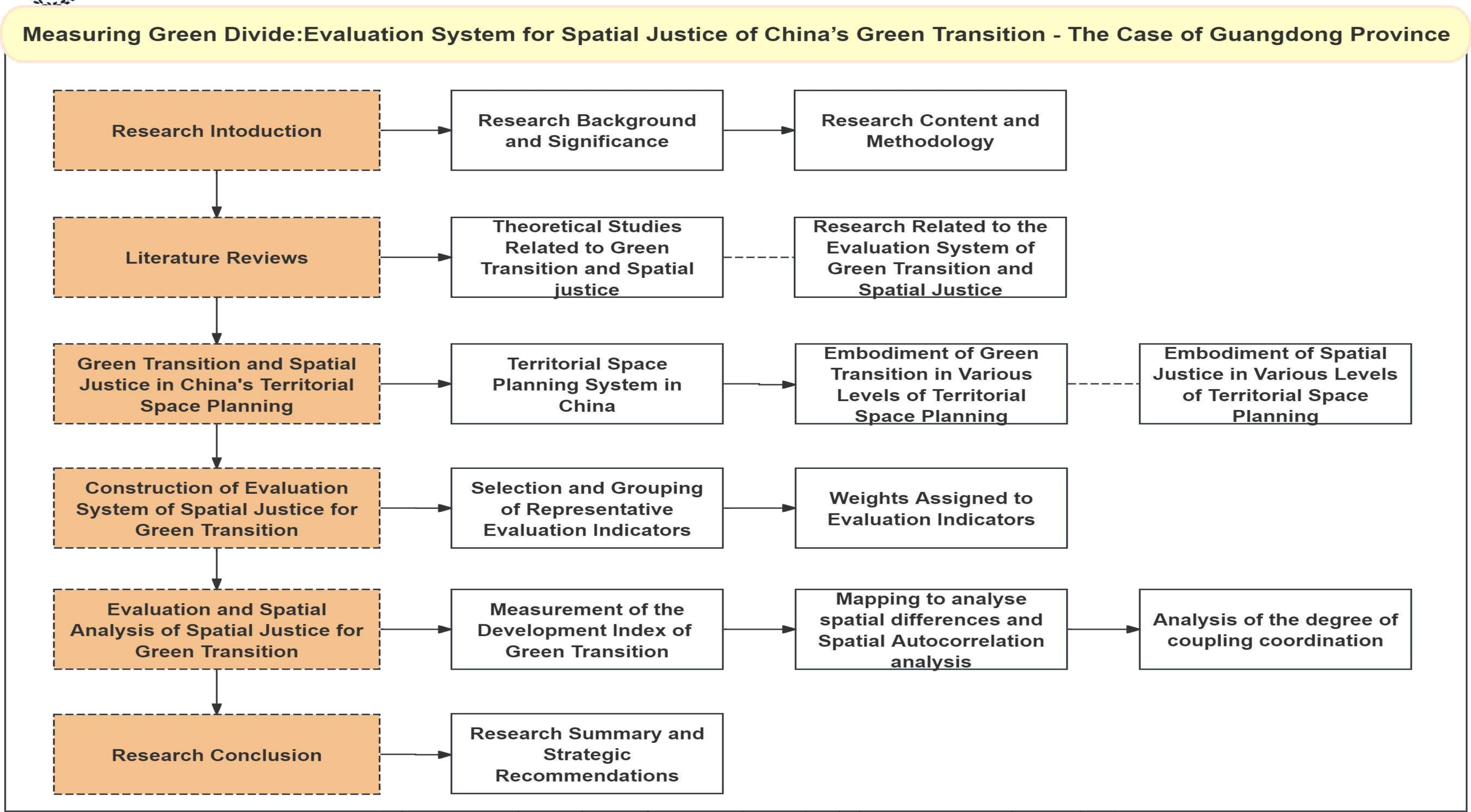
The construction of the evaluation system of spatial justice for green transition will be based on the combination of qualitative and quantitative analyses. For the indicators of the preliminary evaluation system framework, a qualitative method is used to determine the scope and select the indicators on the basis of theoretical research. Based on the evaluation indicators selected by the above methods initially construct the evaluation index system of spatial justice for green transition. Then the entropy weight method is used to assign values to the weights of the evaluation indicators, and finally the complete evaluation system is established.

1.2.4 Practical Application: Evaluation and Spatial Analysis of Spatial Justice for Green Transition in Guangdong Province

Taking Guangdong Province as a case, the spatial justice of green transition in its 21 municipalities is evaluated during the period of 2022. According to the evaluation system, the indicator data of 21 municipalities in Guangdong Province were collected. Then the score of each municipality on the development of spatial justice for green transition is calculated to measure the devlopment level of spatial justice for green transition in individual municipalities. Based on the score results, the Graduated Analysis is applied to classify cities with different levels of development in different years and visualised on GIS software, so as to preliminarily derive the temporal and spatial variations of the development level of spatial justice for green transition of the municipalities in Guangdong Province. Furthermore, using the degree of coupling and coordination analysis to measure the degree of coordination between green transformation and spatial justice among different regions. Then the spatial and temporal variations of the score results are further analysed by using Moran'I index for Spatial Autocorrelation Analysis. The global Moran'I index is used to reflect the spatial correlation of the development level of different cities, and the local Moran'I index is used to reflect the spatial agglomeration pattern of the development level of different cities under study. Through the above spatial analysis, the balanced degree of development of spatial justice of green transition in different time periods in Guangdong Province is shown, so that the importance of spatial justice in the development of green transition can be further testified.

1.2.5 Research Summary and Strategic Recommendations

Combining the results of the above analysis, the current status of the development of spatial justice for green transition in Guangdong Province is summarised. It also refers to the advanced experiences of developed countries, summarises the commonalities and gaps between the two, and attempts to propose improvement strategies based on the framework of Territorial Space Planning in Guangdong Province.



(Figure 1.1 Flow Chart of Research Methodology *Source:The Author)*

LITERATURE REVIEW & POLICY ANALYSIS

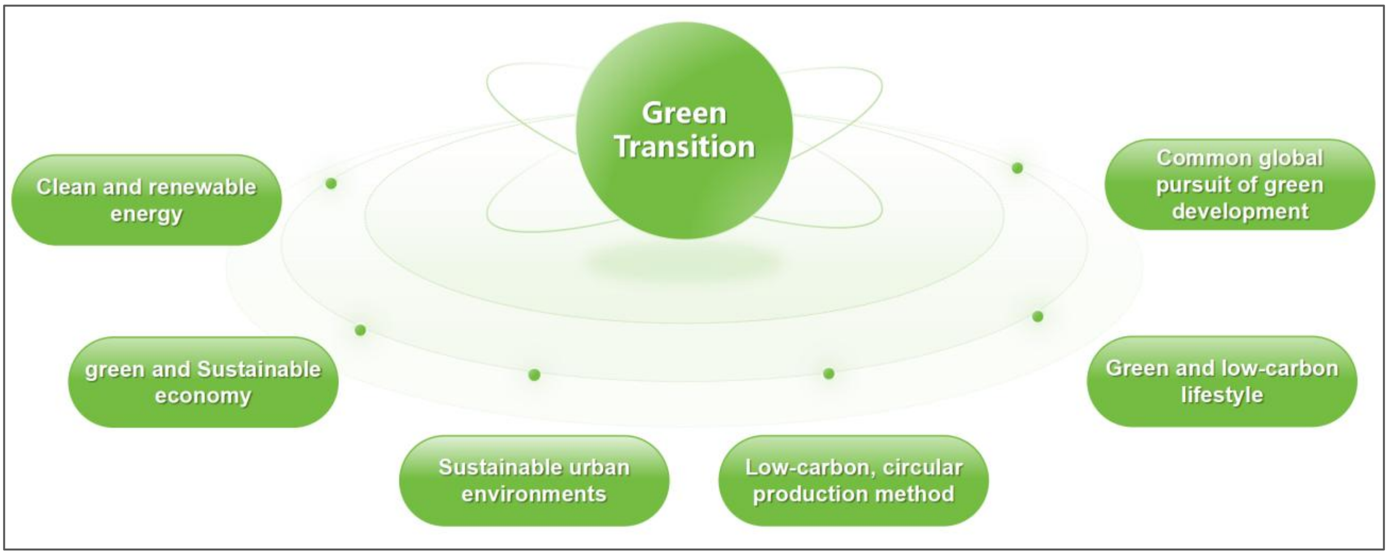
2. LITERATURE REVIEW

In recent years, with the increasing global pursuit of low-carbon development, green transition has become a hot research topic among scholars. Spatial justice, on the other hand, has been favoured by sociologists and geographers since the beginning of modern urban developmemt. To study the development of spatial justice in green transition, firstly, it is necessary to clarify the definition and connotation of the two, and secondly, through the existing research, it is also possible to have a glimpse of the development of the two in modern society. Based on the research methodology of this thesis, it is necessary to summarise and analyse the construction of the evaluation system of green transition and spatial justice as well as the relevant studies on spatial analysis methods, so as to lay a theoretical foundation for the thesis research.

1.1 Overview of the Green Transition

1.1.1 Green Transition in Global

According to the UN-Habitat declaration in its Strategic Plan 2020-2023, green transition refers to a strategy for social change that will enable us to transform the current environmentally unsustainable global situation into a new sustainable paradigm that ‘promotes development and peace and aims to improve the living conditions of all people,’ ensuring environmentally sustainable and more equitable societies[1,2].The green transition involves a comprehensive societal change encompassing economic, social, policy and technological aspects, the specific connotations of which can be elaborated on in terms of energy use, economic models, urban development, modes of production, lifestyles, global cooperation, and so forth. In terms of energy use, green transition is the transition to clean and renewable energy: the large-scale promotion of renewable energy projects, and the development and adoption of clean energy sources (e.g., solar, wind, and hydropower) as a substitute for fossil fuels to reduce carbon dioxide and other greenhouse gases [3], as well as the reduction of energy consumption and the improvement of energy efficiency through technological innovations and energy management strategies. In terms of economic modelling, the Green Transition is the transition to a green and sustainable economy: a green economy promotes sustainable economic development and improvements in people's lives by fostering a coherent approach to environmental and social well-being [4], increasing resource efficiency, ensuring ecological resilience and enhancing social equity [5]. In terms of urban development: the Green Transition is the transition to sustainable urban environments: creating more energy-efficient and inclusive habitats through the construction of green buildings, smart city technologies and green transport systems[6]. In terms of production methods, the green transition is the transition to low-carbon, circular production methods: more renewable energy inputs into production, maximising resource efficiency and reducing energy consumption[7], and extending the life cycle of products to enable their reuse and recycling [8]. In terms of lifestyles, the green transition is the transition to a green and low-carbon lifestyle: shifting from traditional lifestyles to a low-carbon lifestyle, reducing the carbon footprint of our lives, choosing sustainable consumption, choosing products and services with lower environmental and social impacts, and raising environmental awareness [3]. In terms of global cooperation, the green transition is the transition to a common global pursuit of green development: the green transition is global, and international support, especially for developing countries, is needed to achieve a globally just green transition[9].



(Figure 2.1 Key Words of Green Transition in Global *Source:The Author*）

1.1.2 Green Transition in China

The development of China's green transition has been a gradual but complex process that has gone through several key historical stages. Each stage reflects a shift in policy priorities, economic goals and environmental awareness, all aimed at balancing economic growth with sustainable development.

(1) Early environmental awareness and initial policies (1980s-1990s)

In the 1980s, as China embarked on economic reforms, the government recognised the environmental challenges posed by rapid industrialisation. Although economic growth remained the main concern, initial environmental protection policies were implemented to address pollution and resource depletion [10]. During this period, environmental policies were largely reactive and aimed at managing the consequences of economic activities rather than promoting sustainable practices.

(2) Shift towards sustainable development (2000s)

The early 2000s marked a shift towards integrating sustainable development into national policy, and in 2003 China introduced the concept of a 'circular economy' as a strategy for increasing resource efficiency and reducing waste [11]. The 11th Five-Year Plan (2006-2010) was particularly important as it included binding environmental targets such as reducing energy intensity and controlling pollution levels, signalling a more proactive approach to environmental management [12].

(3) Low-carbon economy and green growth initiatives (2010s)

China began to embrace the concept of a low-carbon economy in the 2010s as international pressures and domestic environmental concerns increased. 'The 12th Five-Year Plan (2011-2015) includes specific targets to reduce carbon intensity and increase the share of renewable energy in the energy mix. The establishment of pilot carbon trading schemes in several regions laid the foundation for a national carbon trading market[13]. This decade saw a shift from pollution control to a comprehensive green growth strategy, including investments in renewable energy, energy efficiency and technological innovation.

(4) Carbon Neutrality and Comprehensive Green Transition (2020-present)

In the context of China's modernisation and development, green transition refers to an economy's shift from a traditional model of high emissions and pollution to a low-carbon, sustainable path of economic development, in order to achieve the dual goals of economic growth and environmental protection. In this process, not only does it require a cleaner energy structure, but it also involves a wide range of policy and technological innovations, as well as the promotion of an industrial structure, pollution management and ecological restoration in an all-round changes. Li & Wang (2022) point out that the core of green transition lies in the application of policy support, energy transformation, green finance and innovative technologies in order to enhance the efficiency of resource utilisation and to reduce carbon emissions[10]. Liu et al. (2021) emphasise that such a transition is regarded as a necessary pathway to achieve carbon neutrality and sustainable development[14]. In addition, green transition requires a socially economic and ecological environments to maintain harmony between them to meet the needs of long-term development.

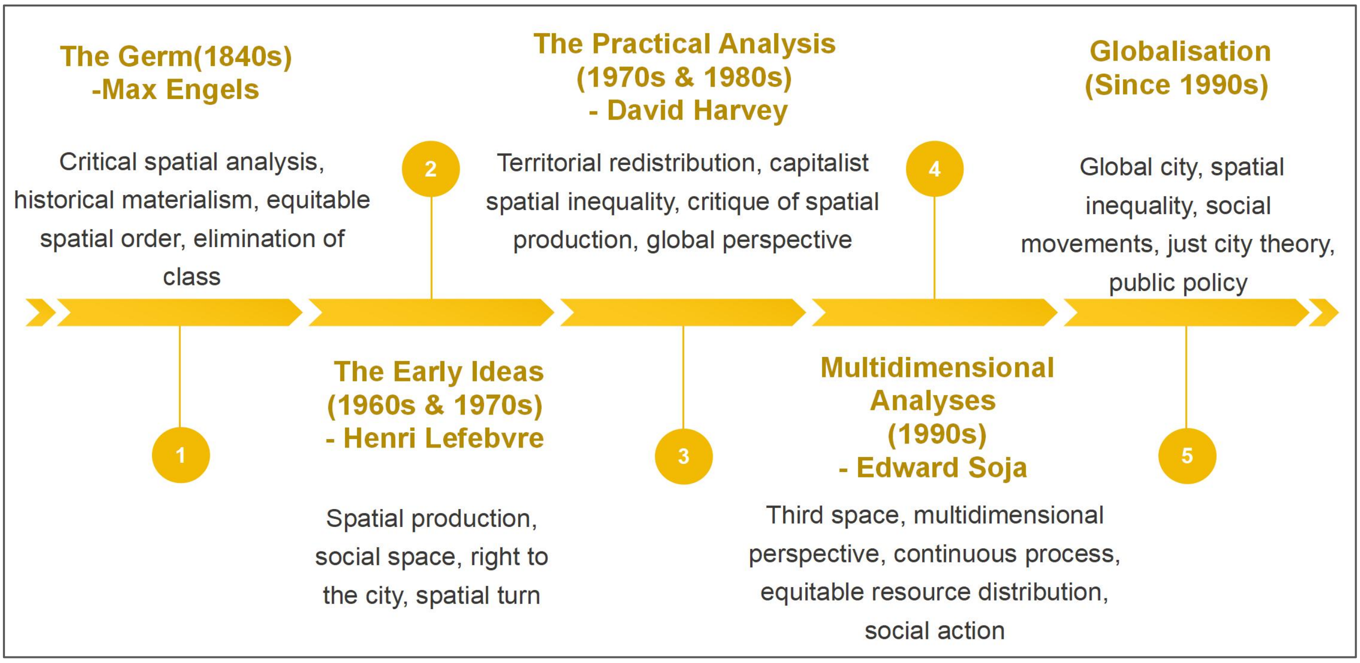
In order to promote the development of a green transition, the Chinese Government has incorporated carbon neutrality targets into its modernisation path. China's commitment to

achieve carbon neutrality by 2060 sets the foundational goal for green transition policies. This commitment has led to the development of policies targeting carbon reduction in a variety of sectors, including energy, transport and industry. Policies such as the establishment of a national carbon trading market aim to incentivise emissions reductions in high-carbon sectors[10, 11]. In addition, China's 'dual-carbon' policy framework (carbon peaking and carbon neutrality) outlines specific milestones and regulatory guidelines for monitoring the carbon emission trajectories of provinces and industries [13].
China's green transition policy emphasises a shift from reliance on coal to renewable energy sources such as wind, solar and hydropower[14]. The 14th Five-Year Plan for renewable energy development sets specific targets to increase the share of renewable energy in the country's energy mix, reduce the share of coal, and improve grid infrastructure to support intermittent renewable energy[12].
A key component of China's green transition policy is the promotion of green technologies and accelerated industry transformation. The policy encourages research and development of low-carbon technologies, electric vehicles and sustainable manufacturing processes [11]. The focus on green innovation aims to reduce the cost of sustainable technologies and enable traditional industries such as steel and cement to adopt cleaner processes [10].
China has developed policies to support green finance in order to mobilise funds for environmentally sustainable projects. The establishment of green bonds, green loans and incentives for environmental investments are key policy tools aimed at attracting public and private funding for green projects [11]. The integration of financial mechanisms supports the widespread adoption of green technologies and sustainable practices across a wide range of industries.
Ecological protection and pollution control are integral to China's green policy. The government has implemented strict environmental regulations to control air and water pollution, manage waste, and restore degraded ecosystems [13]. These regulatory measures also aim to promote sustainable economic zones that prioritise environmental health and economic activity [10].

2.2 Development and Research on Spatial Justice Theory

2.2.1 Development of spatial justice theory

The theory of spatial justice explores the projection of social justice in the spatial dimension, understanding justice from the spatial dimension, exploring the process of generating spatial injustice and finding ways to solve it, and focusing on the fair distribution of resources, rights and opportunities and the quality of life of people in different spaces. Spatial justice theory has been developing along with the crisis of urban development, and its development stages can be divided into the germ of spatial justice theory (1840s), represented by Marx Engels; the early ideas of spatial justice theory (1960s and 1970s), represented by Henri Lefebvre; the practical analysis of spatial justice theory (1970s and 1980s) , represented by David Harvey; multidimensional analyses of spatial justice (1990s), represented by Edward Soja; spatial justice theory and globalisation (since the 1990s), represented by Saskia Sassen, Massey, Doreen, Susan S. Fainstein, and others.



(Figure 2.2 Historical Development of Spatial Justice Theory *Source:The Author*）

(1) The Germ of Spatial Justice Theory (1840s) - Marx Engels

As the germ of the theory of spatial justice, the spatial justice theories of Marx and Engels have had a significant impact on the understanding of the issue of spatial justice in their writings and thoughts, even though they are not presented as an explicit concept of "spatial justice". The spatial justice constructed by Marx and Engels is a kind of critical justice, which is based on the deep thinking and serious criticism of the spatial injustice produced by the specific historical environment in which they lived. The research process of Marx and Engels on the idea of spatial justice is not simply a mechanical application of the value dimension of justice in the spatial field, but a process of establishing the organic connection between spatiality and justice and combining them to form a whole on the basis of the materialist conception of history and the entire social practice of "real people" [27]. The goal pursued by Marxist spatial justice thought is to establish a fair and just, human-centred spatial order in which human beings and nature develop harmoniously. In the new world picture of the "realistic individual", class exploitation disappears, space becomes equally shared for all people to achieve all-round development, and spatial injustice such as spatial exclusion, spatial separation, and spatial conflict is completely eliminated [28].

(2) The Early Ideas of Spatial Justice Theory (1960s and 1970s) - Henri Lefebvre

Henri Lefebvre, recognised as the "father of the critical theory of everyday life" and the pioneer of urban sociology, initiated the "spatial turn" in contemporary philosophy and social sciences. Lefebvre created a theory of social space around the core concept of "spatial production", in which he argued that space is not a neutral container, but a product of social relations, and that the process of spatial production reflects and produces power relations and inequalities in society. At the same time, he divided space into material space, spiritual space and social space, breaking the traditional dualistic thinking of space and giving space a social meaning [29]. Lefebvre also developed the concept of the "right to the city", and research on geography, justice and the urban condition played an important role in the evolution of the conceptualisation of spatial justice 18 Soja assessed Lefebvre's idea as a new and radical approach to the conceptualisation of space and the spatialisation of social life [2].

Lefebvre's ideas emphasise that a more equitable social and spatial order can be achieved by changing the ways in which space is produced and the mechanisms by which it is distributed. Although Lefebvre still did not explicitly put forward the concept of "spatial justice", and the theory of spatial justice is still at an early stage of thought, his theory inherits and develops Marx's theory of spatial justice, and provides an important foundation for the study of spatial justice.

(3) The Practical Analysis of Spatial Justice Theory (1970s and 1980s) - David Harvey

David Harvey is deeply influenced by Marxism and is a representative figure of Western Marxist theory. Harvey's spatial spatial justice thought is based on the absorption of Lefebvre's spatial thought, and forms his own spatial justice thought in the process of research on space and capital. He combined geography with urban planning and analysed spatial justice theory within the framework of urban planning practice. Borrowing the concept of "territorial justice" put forward by Brady Davis in 1968[30], Harvey creatively put forward the concept of "territorial redistribution", which is defined as a just geographical distribution of social resources in a just way. Although this concept expresses concern and emphasis on the results and process of geographical distribution, Harvey's theory is based on how to eliminate spatial distributional injustice. He pointed out that the capitalist mode of production creates and maintains spatial inequality through the commodification and privatisation of space, and that spatial justice can only be truly achieved by transforming the social production process of “space”, and by making changes to social structures and institutions [31]. Harvey considered the production of just geographic differences of justice as the focal point of spatial justice exploration, critiquing spatial injustice on the one hand and revealing how spatial injustice is produced on the other. He established the core position of the concept of space: social process determines spatial form, focusing on the process that causes spatial injustice. He divided contemporary production into three basic processes: urban spatial production, global spatial production, and natural spatial production, and through analyses of these three types of spatial production processes, he critiqued the injustices rooted in spatial production processes from three aspects.At the same time, influenced by Marx's attention to discernment, Harvey viewed difference and justice dialectically, arguing that spatial justice is not the justice of eliminating the geography of difference but the justice of respecting difference. Based on the above, he suggested that the construction of spatial justice must confront unjust social processes as well as weave in and out of various discourses of difference and heterogeneity [32].Compared to spatial theorists such as Lefebvre who confined themselves to the study of urban spatial justice only, Harvey, who is in the global era, has a broader perspective on spatial justice on the issue of spatial justice. The dialectical view of the principle of justice also allows Harvey to fully consider diversity and difference in his exploration of spatial justice, pointing the way to the realisation of spatial justice and providing theoretical support for social movements and policy formulation.

(4) Multidimensional Analyses of Spatial Justice (1990s)- Edward Soja

Edward Sawyer is known for his contributions to spatial justice and critical geography. Sawyer provided an integrative and multidimensional perspective to analyse and address spatial inequalities, expanding the theoretical framework of spatial justice through the concept of the ‘third space’, which integrates physical, social, and psychological spaces to provide a more multidimensional perspective. [33]In The Search for Spatial Justice, he creates a theoretical framework for spatial justice, for which he explains, “Spatial justice is not merely an outcome or an outcome of a problem. Spatial justice is not merely an outcome or a goal but a continuous process of achieving fairer spatial distribution of resources, opportunities, and access. It encompasses not just the equitable distribution of resources, opportunities, and access. encompasses not just the equitable distribution of resources but also the spatial organisation and design of societies that promote greater social justice. It encompasses not just the equitable distribution of resources but also the spatial organisation and design of societies that promote greater social justice.” And he pointed out that the search for spatial justice is about expanding the concept of socio-economic-environmental justice into new areas of understanding and political practice. In addition, he advocated that the principles of spatial justice should be taken into account in urban planning and policymaking, and that spatial justice should be achieved through social movements and collective action.[2]

（5）Spatial Justice Theory and Globalisation (Since 1990s)

In the 1990s, social inequalities at the global and local levels were exacerbated by globalisation and the spread of neoliberal policies, an economic model that valued market liberalisation, privatisation, and the reduction of government functions, leading to the concentration of resources and power[17]. In this context, spatial theorists have focused on analysing the spatial inequalities generated by the globalisation process, particularly in cities. Saskia Sassen's theory focuses on the global city, globalisation and its impact on spatial and social inequalities in cities, and she has developed the concept of the 'global city', which is a key node of the global economic system. The global city is a key node of the global economic system, but at the same time it is also a concentrated manifestation of social and spatial inequality. There are clear class divisions and spatial segregation within the global city [35].British geographer Doreen Massey explored spatial inequalities and power relations in the global city in Globalisation and the Politics of Geography, analysing the impact of globalisation on different regions and social groups, and she emphasised that by altering spatial organisation and social relations, more equitable social change can be promoted [36].Susan S. Fainstein is a leading scholar in the field of urban development, urban policy, and social justice studies. Fainstein developed the theory of the 'just city', which advocates social and spatial justice through urban planning and policy. She identified three core values that should be pursued in a just city: equity, diversity and democracy, and proposed a number of strategies to achieve spatial justice, including increasing public investment, formulating inclusive housing policies, improving public transport systems, and protecting public space and the natural environment[37]. At this stage, spatial justice theory has undergone significant development, encompassing theoretical expansion, globalisation impacts, and urban social movements, as well as playing an important role in practical urban planning and public policy, providing theoretical support for the realisation of a more equitable and sustainable social space.

2.2.2 Research on Spatial Justice Theory in China

The development of spatial justice theories in the West has often been accompanied by crises arising from the modernisation of cities, whereas the modernisation of Chinese cities started late, and the study of the impacts of urbanisation came later than in developed countries. Despite the late start, China's urbanisation development has been explosive and rapid, and the consequences have been heavy, with spatial injustices such as tense human-land relations, uneven distribution of social resources, and uneven regional development plaguing Chinese society. In this context, the spatial justice theory, which has been developed relatively maturely in western developed countries, has been introduced by Chinese scholars. By summarising and outlining the western spatial justice theory, Chinese scholars have been inspired to create a theoretical system of spatial justice that combines with their own national conditions, and combines it with the practice of urban development in order to look for solutions to the problem of spatial injustice in the process of urbanisation. The initial research focused on the broad theme of urbanisation and development. REN reflected on the problems existing in the process of China's urbanisation and development, pointed out that China's interest-oriented spatial production, conditioned by the relative lack of institutional justice, has harmed the public's spatial rights and interests, put forward the basic principles of spatial justice and proposed a basic path for building a harmonious city based on spatial justice in China [18].

With the gradual maturation of research on the theory of spatial justice, studies in recent years have been conducted at a more detailed level, involving various parts of urban development, including land use, infrastructure, public services, public space, green space, and urban-rural relations.Wang et al. used Shanghai as a case study to explore the connotations of spatial equity in land use in the townships and its impact on the residents' acceptance of land-use policies [19]; based on spatial equity theory, Chao examined the accessibility of facilities, work-life relationship and neighbourhood integration of residents in social housing communities in Guangzhou[20]; Xu et al. used Beijing as a case study to construct a two-level, four-step analytical framework consisting of quantity, structure, pattern, and coupled coordination to perceive the spatial justice of living service resources [21]; Li et al. used Qingdao as a case study to analyse the spatial equity of park green space at different scales for different modes of travel [22]; Wu et al. examined the availability of green space for different socio-economic groups in China's urban areas; Zhu et al. explored the spatial inequality of rural communities in the process of the urban-rural spatial structural compactness in China [23]. These studies have not only provided a theoretical basis for understanding and addressing spatial inequality in cities, but have also had a profound impact on urban planning, public policy and social governance.

2.3 Relationship between Green Transition and Spatial Justice

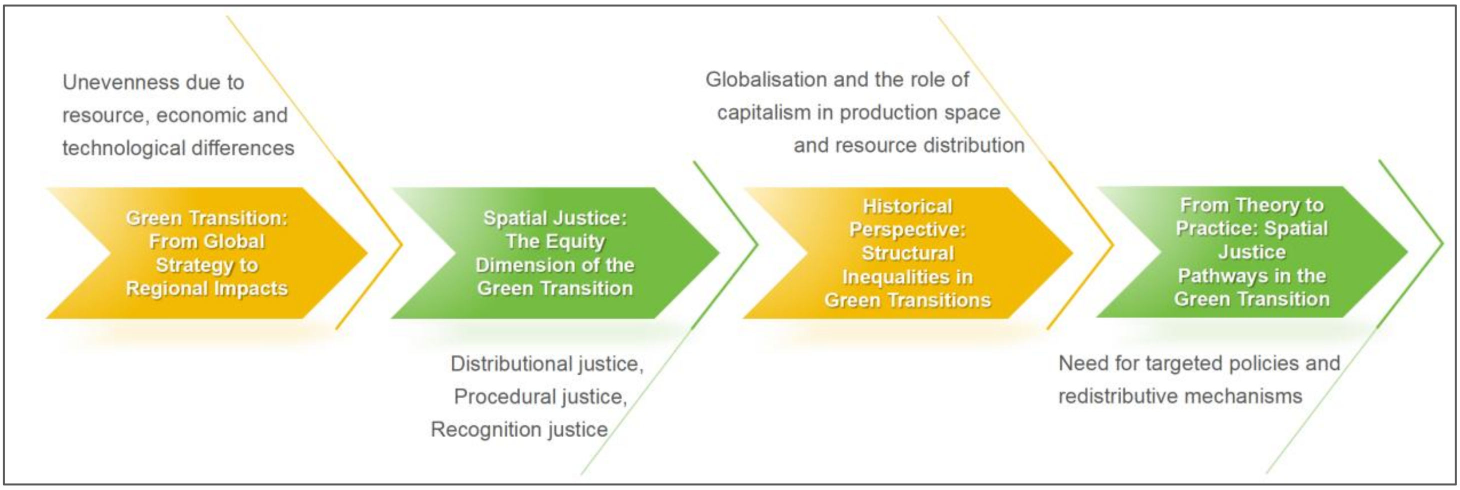
The green transition, as a global strategy to address climate change, involves far-reaching social, economic, policy and technological changes. While the green transition aims to promote sustainable development of societies, its implementation and impact have been uneven across regions. This is due to differences in resource endowments, economic structures and technological levels in different regions. For example, resource-rich developed regions are more likely to benefit from the development of new energy sources, while lagging regions that rely on fossil fuels face industrial decline and employment crises. This imbalance lays the foundation for understanding the relationship between green transition and spatial justice.

The theory of spatial justice provides a powerful analytical framework for studying inequality in green transition. Justice involves not only the distribution of resources, but also procedural fairness and identification with local culture. In green transition, this means that we should not only focus on how different regions benefit or suffer economically, but also examine how the participation in decision-making and cultural identity of these regions affect the success or otherwise of green transition projects. Distributional justice, procedural justice and recognition justice are the basic dimensions of analysing spatial justice in green transition.

Distributional justice is the basic dimension of spatial justice: it focuses on the uneven spatial distribution of resources, benefits and burdens. Distributional justice is particularly evident in green transition, with developed regions benefiting more from new energy technologies, green jobs, etc., while industrial zones and poorer regions dependent on traditional energy sources face the burdens of unemployment, economic decline, and so on. Such inequalities exacerbate socio-economic disparities between regions. Procedural justice emphasises the importance of fair participation in the decision-making process:The participation of local communities is often overlooked in the decision-making process of the green transition, especially in the siting of renewable energy infrastructure, where the voices of local residents are often marginalised. Without procedural justice, green transitions may be seen as imposed policies that are prone to local resistance and social conflict. Recognition justice further emphasises the role of cultural and historical factors in green transitions:Local communities' identification with their culture and way of life is often in conflict with green transition projects (e.g. wind farms, solar facilities). The examples in the document show that green projects that ignore local cultural identities are prone to fail in practice and may even exacerbate local social conflicts.

To better understand spatial inequalities in green transitions, it is important to bring in historical context. The role of globalisation and capitalism in the spatial and resource distribution of production has been discussed above, and these historical factors have further exacerbated regional inequalities in green transitions. For example, resource concentration and capital accumulation during the industrialisation era have given developed countries and urban areas a greater advantage in the modern energy mix transition. Marginalised regions, on the other hand, are more vulnerable in the face of the green transition due to longstanding economic disadvantages and resource plunder.Analyses by Harvey and other scholars show that the spatial production logic of capital has exacerbated inequality in these regions, and that the historical continuation of this inequality is manifested in the green transition by the concentration of green technologies and industrial investment in developed regions, while poorer regions continue to bear the environmental and economic burdens. This structural inequality is particularly evident globally, especially in the green economy development gap between developing and developed countries.

In order to achieve spatial justice in the green transition, policymaking must be more targeted. Regional inequalities resulting from the transition can be effectively addressed through spatially targeted policies and redistributive mechanisms. Specifically, policies for the green transition should develop different solutions according to the economic capacity, historical background and social needs of different regions. For example, a cross-regional redistribution mechanism can ensure that when developing a green economy, poorer regions can receive more technical and financial support, so as to avoid becoming ‘losers’ in the green transition. In addition, Community Benefits Agreements (CBAs) can be an effective tool for addressing spatial justice issues. This mechanism can establish a cooperative relationship between local communities and green projects, ensuring that local residents receive direct economic or social benefits while participating in the projects. This has been shown in many studies to be an important means of addressing local resistance.



(Figure 2.3 Relationship between Green Transition and Spatial Justice *Source:The Author*)

2.4 Research on the Evaluation Indicator System for Green Transition and Spatial Justice

The construction of the evaluation index system should be composed of two parts: the selection of indicators, the grouping and weighting of the indicators.

2.4.1 Selection of Indicators for the Evaluation Indicator System

Evaluating the interaction between spatial justice and green transformation requires a comprehensive framework, but there is no clear evaluation system framework in the current research. Based on this, the evaluation system studies of green transition and spatial justice are analysed and summarised separately, and the evaluation system of this study will refer to the results of the integration of the two.

Evaluating the effectiveness of green transition requires a comprehensive assessment of various environmental, economic and social indicators. Due to the policy orientation of the green transition, there are many official reports and documents that can be used as references for its evaluation criteria: the United Nations Environment Programme (UNEP) has developed a system of environmental indicators for evaluating green economic policies, including indicators such as carbon emission reductions, renewable energy use, energy efficiency, and biodiversity; and the Organization for Economic Co-Operation and Development (OECD) has provided a system of evaluation for measuring the progress of green growth, including indicators such as green GDP, green job opportunities, green technology investment, and resource efficiency, green technology investment and resource efficiency; United Nations Development Program (UNDP) has proposed a system of social indicators related to sustainable development, including indicators for public health improvement, social equity, public participation, and environmental awareness. China has a clear indicator system for green development and ecological civilisation construction. The green development indicator system includes indicators on resource utilisation, environmental governance, environmental quality, ecological protection, quality of growth, and green life, while ecological civilisation construction includes indicators on resource utilisation and ecological environmental protection in two major categories. The research of related scholars can also provide reference, such as Feng et al. who constructed a dynamic assessment index system for urban development transition based on resource consumption, economic development and social welfare [24]; and Xu et al. who constructed an evaluation system for energy consumption and green development [25].

Evaluating spatial justice involves assessing the equity and fairness of the spatial arrangement and distribution of resources, services and opportunities in urban and regional contexts.GHOUCHANI et al. created a system of indicators for evaluating spatial justice in cities, demonstrating that when cities are in a position to include indicators such as simplicity and readability, equality of opportunity and human scale [26]; Guo et al. based on the perspective of spatial justice, constructed a system that includes Green Management, Green Building, Green Transportation, and Green Management. Green Building, Green Transportation, and Green Culture [27]; Uwayezu proposed 60 indicators which measure the degree of spatial justice and land tenure security along a continuum of spatial justice and land tenure security, including zoning rules and spatial planning processes, different urban redevelopment programmes through land acquisition, affordable housing development, slum upgrading, shanty towns and squatter settlements , slum upgrading, relocation of squatters and slum dwellers, and provision and use of urban amenities, among other indicators [28].

2.4.2 Methodology for Grouping and Weighting of the Evaluation Indicator System

The IPCC proposed an Integrated Assessment Model (IAM) for climate change mitigation levelling, including scenario analysis, cost-benefit analysis, and multi-criteria decision analysis (MCDA).Fu et al. used Data Envelopment Analysis DEA (a non-parametric analytical method), combined with window analysis, to measure the dynamic efficiency of the green transition of industry in various regions of China [29];Jian et al. developed a framework for assessing justice in public open spaces, including five constructs: access and management, sociability and diversity, demand and supply, social class and information, and social inclusion[30]; Shamei et al. adopted the Topsis model, using the entropy method to assign and standardise the weights, and then used the hierarchical analysis to extract the weights of each indicator, from which the score of each area is derived to determine the spatial justice of the Quaternary areas of Shahriar region [31]; Guo et al. through a comparative analysis of the authoritative international and Chinese green community evaluation systems. quantifying, weighting, and classifying indicators using hierarchical analysis [27]; Nesbitt et al. used Spearman correlation and spatial autoregressive models to analyse the equity of urban vegetation distribution in 10 U.S. urban areas at the block group and census tract levels[32]; Zhang et al. used the Kruskal-Wallis test to determine significant differences in urban green space availability, proximity, and desirability across six levels of residential communities in Yangzhou City, Jiangsu Province, China[33].

2.5 Spatial Analysis Methods for Green Transition and Spatial justice

Based on spatial justice, Ghasemi et al. investigated the use of multi-criteria decision making (MCDM) and GIS methods to analyse the spatial distribution pattern of urban green spaces in Tehran using the nearest neighbour method and the Multi-Distance Spatial Cluster Analysis (Ripleys K) function to analyze the the spatial distribution pattern of urban green spaces in Tehran with CoCoSo to analyse its spatial organization of the spatial distribution and accessibility of parks and urban green spaces in Tehran [34]; Beber et al. attempted to create geospatial datasets for analysis and decision-making, to promote the advancement of geospatial procedures and to show how spatial datasets can support decision makers in planning interventions tomitigate the greenhouse effect, identify vulnerable areas and support sustainable management [35]; Mi et al. used spatial divergence analysis, spatial clustering analysis, and spatial autocorrelation analysis to represent the spatial and temporal characteristics of green innovation in China [36]; Xu et al. used the entropy method, coupling coordination model, spatial Markov model, and grey model and other quantitative methods to explore the dynamics and evolutionary trend of the coupling coordination degree between energy consumption and green development in China from 2006 to 2020 [25].

Green Transition and Spatial Justice in China's Territorial Space Planning

3 Green Transition and Spatial Justice in China's Territorial Space Planning

3.1 Territorial Space Planning System in China

In May 2019, the State Council of the Central Committee of the Communist Party of China (CPC) issued a programme document on Territorial Space Planning, "The guidance on establishing the territorial spatial planning system and supervising its implementation" (hereinafter referred to as "the Guidance"), representing the era of urban development in China. Territorial Space Planning system is "a guide for national spatial development, a spatial blueprint for sustainable development, and a basic basis for all kinds of development, protection and construction activities"... [57]Territorial Space Planning integrates the Main Functional Area Planning, Land Use Planning, Urban and Rural Planning and other spatial planning into a unified Territorial Space Planning, realising the 'Multi-Planning Integration'". Territorial Space Planning was introduced to address the real-life contradictions in the planning system, such as too many types of planning, overlapping content, and complex approval processes, and more fundamentally to build an ecological civilisation with the people in mind, achieving high-quality urban development and high-quality life for the people while creating a new pattern of territorial space development and protection and accelerating the formation of green modes of production and lifestyles[58].

In the past 40 years before the introduction of Territorial Space Planning, China has been searching for the truly correct path for urban development, and the planning system has been continuously improved. From reform and opening up to the present, China's Territorial Space Planning has gone through three stages. At the beginning of China's reform and opening up (1978-early 21st century), spatial planning was dominated by land planning, aiming to scientifically develop land use resources and promote agricultural development. With the development of industry and urbanisation (early 21st century-2018), the country's spatial planning transformed into urban and regional planning, aiming to promote urbanisation and industrialisation. Currently (2018-present), China is focusing more on high-quality development, rational development of resources, protection of the ecological environment, building an ecological civilisation and promoting sustainable national development.

Departments	NDRC		MHURD	MLR	MEP	NDRC			
Subdivided Periods	1981–1993	1981–2005	1981–2007	1986–2005	2002	2006–2018			2011
Planning Types Planning Levels	Territorial-Planning	Five-Year Plan	Urban-Planning-System	LandUse Master Planning	Ecological-Function-Zoning	Five-YearPlanningSystem			Major Function-Oriented Zoning Planning
						Five-Year Master Planning	Five-Year Special Planning	RegionalPlanning	
National-level	•	◎		◎		◎	◎		•
Trans-provincial-level	•							•	
Provincial-level	•	◎	•	◎	•	◎	◎		•
Inter-city-level	•		•					•	
City-level	•	◎	•	•		•	◎		
County-level	•	◎	•	•		•	◎		
Town/ township-level									

Departments	MHURD			MLR	MEP			NDRC			MNR		
Subdividedperiods	2008–2018			2006–2018	2012			After2019			After2019		
Planning Types Planning Levels	Urban–Ruralplanningsystem			landuse master planning	Ecological-function zoning	Environmental function zoning	UrbanEn-vironment Master Planning	Developmentplanningsystem			Spatialplanningsystem		
	Urban system planning	Urbanand rural master planning	Detailed urban planning					Five-year master planing	Five-year special planning	Regional planning	Master planfor territorial space	Special planning for territorial space	Detailed planning for territorial space
National-level	•			◎	•	•		◎	◎		•		•
Trans-provincial-level										•		•	
Provincial-level	•			◎	•	•		◎	◎		•		•
Inter-city-level	•									•		•	
City-level		•	•	•		••		◎	◎		•		•
County-level		•	•	•		•		◎	◎		•		•
Town/ township-level		•	•	•							•		•

(Figure 3.1 "China's spatial planning led by the four government departments in four stages after 1949" *Source: Zhang et al.*[1])

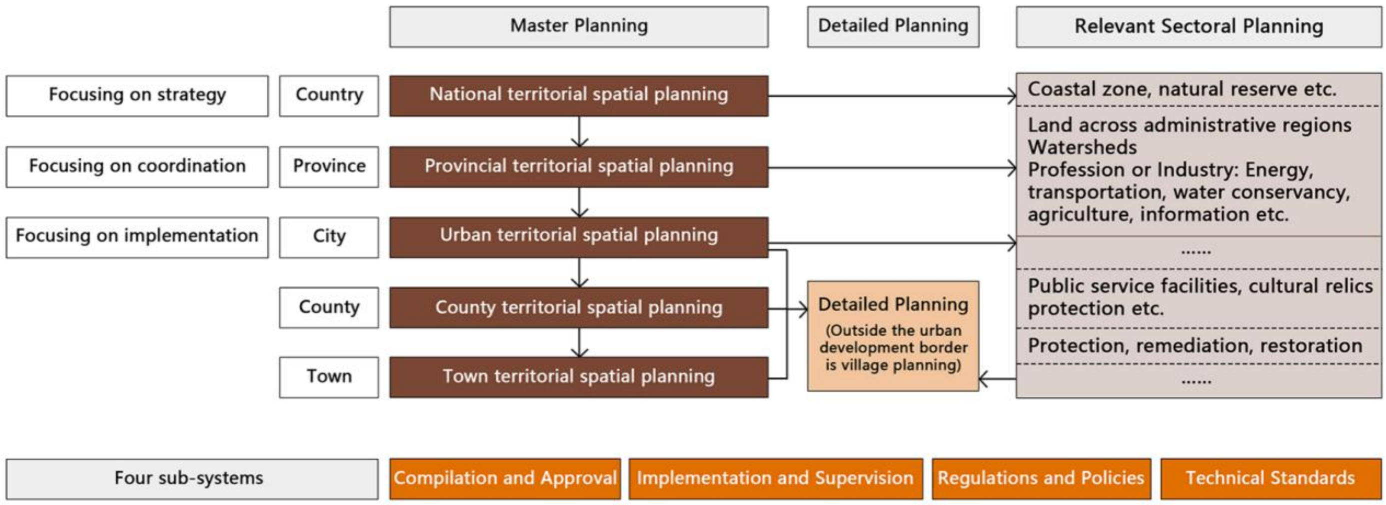
Territorial Space Planning is divided into five levels, three categories and four systems, "five levels" refers to the planning of vertical division of the national, provincial, municipal, county and township levels, of which the national that is, the general programme of Territorial Space Planning, is the overall layout of the national territorial space, the national policy of territorial space protection, development, use, restoration and the general outline; and the provincial level of the planning of the role of carrying on the top to start with, while guiding the preparation of the following levels; municipal, county and township level space planning municipal higher government to the lower level of government requirements for

1 Yongjiao Zhang, Xiaowu Man, and Yongnian Zhang, 'From "Division" to "Integration": Evolution and Reform of China's Spatial Planning System', *Buildings* 13, no. 6 (19 June 2023): 1555, https://doi.org/10.3390/buildings13061555.

specific implementation; based on this formed since the upper level to lower level of government requirements. [58]The provincial-level planning plays the role of carrying forward the national Territorial Space Planning and guiding the preparation of the following levels of Territorial Space Planning. [60]The municipal, county and township-level space planning is the concrete implementation of the requirements of the higher level of government to the lower level of government, based on which the institutional framework for the implementation of the national development strategy has been formed from the top to the bottom.[61]

“Three categories” refer to planning horizontally including master planning, detailed planning and special planning three categories, of which detailed planning is divided into control detailed planning and construction detailed planning. Territorial Space Planning, as mentioned above, is divided into five levels of corresponding spatial planning at all levels; Detailed Planning is compiled by the municipal and county governments to guide the implementation of specific land use and development and construction intensity arrangements, and is the legal basis for carrying out Territorial Space Planning and protection activities, implementing Territorial Space Use Control, issuing planning permits for urban and rural construction projects, and carrying out various types of construction activities; and Specialised Planning refers to the special arrangements for the spatial Special planning refers to the special arrangements for the development, protection and utilisation of space in specific areas. The relationship between them is that the master plan is the basis for the detailed plan and the special plan, and the special plans for different topics need to be coordinated with each other and articulated with the detailed plan.[62] [63]

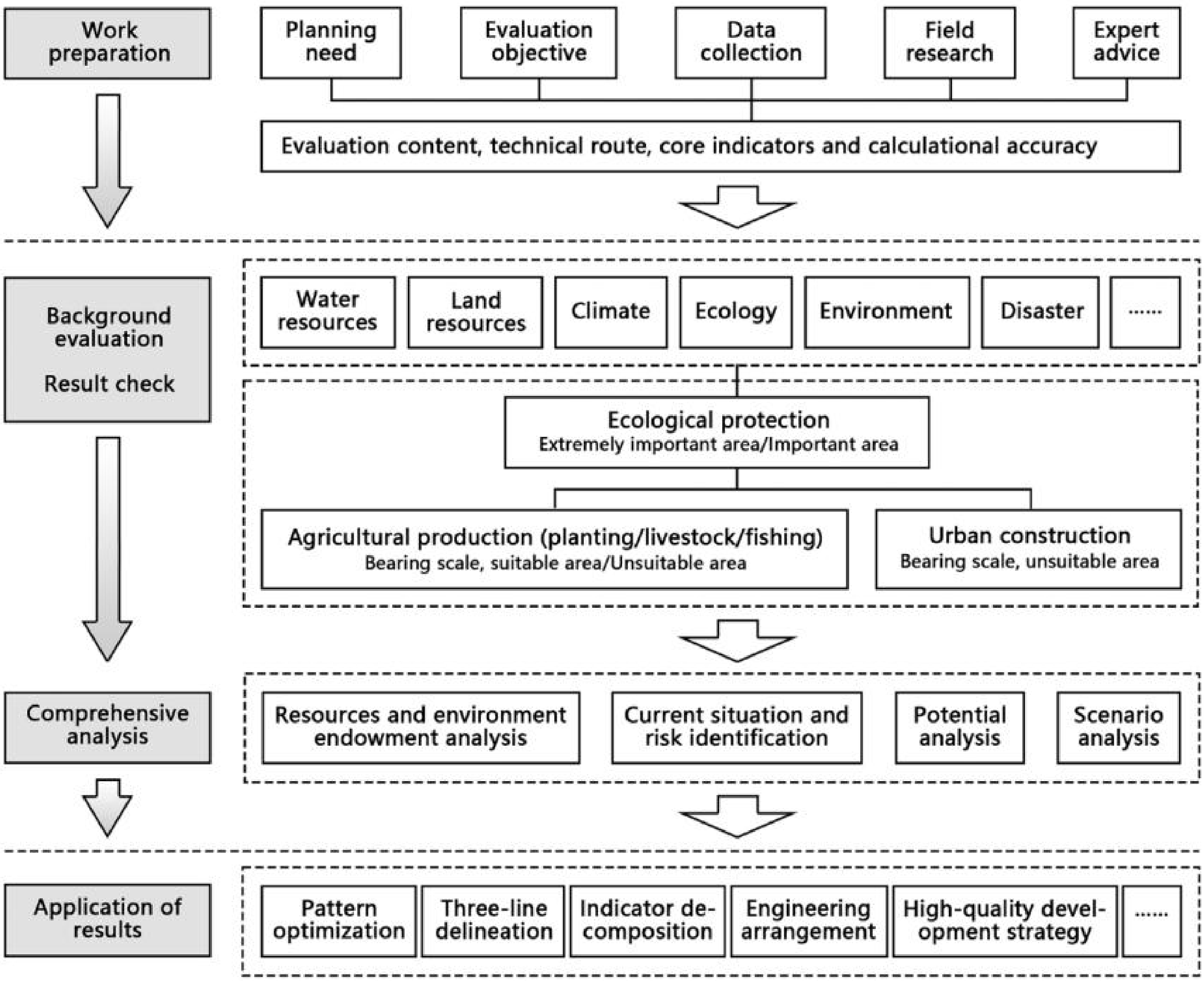
The "four systems" refer to Compilation and Approval, Implementation and Supervision, Regulations and Policies, and Technical Standards. [64]It is clear that the formulation, introduction and implementation of control plans need to follow a scientific and controllable procedure. The Guidance suggests that, firstly, the preparation process needs to implement the strategy of national security and coordinated regional development, ensure the scientific nature, adhere to the ecological priority and green development, and strengthen the coordination between various types of plans at all levels during the approval process, and establish a systematic control system in accordance with the principles of "who prepares, who implements" and "who approves, who supervises". In accordance with the principle of "who prepares, who implements" and "who approves, who supervises", systematic implementation and supervision procedures should be established. At the same time, Governments at all levels also need to strengthen the construction of relevant regulations and policies, and formulate and improve various technical standards.[65]



(Figure 3.2 "The system framework of Chinese territorial spatial planning." *Source:Hu et al.*[2])

Dual evaluation and the delineation of the three control lines are important contents and basic elements of Territorial Space Planning. Dual evaluation is a necessary step in the process of preparing Territorial Space Planning, and refers specifically to the evaluation of the carrying capacity of resources & environment and the evaluation of the suitability of territorial space development, which is the reference basis for optimising the pattern of development and conservation of territorial space, completing the positioning of the main functions of the region, and delineating the three control lines, which is essential for completing spatial governance.[66]

[2] Gangyu Hu et al., 'The Formation of the Chinese Territorial Spatial Planning System and International Comparison', *Transactions in Planning and Urban Research* 2, no. 1 (March 2023): 16–36, https://doi.org/10.1177/27541223231153420.



(Figure 3.3 “The workflow diagram of Double Evaluation” *Source:Hu et al.*[3])

The three control lines include the red line of ecological conservation, the line of permanent basic farmland, and the urban development boundary, which fully embodies the three major security objectives of territorial spatial planning for territorial space planning: food security, social security and ecological security (see figure 3.4). [64]The red line of ecological protection (bottom layer) represents the foundation of ecological security, aiming to prevent environmental degradation and ecosystem destruction through the delineation of ecological function areas and nature reserves. Protection at this level includes soil and water conservation, biodiversity maintenance and desertification control. The urban-rural development boundary (middle tier) is used to safeguard social security, limit urban sprawl, and ensure that urban-rural development is in line with the carrying capacity of resources and the environment through rational urban boundary planning. The scale and appropriateness of

Hu et al.[3] Hu et al.

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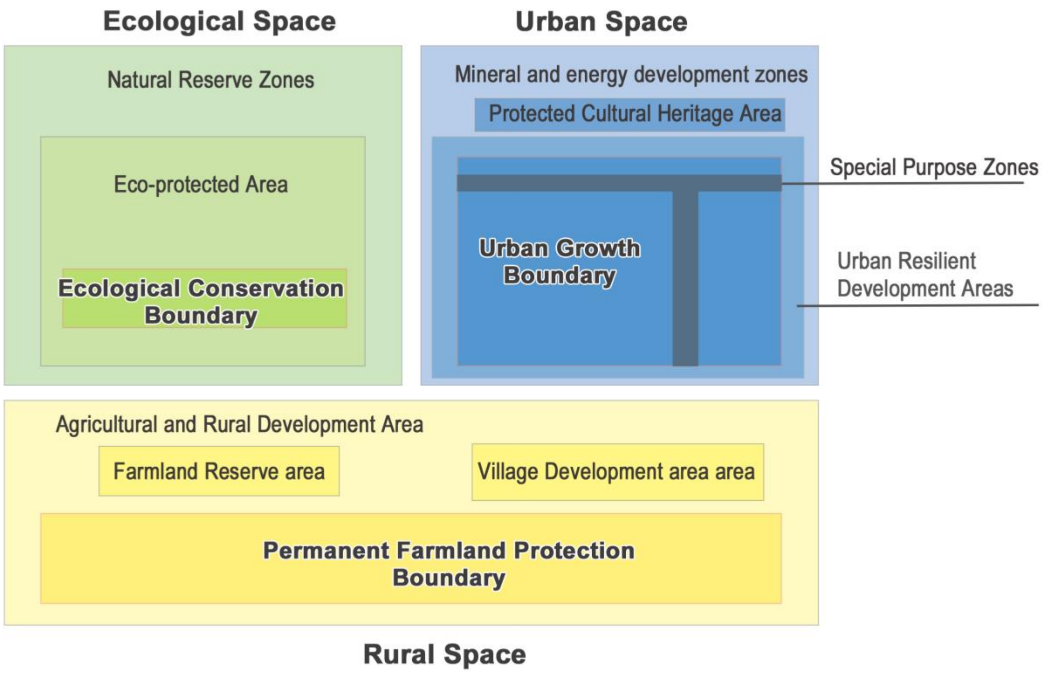
urban and rural development can be planned through the assessment of the resource environment. Permanent basic farmland (top tier), as the highest-priority food security measure, protects the country's agricultural land and ensures that food production is not affected by other land use demands, such as urban expansion.[66]

(Figure 3.4 "Three bottom lines for China's national territorial spatial planning" *Source: Liu et al.*[4])

By implementing the three control lines into specific spaces (see figure 3.5), it is possible to observe more clearly how they are implemented. Firstly, the national territory is divided into three major spaces, ecological space, urban space and rural space. Ecological space contains nature reserves and eco-protected areas, the core of which is the red line of ecological protection, the most strictly protected area, followed by eco-protected areas, areas that are strictly protected, while nature reserves assume certain restrictions on development but still allow for sustainable use of some of the ecological functions. Urban space includes urban growth boundaries, special use areas and urban resilient development areas. The core is the urban growth boundary, special use zones are used to meet specific needs, such as mineral and energy development zones and cultural heritage preservation zones, and urban resilient

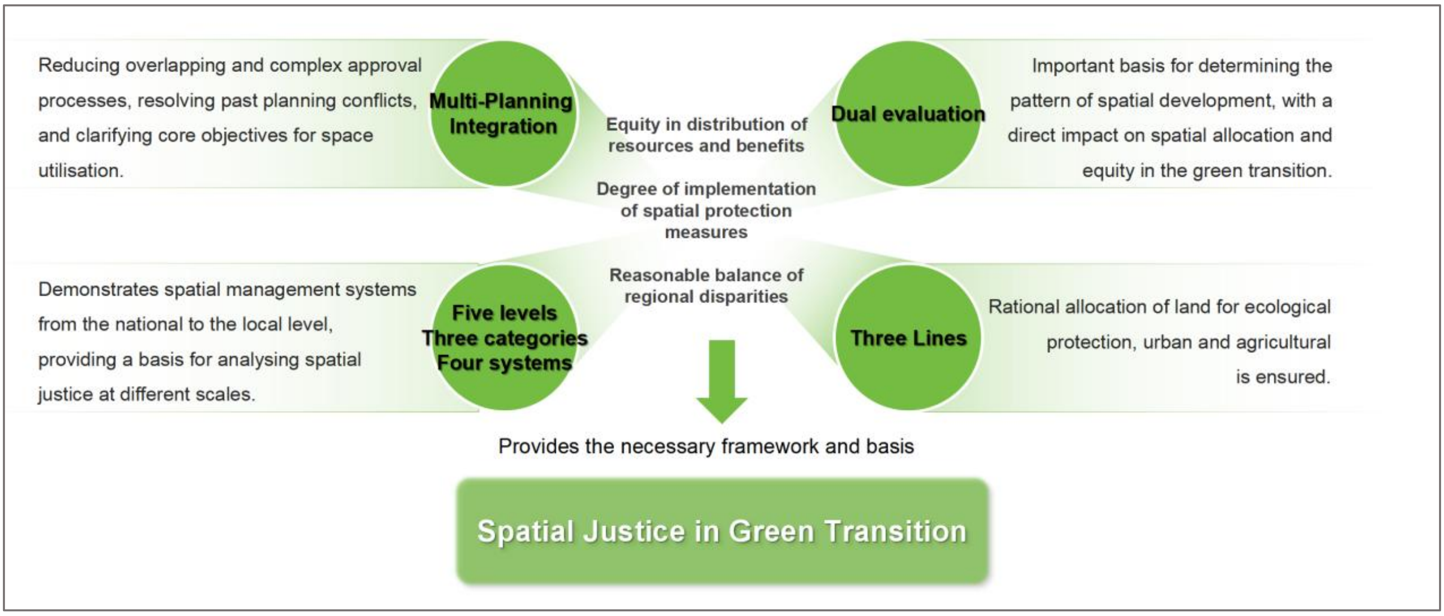
[4] Yansui Liu and Yang Zhou, 'Territory Spatial Planning and National Governance System in China', *Land Use Policy* 102 (March 2021): 105288, https://doi.org/10.1016/j.landusepol.2021.105288.

development zones are designed to increase the capacity of cities to cope with environmental and economic challenges. Rural space consists of agricultural and rural development zones, containing permanent basic farmland protection zones, farmland reserve zones and village development zones. The core area is the permanent basic farmland protection zone, the farmland reserve zone provides space for the expansion of future agricultural development, and the village development zone is used to plan the development and transformation of rural settlements.[67]



(Figure 3.5 Three Control Lines into Three Spaces *Source:The Author*)

In general, the implementation of Territorial Space Planning is a fundamental guarantee for the realisation of spatially just, green transition development. The 'multi-planning' system of Territorial Space Planning integrates the main functional area planning, land use planning, urban and rural planning, and so on, into a unified spatial plan. By reducing overlaps and complex approval processes, the system resolves the contradictions in past planning and clarifies the core objective of spatial use, namely to achieve ecological civilisation and high-quality urban development. This provides a platform for co-ordinated development for green transition, thereby promoting green production methods and green lifestyles. The structural framework of 'five levels, three categories and four systems' demonstrates the spatial management system from the national to the local level, especially the implementation and enforcement at the provincial, municipal, county and township levels, which provides a basis for analysing spatial justice at different scales. The hierarchical management allows observing the rights and responsibilities of each level of government in terms of resource allocation, ecological protection and social development. In the process of compiling territorial space planning, dual evaluation (evaluation of the carrying capacity of resources and environment and evaluation of the suitability of territorial space development) is an important basis for deciding the pattern of spatial development. Through the dual evaluation, the development and protection of different regions can be rationally planned to guarantee the rational use of resources and the sustainable development of the environment, which has a direct impact on the spatial distribution and fairness in green transition. The three control lines - the ecological conservation red line, the permanent basic farmland line and the urban development boundary - represent ecological security, food security and social security respectively. The existence of these three control lines effectively guarantees ecological conservation and the rational allocation of urban and agricultural land. Spatial justice in green transition can be explored in depth by analysing the distribution of resources, the protection of ecological functional areas and the impact of socio-economic activities under different control lines. Therefore, through the background of the above planning system, it is possible to study whether the distribution of resources and benefits is fair, spatial protection measures are effectively implemented, and urban-rural disparities are reasonably balanced in different regions in the process of green transition. These provide the necessary framework and basis for an in-depth study of spatial justice in green transition.



(Figure 3.6 Relationship between China's Territorial Space Planning and Spatial Justice in Green Transition *Source:The Author*）

3.2 Rationale for Selecting Guangdong Province as a Case Study in Spatial Justice and Green Transition

Guangdong Province is located in southern China, along the South China Sea (See Figure 3.7). Its location makes it an important hub for international trade, connecting China with South-East Asia, Europe and the Americas. At the same time, Guangdong borders the Hong Kong and Macau Special Administrative Regions, and is at the heart of the Greater Bay Area, one of the world's most dynamic economic zones. Guangdong Province has long been a 'leader' in China's economy, with a total GDP of more than RMB 12 trillion in 2023, accounting for about one-tenth of the country's total, and is an important pillar of the national economy. [68]Its economic structure is dominated by the industrial and service sectors. As a region with a high degree of industrialisation and informationisation, Guangdong's economic model has long put enormous pressure on resource consumption and the environment, and a green transition is imminent.

(Figure 3.7 The Location of Guangdong *Source:China Discovery Website*[5])

[5] https://www.chinadiscovery.com/assets/images/guangdong/maps/guangdong-world-map-768.jpg

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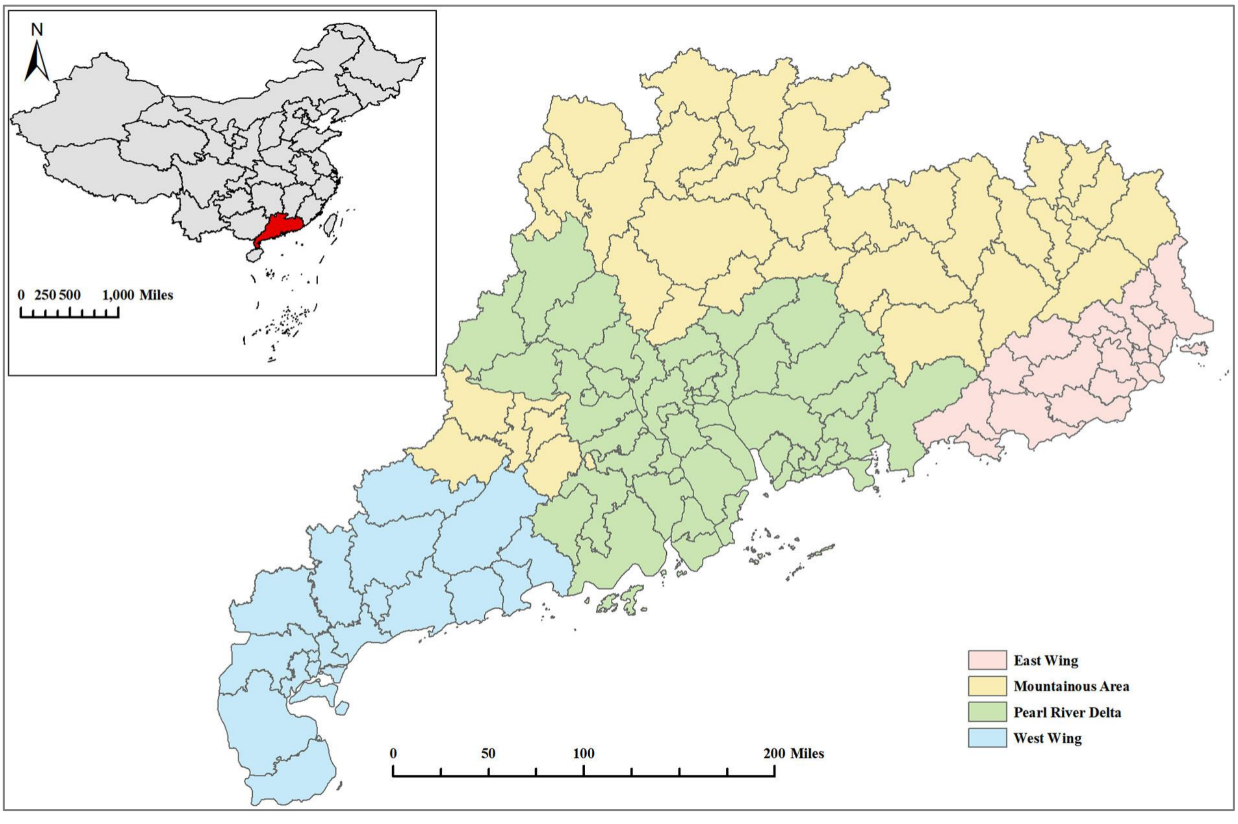
Guangdong's economic success has been accompanied by serious ecological and environmental problems. The Pearl River Delta (PRD) region has been the ‘hardest hit’ by pollution due to rapid industrialisation, such as water resource pollution (Pearl River Basin) and air quality problems (high PM2.5 concentration). [69]Green transition is not only an inevitable choice for economic transformation, but also an urgent need for ecological restoration. At the same time, green transition puts forward new requirements for the sustainable development of regional economy, such as clean energy substitution, industrial energy saving and ecological restoration.

Unbalanced regional development is another serious problem on Guangdong's development path. Within Guangdong, there is a typical pattern of polarisation between the PRD and Northwest Guangdong (NWD). [70]While the PRD region, such as Guangzhou, Shenzhen, Foshan and Dongguan, has one of the highest levels of development in the country, the north-western part of eastern Guangdong is lagging behind in economic development, with a weak industrial base and relatively backward urban and rural infrastructure. This imbalance in regional economic development leads to the possibility of inequity in the distribution of policies and resources in the green transition as well, and this regional development difference makes the green transition process a significant spatial justice issue.



(Figure 3.8 The location of Guangdong Province and the division of its four regions
Source:Han et al.[6])

At the same time, however, Guangdong Province has long been at the forefront of green transition development in the country. As early as the 11th Five-Year Plan period, Guangdong launched an energy conservation and emission reduction programme and took the lead in exploring green transition of industries. For example, the PRD region became one of China's first carbon emissions trading pilots, accumulating experience for the subsequent construction of the national carbon market.[71] In addition, Guangdong has vigorously promoted green financial policies and innovated in areas such as green credit and green bonds to provide enterprises with financial support for transformation. For example, the establishment of the Guangzhou Carbon Trading Centre marks Guangdong's leading position in the carbon market, providing a practical basis for research into the fairness of fund allocation in green transition.[72] Nonetheless, the implementation of green policies is not equally effective in different regions. For example, economically developed regions in the PRD can respond quickly to green financial policies, while regions in the eastern and northwestern parts of Guangdong may find it difficult to enjoy the same policy dividends due to backwardness in industrial structure or insufficient implementation of policies, and this inequality reflects the disparity in spatial justice.[73]

The level of economic development and internal regional differences in Guangdong epitomise China's economic development and are highly typical. The level of industrialisation and modernisation in the PRD is similar to that of the Yangtze River Delta and the Beijing-Tianjin-Hebei region, while the development pattern of Northwest Guangdong can reflect the characteristics of China's widely underdeveloped regions. Therefore, studying Guangdong's green transition and spatial justice issues can provide policy references for the rest of the country. As the frontier of China's opening up to the outside world, Guangdong has an important position in the global economy, and its green transition process has received extensive attention from the international community. For example, Guangdong's green finance, carbon trading and clean energy transition can provide replicable experiences for other developing countries, especially in terms of how to achieve equitable distribution while balancing economic development and ecological protection.

[6] Han, Lu & Xiong, Wenxue & Li, Mingzhen & Li, Rui & Wu, Jiabao & Tang, Xijia & Ling, Li & Liu, Xiaohua. (2022). Couple-level determinants of syphilis infection among heterosexual married couples of reproductive age in Guangdong Province, China: A population-based cross-sectional study. Frontiers in Public Health. 10. 10.3389/fpubh.2022.1004246.
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3.3 Embodiment of Green Transition in Various Levels of Territorial Space Planning

Green transition policies echo each other in national and provincial-level territorial spatial planning, promoting sustainable economic and social development in a comprehensive manner through multifaceted measures such as ecological protection, low-carbon economy, land optimisation, green transport, urban-rural coordination, environmental governance and technological innovation. In terms of ecological protection and restoration, the two levels of government share the same objective of protecting ecosystems and enhancing their resilience through rigorous policy frameworks and programmes to achieve long-term ecological sustainability. Low-carbon economy and green industries are strategic priorities, with a view to reducing reliance on traditional fossil fuels through optimising the energy mix and promoting green industries. The core of land use optimisation lies in scientific planning and zoning to achieve efficient and intensive use and maximise economic, ecological and social benefits. Green transport and infrastructure development, on the other hand, will achieve green transition in the transport sector through energy-saving and emission reduction technologies and intelligent transport systems. The key to green development in urban and rural areas lies in optimising urban and rural spatial layout, balancing ecological and economic activities, and promoting green revitalisation and modernisation of rural areas. Environmental policy and pollution management emphasise cross-regional cooperation and a sound monitoring and management system to ensure continuous improvement in environmental quality. Green technology and innovation are the core drivers of green transition, promoting technological research and development and industrial upgrading through policy and financial support, and encouraging the development of green finance and innovation mechanisms.

3.3.1 National Level[74]

China was comprehensively promoting green transition through multifaceted measures to achieve sustainable economic and ecological development. It has set up ecological protection zones and ecological red lines, and implemented large-scale ecological restoration projects, such as the restoration of wetlands and forests, to promote biodiversity conservation. Vigorously promote the development of renewable energy, covering wind, solar and hydropower, while encouraging the development of green industries and establishing a carbon trading system to reduce carbon emissions. Enhance the efficiency of intensive land use through land use zoning and vertical urban development, while encouraging the redevelopment of unused land. Developing green transport systems, such as metro, bus rapid transit and electric vehicles, and promote energy-efficient buildings and green infrastructure. Integrated urban-rural development is another important direction, advocating the protection and expansion of green space and supporting green agriculture and rural eco-tourism. Strict environmental regulations and monitoring systems ensure effective management of environmental elements such as air, water and soil, while strict waste management and recycling policies are implemented to reduce pollution. In addition, China was vigorously promoting research and development of green technologies, including innovations in clean energy, waste treatment and sustainable materials, supporting the industrialization of green technologies and promoting the development of energy-saving and emissions-reduction technologies.

Dimensions	Specific Measures
Ecological Conservation and Restoration	- Establish and enforce ecological conservation areas and ecological redlines; - Implement large-scale ecological restoration projects, including reforestation and wetland restoration; - Promote biodiversity conservation by protecting endangered species and their habitats.
Low-Carbon Economy and Green Industries	- Promote the development of renewable energy sources like wind, solar, and hydroelectric power; - Support green industries such as energy-efficient technologies and circular economy initiatives; - Implement carbon trading systems and incentives for reducing carbon emissions.
Optimized Land Use and Efficient Utilization	- Enforce land-use zoning to prioritize high-value and sustainable land uses; - Encourage urban densification and vertical development to reduce urban sprawl; - Promote the reclamation of unused or underused land for productive purposes.
Green Transportation and Infrastructure	- Develop and expand public transportation networks, including metro, bus rapid transit, and rail systems; - Promote the use of electric and hybrid vehicles through incentives and infrastructure support; - Invest in green infrastructure, such as energy-efficient buildings and smart grids.
Urban-Rural Green Development	- Promote the integrated development of urban and rural areas, ensuring green space and sustainable development in both; - Support sustainable agricultural practices and rural eco-tourism; - Enhance green spaces and recreational areas in urban environments.

Environmental Governance and Pollution Control	- Implement stricter environmental regulations and monitoring systems for air, water, and soil quality; - Promote waste reduction, recycling, and safe disposal practices; - Strengthen enforcement against illegal pollution and environmental violations.
Green Technology and Innovation	- Support research and development in green technologies, including clean energy, waste treatment, and sustainable materials; - Encourage innovation in energy-saving and emission-reduction technologies; - Foster public-private partnerships for green innovation and commercialization.

(Table 3.1 Embodiment of Green Transition in National Level of Territorial Space Planning *Source:The Author*)

3.3.2 Provincial Level- Base on Guandong Province[75]

Guangdong Province is actively promoting green transition development through a number of measures to achieve coordinated and sustainable ecological and economic development. The province focuses on balancing ecological, agricultural and urban land use, protecting natural resources and biodiversity, and enhancing natural functions through ecological restoration projects covering forests, wetlands and coastal ecosystems. The province focuses on transforming its energy structure, reducing the intensity of energy consumption, promoting the development of high-quality green industries, and encouraging green financial and technological innovation. Guangdong Province is actively optimising its urban spatial structure and strengthening agricultural land protection, while promoting efficient land use and land redevelopment to enhance the comprehensive use of land resources. In the area of transport, Guangdong Province also attaches importance to the construction of green and intelligent transport systems, building green infrastructure, improving the efficiency of public transport, and promoting new energy means of transport. In terms of integrated urban and rural development, Guangdong Province is committed to building a diversified green space system, optimising urban layout, upgrading the living environment in rural areas, and promoting the construction of green infrastructure. For environmental governance, Guangdong Province promotes cross-regional air and water pollution control, strengthens integrated watershed management, and reduces sources of pollution through stricter environmental protection enforcement, especially in ecological restoration in mountainous areas. Guangdong Province also promotes green technology innovation, especially in the Pearl River Delta region, combining science and technology with ecological protection to promote regional ecological protection and technological upgrading, as well as supporting the establishment of green finance and innovation platforms.

Dimensions	Specific Measures
Ecological Protection and Restoration	- Achieve a rational balance among ecological, agricultural, and urban spaces; -Protect natural resources and biodiversity; -Enhance natural ecological functions; -Implement restoration of forests, wetlands, and coastal and marine ecosystems.
Low-Carbon Economy and Green Industry	- Promote energy structure transformation; -Reduce energy consumption intensity; -Develop high-quality green industries; -Encourage technological innovation, and foster green finance.
Optimized and Intensive Land Use	- Optimize urban spatial structure -Improve urban and rural layout -Strengthen agricultural land protection -Enhance biodiversity, promote land reclamation -Encourage efficient land use.
Green Transportation and Infrastructure	- Develop a green, intelligent, and safe transportation network; -Construct a green infrastructure system -Promote smart and green transportation -Enhance public transport and logistics efficiency.
Urban-Rural Green Development	- Construct a diversified green space system within cities -Optimize urban spatial layout -Promote rural revitalization -Improve living environments -Enhance green infrastructure construction.
Environmental Governance and Pollution Control	- Implement comprehensive air, water, and soil pollution control; -Strengthen integrated river basin management; -Promote air pollution control across regional boundaries; -Implement ecological restoration in mountainous areas.
Green Technology and Innovation	- Promote green technology initiatives - Encourage ecological restoration and greening actions -Focus on key areas like the Pearl River Delta, and integrate technology and ecological practices to enhance ecological protection.

(Table 3.2 Embodiment of Green Transition in Provincial Level of Territorial Space Planning *Source:The Author)*

3.3.3 Municipal Level- Base on the Municipalities of Guandong Province[76] [77] [78] [79] [80] [81] [82] [83] [84] [85] [86] [87] [88] [89] [90] [91] [92] [93] [94] [95] [96]

Based on the seven dimensions of the national and provincial Territorial Space Planning regarding green transition, the green transition development of the Territorial Space Planning of 21 municipalities is specifically analysed, and an evaluation form for the green transition development is summarised, with an item to be ticked if a municipality's Territorial Space Planning contains an evaluation item.

Cities with excellent overall green transition performance:

-Shenzhen and Guangzhou: Both cities ticked most of the green transition dimensions, including environmental protection, new energy industry, green transport and waste-free city. This indicates that they are actively promoting eco-friendly and sustainable development strategies in their territorial spatial planning.

-Shantou and Huizhou: These two cities also perform well on several dimensions of ecological protection and green industry, showing a strong awareness of green development.

Cities covered by some green transition policies:

- Shaoguan, Meizhou, and Zhanjiang Although they are covered in terms of ecological protection and some of the green industries, the overall green transition planning coverage is relatively incomplete, and there may be room for further optimisation.

- For example, Meizhou has plans for intensive land use and ecological protection of the red line, but has less content on green transport and new industries.

Cities with relatively insufficient green transformation content:

-Cities such as Chaozhou and Jieyang have fewer ticks in the table, suggesting that the layout of these cities' plans in terms of green transformation is relatively weak, especially in terms of innovative technology and green industries, which need to be strengthened.

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Municipalities	**Environmental Conservation and Restoration**		**Low-Carbon Economy and Green Industry**					**Optimisation and intensification of land use**		
	Ecological Protection Red Line (EPRL)	Ecosystem Restoration Project	New Energy Industries	Contemporary Agriculture	Maritime Economy	High-tech Industries	Contemporary Tourism	Intensive Land use	Inventory Land Revitalisation	Stereoscopic Space Development
Shenzhen	√	√		√	√	√	√	√		√
Maoming	√	√		√	√	√	√	√		
Shaoguan	√	√		√		√	√	√		
Yangjiang	√	√	√	√	√	√	√		√	
zhaoqing	√	√		√				√	√	√
Zhanjiang	√	√	√	√					√	
Jiangmen	√	√	√		√	√		√	√	
Shanwei	√	√	√	√	√	√		√		
Shantou	√	√	√	√	√	√	√	√	√	
Jieyang	√	√				√		√	√	
Huizhou	√	√	√	√	√	√	√	√		
Zhongshan	√	√				√		√		
Yunfu	√	√	√					√		

Foshan	√	√		√		√	√	√		
Meizhou	√	√				√		√		
Heyuan	√	√					√	√		
qingyuan	√	√	√					√	√	
Zhuhai	√	√				√		√		
Chaozhou	√	√	√		√				√	
Dongguan	√	√				√		√		
Guangzhou	√	√		√		√	√	√	√	√

Municipalities	**Green transport and infrastructure**				**Environmental Governance and Pollution Prevention**				**Green Technology and Innovation**
	Green Open Space	Information Infrastructure	Express and Slow Traffic System	New Energy Transport	Waste-free City	Water-saving City	Sponge City	Integrated Disaster Prevention	
Shenzhen	√		√		√	√	√	√	√
Maoming	√					√	√	√	√
Shaoguan	√					√	√	√	√
Yangjiang	√								
zhaoqing	√					√	√	√	

Zhanjiang	√		√	√		√	√	√	
Jiangmen	√	√		√	√	√		√	√
Shanwei	√			√		√	√		√
Shantou	√					√	√		√
Jieyang	√							√	√
Huizhou	√		√			√	√		√
Zhongshan	√	√							√
Yunfu	√				√	√	√		√
Foshan	√			√	√			√	√
Meizhou	√								
Heyuan	√	√			√			√	√
qingyuan	√				√				√
Zhuhai	√	√	√					√	√
Chaozhou	√								
Dongguan	√	√			√			√	√
Guangzhou	√				√	√	√	√	

(Table 3.3 Tick List of Green Transition in Municipal Level *Source:The Author*)

3.4 Embodiment of Spatial Justice in Various Levels of Territorial Space Planning

The State and Guangdong Province are actively promoting spatial justice in spatial planning through a variety of measures to ensure the equitable distribution of resources and services. Equitable distribution of resources is reflected in the promotion of equitable accessibility of resources and services through transparent and open platforms and rational resource allocation to ensure a more balanced distribution of resources between urban and rural areas and regions, especially in less developed areas. By strengthening the coordinated development of city clusters and metropolitan areas and the balanced allocation of public services between urban and rural areas, governments at all levels are committed to promoting urban-rural integration and balanced regional development, and to avoiding the over-concentration of resources in developed regions. Equalisation of public services is a key path to achieving social equity, ensuring that every citizen, especially disadvantaged groups and rural residents, enjoys the right to basic public services through improved infrastructure and equitable distribution of resources. Public participation, on the other hand, is an important means of enhancing spatial justice; through institutionalised and transparent public participation, the public's right to information and participation in the planning and decision-making process is guaranteed, thereby enhancing the fairness and effectiveness of policies.

3.4.1 National Level[74]

The national level is committed to promoting spatial justice and the balanced development of public services through a number of initiatives. First, it proposes to ensure fairness in the distribution of resources through resource-sharing platforms and the optimisation of resource layouts, as well as to promote the rational flow of resources between urban and rural areas. By promoting the development of city clusters and metropolitan areas, the State has strengthened urban-rural interaction, narrowed the gap between urban and rural areas, and ensured the rational flow of population and resources. In the area of public services, the State pays particular attention to the equalisation of basic services, such as education and health care, and in particular to narrowing the gap between urban and rural areas and between regions, while at the same time upgrading the level of digitised services to ensure that residents in all regions enjoy equal access to services. In addition, the State has safeguarded public participation mechanisms through legislation and established a public feedback platform to ensure transparency and public participation in the process of Territorial Space Planning.

Dimensions	Specific Measures
Resource Allocation Accessibility	- Develop a national resource allocation strategy to optimize resource distribution. - Promote rational and sustainable resource development, avoiding unfair competition for regional resources. - Build resource-sharing platforms to enhance transparency and accessibility of resource information.
Coordinated Regional and Urban-Rural Development	- Optimize the layout of city clusters and metropolitan areas to facilitate the flow of resources between urban and rural areas. - Strengthen rural infrastructure to improve the quality of life in rural areas. - Promote policies for urban-rural integration to ensure equitable distribution of population and employment opportunities.
Equalization of Public Services	- Improve the equitable distribution of public services like education and healthcare between urban and rural areas. - Promote the construction of digital infrastructure to expand access to information services. - Enhance public service provision in impoverished areas to reduce regional disparities.
Public Participation	- Improve laws and regulations to ensure public participation in the planning process. - Establish platforms for public feedback, encouraging diverse stakeholders to participate in discussions and decision-making. - Increase transparency and openness of planning information, allowing the public to understand planning content.

(Table 3.4 Embodiment of Spatial Justice in National Levels of Territorial Space Planning
Source:The Author)

3.4.2 Provincial Level- Base on Guandong Province[75]

Through multifaceted initiatives, Guangdong Province has actively promoted the equitable distribution of resources and the coordinated development of urban and rural areas in an endeavour to narrow regional disparities. Through a cross-regional resource-sharing mechanism and improved rural infrastructure, Guangdong Province has enhanced equity in access to and distribution of resources and promoted the development of green industries to less developed regions. Paying special attention to the coordinated development of the Pearl River Delta region and the Guangdong-Hong Kong-Macao Greater Bay Area, Guangdong Province has facilitated the modernisation process of urban and rural areas and the implementation of the rural revitalisation strategy through the interconnection of urban and rural infrastructures. In the area of public services, Guangdong Province focuses on optimising the distribution of healthcare resources and accelerating the construction of digital infrastructure, especially in rural areas, and is committed to reducing the gap in public services between urban and rural areas. In addition, Guangdong Province has emphasised the enhancement of planning transparency, encouraged community participation in environmental governance, and increased public awareness of planning and influence in decision-making, thereby promoting wider public participation.

Dimensions	Specific Measures
Resource Allocation Accessibility	- **Promote Regional Resource Integration**: Establish cross-regional resource sharing mechanisms, optimizing the integration and management of water, electricity, and transportation infrastructure; - **Improve Rural Resource Accessibility**: Enhance infrastructure development in rural areas, improving transportation and access to resources; - **Optimize Industrial Layout**: Encourage high-tech and green industries to establish in less developed regions, promoting balanced regional economic development.
Coordinated Regional and Urban-Rural Development	- **Develop Urban Clusters and Metropolitan Areas**: Advance the construction of the Guangdong-Hong Kong-Macao Greater Bay Area, strengthening connectivity and coordinated development among cities and optimizing urban functional zoning; - **Rural Revitalization Strategy**: Support the development of rural infrastructure, rural industries, and public services to promote rural modernization; - **Strengthen Urban-Rural Interaction**: Coordinate public services, social security, and employment policies to promote reasonable population and resource flows between urban and rural areas.

Dimensions	Specific Measures
Equalization of Public Services	- **Equitable Distribution of Educational Resources**: Improve the quality of education in rural and remote areas, narrowing the urban-rural education gap; - **Optimize Healthcare Resource Distribution**: Direct healthcare resources towards grassroots and rural areas to enhance primary healthcare services; - **Enhance Digital Service Levels**: Accelerate the construction of provincial information networks, promote the digital economy, and ensure that urban and rural residents can access digital public services.
Public Participation	- **Establish Public Participation Mechanisms**: Widely collect public opinions during planning processes and establish platforms for public involvement; - **Increase Planning Transparency**: Enhance information disclosure during the planning process to enable public understanding and oversight; - **Strengthen Community Involvement**: Encourage community residents to participate in local environmental governance and public affairs, enhancing community self-governance.

(Table 3.5 Embodiment of Spatial Justice in Provincial Levels of Territorial Space Planning *Source:The Author*)

3.4.3 Municipal Level- Base on the Municipalities of Guandong Province[76] [77] [78] [79] [80] [81] [82] [83] [84] [85] [86] [87] [88] [89] [90] [91] [92] [93] [94] [95] [96]

Based on the five dimensions of the national and provincial Territorial Space Planning regarding spatial justice, the spatial justice development of the Territorial Space Planning of 21 municipalities is specifically analysed, and an evaluation form for the spatial justice development is summarised, with an item to be ticked if a municipality's Territorial Space Planning contains an evaluation item.

The scoring scale for spatial justice, on the other hand, focuses on resource allocation, equalisation of public services, and coordinated urban-rural development. Below are the results of the analyses:

Cities with excellent spatial justice policy performance:

-Guangzhou and Shenzhen excelled in a number of dimensions, including resource accessibility, four-tier public service systems, and comprehensive transport hubs, indicating that these two cities have made more comprehensive plans to promote regional equity and balanced resource distribution.

-Foshan and Zhuhai: These two cities also perform well in the dimensions of coordinated regional development, public participation and transport infrastructure, showing a high level of planning.

Moderately performing cities:

-Jiangmen, Shanwei: These cities are involved in resource allocation and coordinated urban-rural development, but the overall planning is slightly deficient in areas such as public participation and integrated transport networks.

-For example, Jiangmen has planned for a balanced distribution of land resources, but needs to improve in promoting equalisation of public services.

Cities with weaker spatial justice development:

-Chaozhou and Dongguan: The lack of ticks for several dimensions in the scoring table for these cities suggests that their planning may not yet have a clear strategy in areas such as equalisation of resources and coordinated urban-rural development, which needs to be further improved.

-For example, Chaozhou has fewer dimensions on transport networks and integrated services, which affects the overall spatial justice performance.

Municipalities	**Resource Allocation Accessibility**		**Equalization of Public Services**				
	Land Resources	Other Resources	Four- level Public Service System	Shared Open Space	housing supply and support	Stereoscopic Transport Network	Full Range of Public Services
Shenzhen	√		√	√	√	√	√
Maoming	√		√				√
Shaoguan	√		√	√		√	√
Yangjiang	√		√				√
zhaoqing	√		√				
Zhanjiang		√	√	√	√		
Jiangmen	√		√				√
Shanwei	√		√				√
Shantou	√		√				
Jieyang	√	√		√			√
Huizhou	√						√
Zhongshan	√	√					√
Yunfu		√					
Foshan	√		√	√		√	√
Meizhou	√		√				

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Heyuan	√						√
qingyuan	√			√			√
Zhuhai			√				√
Chaozhou	√		√	√		√	√
Dongguan	√		√	√	√	√	√
Guangzhou	√		√	√	√	√	√

Municipalities	**Coordinated Regional and Urban-Rural Development**						**Public Participation**
	Radiation Effect(External)	The Role of Carrying On(Internal)	Metropolitan Area Synergy Development	Comprehensive Transport Hub	"Belt and Road"	Rural Revitalisation	
Shenzhen	√	√	√	√			√
Maoming		√	√	√		√	√
Shaoguan		√	√			√	√
Yangjiang		√	√	√	√	√	√
zhaoqing				√		√	√
Zhanjiang		√	√	√	√	√	√
Jiangmen		√	√	√		√	√
Shanwei		√		√	√	√	√

Shantou			√			√	√
Jieyang			√			√	√
Huizhou			√	√		√	√
Zhongshan						√	√
Yunfu						√	√
Foshan	√	√	√	√		√	√
Meizhou		√				√	√
Heyuan		√	√			√	√
qingyuan		√	√	√		√	√
Zhuhai		√	√	√	√	√	√
Chaozhou		√		√		√	√
Dongguan	√	√				√	√
Guangzhou	√	√	√	√		√	√

(Table 3.6 Tick List of Spatial Justice in Municipal Level *Source:The Author*)

Overall:

- **The cities with the best overall performance**: Shenzhen and Guangzhou excelled in the dimensions of ‘green transition’ and ‘spatial justice’. Their national spatial plans show comprehensive consideration of eco-friendliness, resource balance and regional equity.

- **Cities with balanced performance but in need of optimisation**: Shantou, Huizhou, Foshan, etc. are outstanding in some aspects but may be deficient in other dimensions. Their comprehensive development can be further enhanced by strengthening planning in weak areas.

- **Cities that need to be focused on and improved**: Chaozhou, Jieyang, etc., are weak in both green transition and spatial justice. These cities should consider introducing more elements of sustainable development and equitable distribution into their territorial spatial planning to promote long-term development.

Construction of Evaluation System of Spatial Justice for Green Transition

4 Construction of Evaluation System of Spatial Justice for Green Transition

4.1 Evaluation System of Green Transition Development in Guangdong Province

The core objective of this part is to assess the level of green transition development of municipalities in Guangdong Province and to establish a scientific evaluation system. This system consists of four system layers, each of which contains a number of specific indicators. Indicators are divided into positive and negative indicators, with positive indicators representing the higher the better and negative indicators representing the lower the better, and indicator diversification is the key to making the evaluation system more accurate.

4.1.1 Efficiency Level of Resource and Energy Utilization

(1) Energy Consumption per Unit of GDP

This indicator measures the amount of energy consumed per unit of economic output (GDP). It reflects the efficiency of energy use in economic activity. [97]Lower values indicate that economic growth is less dependent on energy, i.e., more energy-efficient technologies or more efficient management methods are used in the production process, and is a key indicator of energy use efficiency.

(2) Water Consumption per Unit of GDP

This indicator measures the amount of water used per unit of economic output, reflecting the efficiency of water use. [98]A low value means less consumption of water resources in economic activities, indicating the use of water-saving technologies or the implementation of effective management strategies. This indicator is critical for areas with limited water resources that need to be allocated appropriately.

(3) Electricity Consumption per Unit of GDP

This indicator measures the amount of electricity consumed per unit of economic output. It directly reflects the efficiency of electricity utilisation in the production process. [99]Lower electricity consumption indicates a more energy-efficient production process and potentially higher utilisation of renewable energy, and is a key indicator for assessing the efficiency of the use of electricity resources.

(4) Land Use per Unit of GDP

This indicator measures the area of land required per unit of economic output. By assessing the efficiency of land use, it is possible to judge the extent to which a region relies on land resources for its economic activities. [100]A lower land utilisation rate indicates that land resources are being used more efficiently, and is an important indicator of resource efficiency in urban planning and agricultural development.

(5) Carbon Emissions

This indicator measures carbon dioxide emissions per unit of economic activity and is one of the core indicators for assessing the efficiency of resource and energy use. [101]Reducing carbon emissions usually implies the use of more efficient energy technologies or more environmentally friendly production methods, and therefore directly reflects the cleanliness and efficiency of resource utilisation.

(6) Population Density

Although population density is not a direct indicator of energy consumption per se, it can reflect the centralising effect of resource use. Cities with high population density are usually able to improve the efficiency of resource utilisation through more centralised services, shared resource facilities (e.g. public transport) etc. [102]Proper planning and efficient city management can effectively reduce energy and resource use per unit of economic activity.

(7) Industrial Solid Waste Comprehensive Utilisation Rates

This indicator reflects the degree of reuse of solid waste in industrial production, which is an important manifestation of resource recycling. [103]A higher solid waste comprehensive utilisation rate indicates that the enterprise effectively recycles and reuses resources in the production process, improves the efficiency of resource use, and reduces the waste of raw materials and the burden on the environment.

System Level	Indicator Level	Units	Indicator Direction
Efficiency Level of Resource and Energy Utilization	Energy Consumption per Unit of GDP	Tonnes of standard coal/10,000 yuan	-
	Water Consumption per Unit of GDP(Cubic metres/10,000 yuan)	m^3/10,000 yuan	-
	Electricity Consumption per Unit of GDP(kWh/10,000 yuan)	kWh/10,000 yuan	-
	Land Use per Unit of GDP	m^2/10,000 yuan	-
	Carbon Emissions	10,000 tons	-

System Level	Indicator Level	Units	Indicator Direction
	Population Density	persons/㎡	+
	Industrial Solid Waste Comprehensive Utilization Rates	%	+

(Table 4.1 Evaluation Indicators of Efficiency Level of Resource and Energy Utilization *Source:The Author*)

4.1.2 Ecological Environment Quality Level

(1) Forest Coverage Rates

Forest cover is an important indicator for assessing the health of regional ecosystems. Forests play a key role in carbon sinks, maintaining biodiversity and regulating climate, etc. [104]An increase in forest cover usually indicates the stability of the ecosystem and improvement in environmental quality.

(2) Ecological Space Ratio

This indicator reflects the proportion of space used for ecological protection and nature maintenance in a region, and can directly assess the sustainability of the natural environment and the effective protection of resources. [105]A higher Ecological Space Ratio means that the natural environment has not been over-exploited.

(3) AQI(Air Quality Index) Compliance Rate

AQI Compliance Rate measures whether the concentration level of pollutants in the air of a region complies with the environmental protection standards, and can directly reflect the air pollution situation of the region.[106] Air quality is critical to human health and ecosystems, and
is therefore one of the core assessment criteria for environmental quality.

(4) Surface Water Quality Ratio

Surface Water Quality Ratio shows whether the concentration of harmful substances in a water body meets the safety standards and is a key indicator of the health of the water environment. Water quality affects biodiversity, human drinking water safety and agricultural production. [107]

(5) Urban Greening Coverage Ratio

Urban Greening Coverage Ratio evaluates the vegetation cover in a city, which helps to regulate urban climate, improve air quality, reduce noise pollution, etc. [108]It is an important way to improve the ecological quality of the city.

System Level	Indicator Level	Units	Indicator Direction
Ecological Environment Quality	Forest Coverage Rates	%	+
	Ecological Space Ratio	%	+

System Level	Indicator Level	Units	Indicator Direction
Level	AQI Compliance Rate	%	+
	Surface Water Quality Ratio	%	+
	Urban Greening Coverage Ratio	%	+

(Table 4.2 Evaluation Indicators of Ecological Environment Quality Level *Source:The Author*)

4.1.3Development Level of Green Industry and Technology

(1) Circular Economy Growth Rates

Circular Economy Growth Rates measure a region's progress in reducing resource wastage and increasing resource recycling. Circular economy emphasises the sustainable use of resources, which helps to reduce the burden on the environment and promote green development.[109]

(2) Green Industry Growth Rates

Green Industry Growth Rates show economic growth in areas such as environmentally friendly technologies, renewable energy and eco-friendly products. [110]It is a key indicator of a country or region's progress in promoting green technologies and a low-carbon economy.

(3) Environmental Protection Industry Growth Rates

This indicator assesses the development of industries related to environmental protection, such as pollution control technology, water treatment and waste management.[110] The growth of the environmental protection industry demonstrates the importance and investment in environmental issues and directly contributes to ecological sustainability.

(4) Number of Green Patent Applications and Granted

The number of Green Patent Applications and Granted represents the innovation activity and official recognition in environmental protection and energy-saving technologies, reflecting the important role of science and technology in promoting green development and contributing to the growth of the green economy, with certain market potential and practical application value.[111]

System Level	Indicator Level	Units	Indicator Direction
Development Level of Green Industry and Technology	Circular Economy Growth Rates	%	+
	Green Industry Growth Rates	%	+
	Environmental Protection Industry Growth Rates	%	+
	Number of Green Patent Applications		+
	Number of Green Patents Granted		+
	Tertiary Industry Ratio	%	+

(Table 4.3 Evaluation Indicators of Development Level of Green Industry and Technology

Source:The Author)

4.1.4 Level of Green Social Development and Policy Support

(1) Per Capita Public Green Space

Per capita public green space reflects the natural environment and ecological welfare that urban residents can enjoy, reflecting the level of green development of the city. [112]More green space not only contributes to the improvement of environmental quality, but also improves the quality of life of residents.

(2) Green Mobility Ratio

Green Mobility Ratio measures the proportion of travelling modes using low-emission or zero-emission modes of transport (e.g. bicycles, electric vehicles, walking, etc.), which is an important indicator for assessing the impact of transport on the environment, reflecting the level of sustainable transport development in the society.[113]

(3) Public Transportation Usage Ratio

Public Transportation Usage Ratio shows the frequency of residents choosing public transport, which helps to reduce the use of private cars, urban carbon emissions and traffic congestion, and is an important indicator for assessing green transport and urban planning.

(4) Fiscal Expenditure on Environmental Protection Ratio

Fiscal Expenditure on Environmental Protection Ratio assesses the government's investment in environmental protection and is a direct indicator of the extent of policy support for green development. [114]A higher expenditure ratio indicates that the government attaches importance
to environmental protection at the policy level.

(5) Number of Digital Economy Policies

The number of Digital Economy Policies indicates the government's efforts to promote the integration of information technology and green technology, and to support the transformation of the green economy and technological innovation. These policies usually help enhance resource efficiency and reduce environmental pollution. [115]

(6) Environmental Concern Index

The Environmental Concern Index measures the degree of importance the public attaches to environmental issues, reflecting society's awareness of ecological protection and green development. [116]A higher index indicates higher public awareness of environmental issues, which helps promote the implementation of green policies.

System Level	Indicator Level	Units	Indicator Direction
Level of Green Social Development and Policy Support	Per Capita Public Green Space	㎡	+
	Green Mobility Ratio	%	+
	Public Transportation Usage Ratio	%	+

	Fiscal Expenditure on Environmental Protection Ratio	%	+
	Number of Digital Economy Policies		+
	Environmental Concern Index		+

(Table 4.4 Evaluation Indicators of Level of Green Social Development and Policy Support *Source:The Author*)

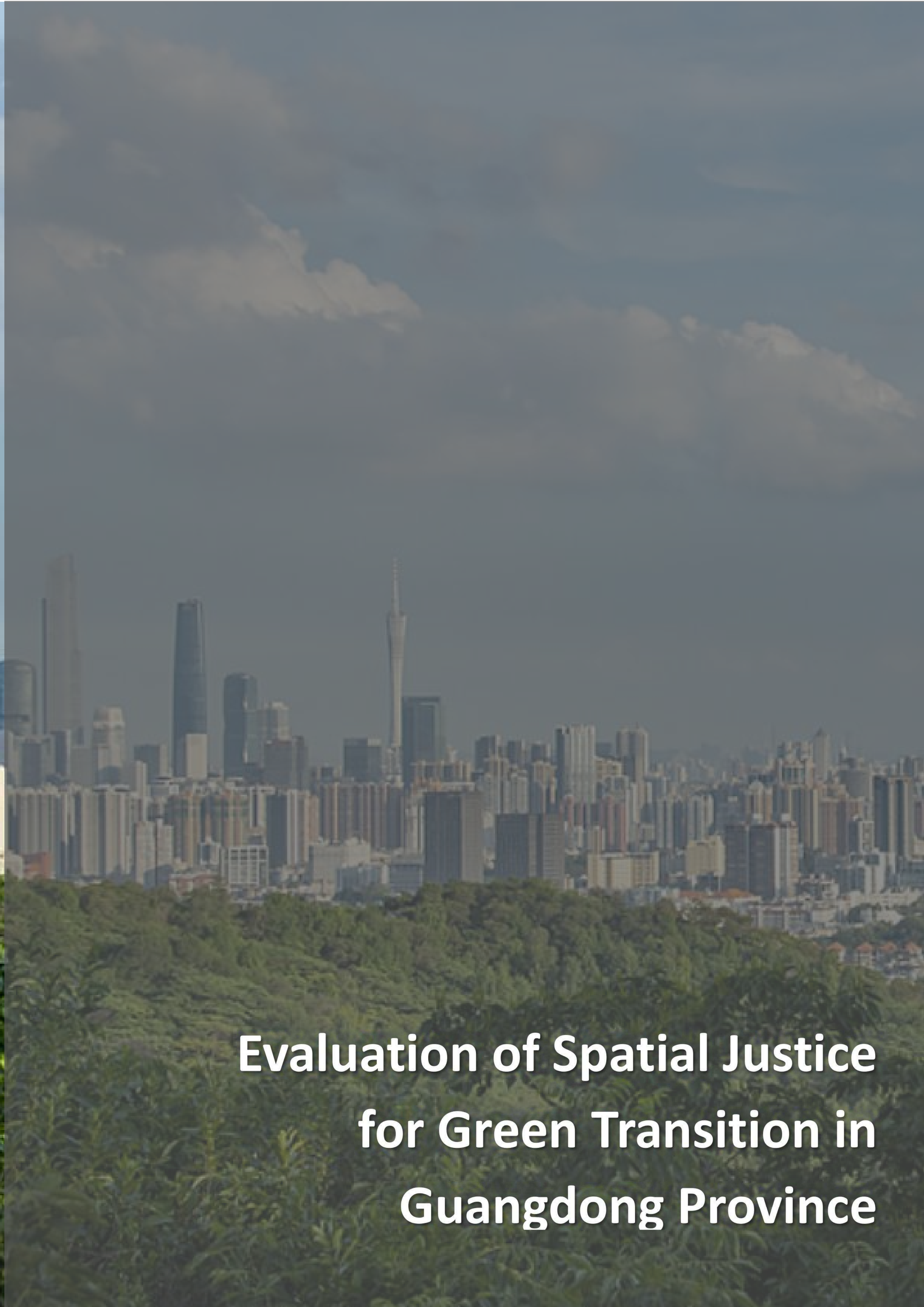
4.1.5 Comprehensive Evaluation Indicators System

Data collection for all of the following indicators was obtained from each municipality's 2022 National Economic Statistics Yearbook as well as the 2022 Urban Construction Yearbook.

Goal Level	System Level	Indicator Level	Units	Indicator Direction
Development Level of Green Transtion	Efficiency Level of Resource and Energy Utilization	Energy Consumption per Unit of GDP	Tonnes of standard coal/10,000 yuan	-
		Water Consumption per Unit of GDP(Cubic metres/10,000 yuan)	m^3/10,000 yuan	-
		Electricity Consumption per Unit of GDP(kWh/10,000 yuan)	kWh/10,000 yuan	-
		Land Use per Unit of GDP	m^2/10,000 yuan	-
		Carbon Emissions	10,000 tons	-
		Population Density	persons/m^2	+
		Industrial Solid Waste Comprehensive Utilization Rates	%	+
	Ecological Environment Quality Level	Forest Coverage Rates	%	+
		Ecological Space Ratio	%	+
		AQI Compliance Rate	%	+
		Surface Water Quality Ratio	%	+
		Urban Greening Coverage Ratio	%	+
	Development	Circular Economy Growth Rates	%	+

Goal Level	System Level	Indicator Level	Units	Indicator Direction
	Level of Green Industry and Technology	Green Industry Growth Rates	%	+
		Environmental Protection Industry Growth Rates	%	+
		Number of Green Patent Applications		+
		Number of Green Patents Granted		+
		Tertiary Industry Ratio	%	+
	Level of Green Social Development and Policy Support	Per Capita Public Green Space	㎡	+
		Green Mobility Ratio	%	+
		Public Transportation Usage Ratio	%	+
		Fiscal Expenditure on Environmental Protection Ratio	%	+
		Number of Digital Economy Policies		+
		Environmental Concern Index		+

(Table 4.5 Comprehensive Evaluation Indicators System *Source:The Author*)



Evaluation of Spatial Justice for Green Transition in Guangdong Province

5 Evaluation of Spatial Justice for Green Transition in Guangdong Province

5.1 Analysis of Development level of Green Transition - Calculation of weights and scores

The entropy method is used to calculate the weight of each indicator in the system layer in the following steps[117]:

Data normalisation process: in order to eliminate the influence of different units, the data are normalised to the range [0,1]. For positive indicators, the formula is used

$$X'_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)}$$

For negtive indicators, the formula is used:

$$X'_{ij} = \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)}$$

Calculation of information entropy $\boldsymbol{E_j}$

$$E_j = -k\sum_{i=1}^{n} P_{ij}\ln P_{ij}, \quad P_{ij} = \frac{X'_{ij}}{\sum_{i=1}^{n} X'_{ij}}$$

Calculation of the coefficient of variation $\boldsymbol{D_j}$

$$d_j = 1 - E_j$$

Calculation of weights $\boldsymbol{w_j}$

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j}$$

5.2 Comprehensive Development Level of Green Transition

5.2.1 Results of Weights

Goal Level	System Level	Indicator Level	Weights
Development Level of Green Transition	Efficiency Level of Resource and Energy Utilization	Energy Consumption per Unit of GDP	0.0212
		Water Consumption per Unit of GDP(Cubic metres/10,000 yuan)	0.0102
		Electricity Consumption per Unit of	0.0128

Goal Level	System Level	Indicator Level	Weights
		GDP(kWh/10,000 yuan)	
		Land Use per Unit of GDP	0.0167
		Carbon Emissions	0.0053
		Population Density	0.0716
		Industrial Solid Waste Comprehensive Utilization Rates	0.0091
	Ecological Environment Quality Level	Forest Coverage Rates	0.0214
		Ecological Space Ratio	0.0222
		AQI Compliance Rate	0.0148
		Surface Water Quality Ratio	0.2567
		Urban Greening Coverage Ratio	0.0239
	Development Level of Green Industry and Technology	Circular Economy Growth Rates	0.0536
		Green Industry Growth Rates	0.0085
		Environmental Protection Industry Growth Rates	0.0146
		Number of Green Patent Applications	0.1230
		Number of Green Patents Granted	0.1148
		Tertiary Industry Ratio	0.0252
	Level of Green Social Development and Policy Support	Per Capita Public Green Space	0.0180
		Green Mobility Ratio	0.0069
		Public Transportation Usage Ratio	0.0170
		Fiscal Expenditure on Environmental Protection Ratio	0.0428
		Number of Digital Economy Policies	0.0316
		Environmental Concern Index	0.0580

(Table 5.1 Results of Weights of Comprehensive Development Level of Green Transition *Source:The Author*)

5.2.2 Results of Scores and Rank

ID	Name	Score	Rank
1	Guangzhou	0.52	3

ID	Name	Score	Rank
2	Shenzhen	0.67	1
3	Zhuhai	0.26	11
4	Shantou	0.33	8
5	Foshan	0.51	4
6	Shaoguan	0.26	10
7	Heyuan	0.18	16
8	Meizhou	0.15	19
9	Huizhou	0.37	7
10	Shanwei	0.22	14
11	Dongguan	0.62	2
12	Zhongshan	0.46	5
13	Jiangmen	0.23	13
14	Yangjiang	0.25	12
15	Zhanjiang	0.39	6
16	Maoming	0.32	9
17	Zhaoqing	0.21	15
18	Qingyuan	0.17	17
19	Chaozhou	0.09	21
20	Jieyang	0.15	18
21	Yunfu	0.14	20

(Table 5.2 Results of Scores and Rank of Comprehensive Development Level of Green Transition *Source:The Author*)

As can be seen from the table, cities in the PRD region such as Shenzhen, Dongguan and Guangzhou ranked high in the overall score of green transformation. This shows that these cities not only excel in resource utilisation efficiency and ecological and environmental protection, but also benefit from high investment in green industries and policy support. **Shenzhen**, in particular, ranks first with a composite score of 0.67, reflecting its huge investment in science and technology innovation and environmental policies.

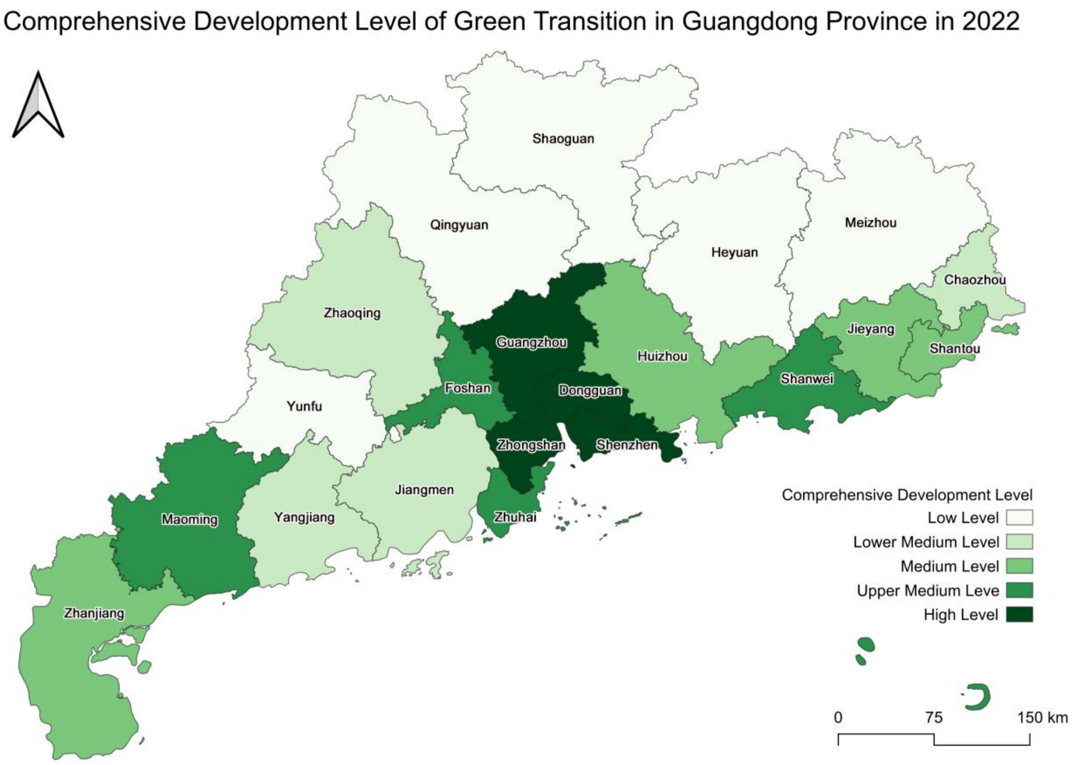
(1) High Scoring Regions

The leading scores of Shenzhen, Dongguan and Guangzhou are closely related to their strong performance in the **Green Industry and Technology Development Level** and the **Resource and Energy Efficiency** System. Shenzhen is far ahead of the other cities in terms of **the number of green patents filed and granted**, as well as in terms of **the growth rate of the circular economy** and **the application of energy-saving technologies**.

(2) Low-scoring regions

In contrast, regions in eastern and northern Guangdong, such as Meizhou and Chaozhou, have low scores, indicating that there are obvious deficiencies in the green transition process in these regions, especially in the **development of green industry and technology** and insufficient investment in **policy support**, leading to their overall lagging scores. For example, the overall score of Meizhou is only 0.15, ranking 19th.This reflects the lagging behind of the eastern part of Guangdong in the green economy transition.

5.2.3 Spatial Justice Analysis-Spatial Differentiation Analysis



(Figure 5.1 Graduated Map of Comprehensive Development Level of Green Transition *Source:The Author*)

(1) Spatial Distribution of Visualisations

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In the map, **Shenzhen, Dongguan and Guangzhou** in the Pearl River Delta (PRD) region are high scoring areas, which are shown in darker colours, indicating that the level of green transition in these cities is significantly higher than that in other regions. **The eastern and northern parts of Guangdong,** such as Chaozhou and Meizhou, are low-scoring areas, which are usually marked with lighter colours on the map.

- **High-scoring clusters**: The PRD city clusters form a clear **cluster of high-scoring areas**. This is not only in terms of resource efficiency and green industry innovation, but also in terms of policy support and technological application.
- **Low-scoring agglomeration area**: The less developed regions in eastern and northern Guangdong (e.g. Chaozhou and Meizhou) show a **low-scoring agglomeration phenomenon**. The slow progress of green transition in these regions reflects the weak economic foundation and insufficient policy support.

(2) How to demonstrate spatial justice

In terms of overall development level, the large difference in progress of green transition between the PRD and the eastern and northern regions of Guangdong reflects the imbalance in the inter-regional distribution of resources, capital and technology. This **uneven inter-regional development** violates the principle of **spatial justice**, as less developed cities face greater challenges in green transition, while policy resources are more concentrated in the economically developed PRD citie. This suggests a significant inequity in the spatial distribution of the green transition process in Guangdong Province.

In order to further explore the differences in the level of performance of the municipalities in various aspects, the scores and spatial differences of the municipalities in each of the four systems were calculated separately. In this case, the weights of the individual indicators for each system need to be recalculated, and the calculation method is the same as above.

5.3 Efficiency Level of Resource and Energy Utilization

5.3.1 Results of Weights

System Level	Indicator Level	Weights
Efficiency Level of Resource and Energy Utilization	Energy Consumption per Unit of GDP	0.1443
	Water Consumption per Unit of GDP(Cubic metres/10,000 yuan)	0.0696
	Electricity Consumption per Unit of GDP(kWh/10,000 yuan)	0.0870
	Land Use per Unit of GDP	0.1138
	Carbon Emissions	0.0361
	Population Density	0.4870

	Industrial Solid Waste Comprehensive Utilization Rates	0.0621

(Table 5.3 Results of Weights of Efficiency Level of Resource and Energy Utilization *Source:The Author*)

5.3.2 Results of Scores

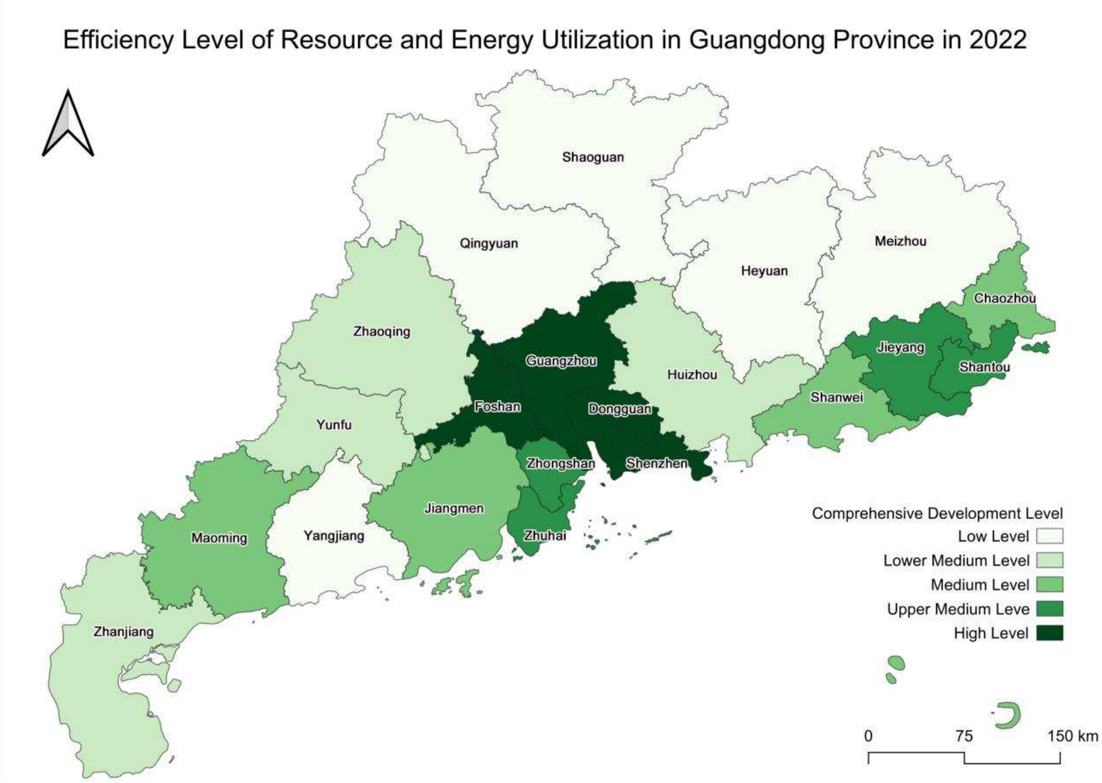
ID	Name	Score	Rank
1	Guangzhou	0.591308605	3
2	Shenzhen	0.976079978	1
3	Zhuhai	0.50625307	5
4	Shantou	0.505044075	6
5	Foshan	0.589467841	4
6	Shaoguan	0.114309368	21
7	Heyuan	0.145639626	19
8	Meizhou	0.177348854	18
9	Huizhou	0.2915867	14
10	Shanwei	0.395110378	9
11	Dongguan	0.660177409	2
12	Zhongshan	0.497906916	7
13	Jiangmen	0.393934316	10
14	Yangjiang	0.232817796	17
15	Zhanjiang	0.283291249	15
16	Maoming	0.381920777	11
17	Zhaoqing	0.333133375	13
18	Qingyuan	0.128828668	20
19	Chaozhou	0.343995437	12
20	Jieyang	0.434586865	8
21	Yunfu	0.246579307	16

(Table 5.4 Results of Scores and Rank of Efficiency Level of Resource and Energy Utilization *Source:The Author*)

The table shows that Shenzhen and Dongguan have the highest scores. The weighting data show that **population density** and **energy consumption per unit of GDP** are the most critical indicators in the system . Shenzhen and Dongguan excel in this system thanks to their high-density urban planning and advanced energy use technologies.Low- score areas are mainly concentrated in some cities in northern and eastern Guangdong, such as Shaoguan, Heyuan and Qingyuan.

- High-score cities（Shenzhen, Dongguan）：Thanks to its advanced urban management and energy-saving technologies, Shenzhen significantly outperforms other cities in terms of energy consumption per unit of GDP and carbon emissions. With its high population density, it is also relatively efficient in resource utilisation. Dongguan also performs well in resource and energy use efficiency due to its well-developed manufacturing sector and efficient energy management system.
- Low-score cities (Shaoguan, Heyuan, Qingyuan: The lagging behind of low-score cities in terms of resource and energy utilisation efficiency mainly stems from a relatively homogeneous economic structure, relatively backward energy utilisation technologies, low population density and insufficient infrastructure and policy support.

5.3.3 Spatial Justice Analysis-Spatial Differentiation Analysis



(Figure 5.2 Graduated Map of Efficiency Level of Resource and Energy Utilization *Source:The Author*)

(1) Spatial Distribution Characteristics

In the **resource and energy efficiency** system, the scores of the PRD cities such as Shenzhen, Dongguan and Guangzhou are significantly higher than those of other cities. Eastern and northern Guangdong, such as Meizhou, Chaozhou and Qingyuan, have lower scores, creating an obvious **high - low spatial differentiation** phenomenon.

- **Pearl River Delta (PRD)**: Shenzhen and Dongguan have higher scores, mainly due to their advanced energy-saving technologies and efficient resource management systems. Shenzhen's **energy consumption** and **carbon emissions per unit of GDP** are both low, indicating its high efficiency in energy utilisation.
- **Guangdong East and Guangdong North**: such as Chaozhou and Meizhou are less efficient in resource utilisation. These areas have a relatively traditional industrial structure and rely on high energy-consuming industries, resulting in poor resource utilisation efficiency. In the map, these cities are usually marked as light-coloured areas, reflecting their relative backwardness in terms of resource efficiency.

The high score of the PRD region is mainly due to its high level of urbanisation and economic base, which supports energy conservation and emission reduction and improved resource efficiency. In contrast, the low scores of Eastern and Northern Guangdong reflect the challenges faced by these cities in improving resource utilisation efficiency, which mainly include a homogeneous industrial structure and a lack of widespread application of green technologies.

(2) How to show spatial justice

The spatial distribution of resource and energy use efficiency reflects **the spatial inequality in the intensive use of resources**. The PRD region is far ahead in resource utilisation efficiency due to its economic scale and technological advantages, while less developed regions are unable to utilise resources and energy efficiently due to their weak economic base. This disparity reflects the inequity in resource allocation and technology application, and exposes the issue of spatial justice, i.e. the differences in resource utilisation and access to energy-saving technologies in different regions.

5.4 Ecological Environment Quality Level

5.4.1 Results of Weights

System Level	Indicator Level	Weights
Ecological Environment Quality Level	Forest Coverage Rates	0.0631

	Ecological Space Ratio	0.0654
	AQI Compliance Rate	0.0438
	Surface Water Quality Ratio	0.7572
	Urban Greening Coverage Ratio	0.0705

(Table 5.5 Results of Weights of Ecological Environment Quality Level *Source:The Author*)

5.4.2 Results of Scores

ID	Name	Score	Rank
1	Guangzhou	0.072848717	18
2	Shenzhen	0.068681396	21
3	Zhuhai	0.073451935	17
4	Shantou	0.069742431	20
5	Foshan	0.07510844	16
6	Shaoguan	0.124950475	9
7	Heyuan	0.107389238	11
8	Meizhou	0.163233123	2
9	Huizhou	0.144877604	5
10	Shanwei	0.097998318	12
11	Dongguan	0.091765665	14
12	Zhongshan	0.850492062	1
13	Jiangmen	0.072398984	19
14	Yangjiang	0.097969416	13
15	Zhanjiang	0.087178311	15
16	Maoming	0.125155863	8
17	Zhaoqing	0.122615222	10
18	Qingyuan	0.136715405	6
19	Chaozhou	0.155493331	3
20	Jieyang	0.149059828	4
21	Yunfu	0.133801682	7

(Table 5.6 Results of Scores and Rank of Ecological Environment Quality Level *Source:The Author)*

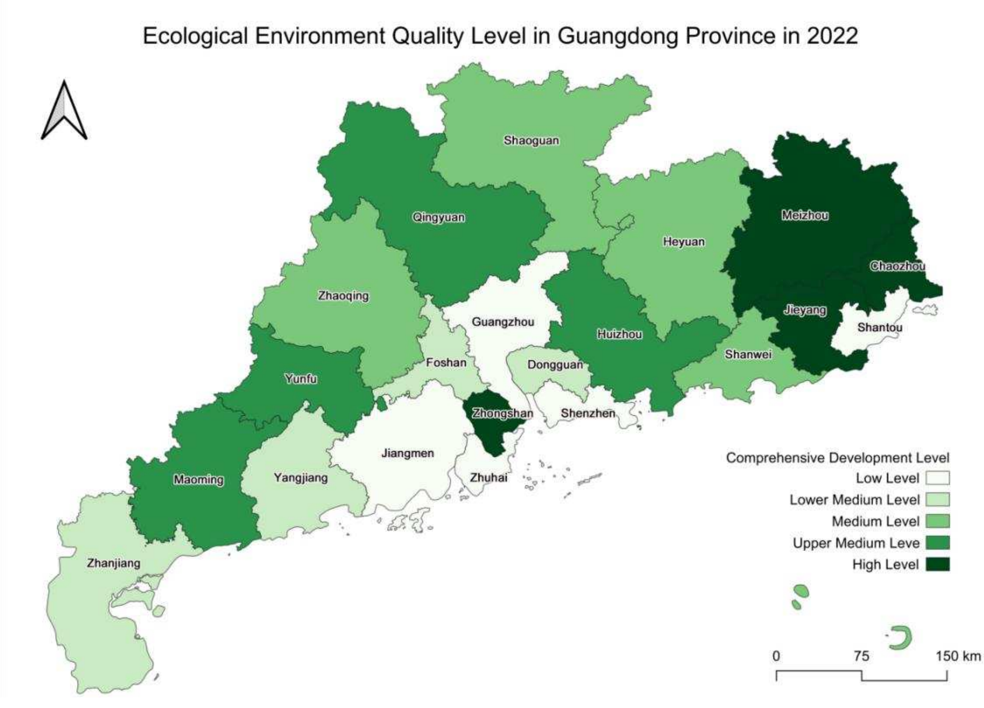
In the **Eco-Environmental Quality System**, Meizhou, Qingyuan and Shantou scored high, mainly in ecological indicators such as **forest coverage** and **water quality compliance rate** . Core cities in the PRD, such as Shenzhen and Guangzhou, scored relatively low on ecological quality due to rapid urbanisation.

- High-score areas（Meizhou:） As an ecological barrier in northern Guangdong, Meizhou's

forest coverage and surface water quality pass rate are among the highest in the province, and these indicators significantly enhance its score in the system.

- Low-score areas (Shenzhen and Guangzhou): As a result of rapid urbanisation, the ecological environment in these cities has come under pressure, particularly in terms of air quality and green space coverage.

5.4.3 Spatial Justice Analysis-Spatial Differentiation Analysis



(Figure 5.3 Graduated Map of Ecological Environment Quality Level *Source:The Author*)

(1) **Spatial Distribution Characteristics**

In the **Eco-Environmental Quality** System, the municipalities in the northern and eastern parts of Guangdong scored higher, while the core cities in the Pearl River Delta (PRD), such as Shenzhen and Guangzhou, scored relatively lower. This forms a pattern of spatial differentiation opposite to that of the resource utilisation efficiency system.

- **Northern Guangdong**: such as Meizhou and Qingyuan, these areas have excellent ecological quality due to their favourable natural conditions and high forest cover. In the map, these areas are labelled as dark green, showing their outstanding performance in terms of forest coverage, air quality and water quality pass rate.

- **PRD region**: such as Shenzhen and Guangzhou, scored lower, mainly due to the higher environmental pressure brought about by urbanisation. The **air quality pass rate** and **urban green coverage rate** of these cities are less favourable than those of other regions, especially in terms of air quality, where these cities have low scores due to industrial emissions and dense traffic.

-**Main Causes:** PRD region is facing greater ecological and environmental pressures due to accelerated urbanisation, especially air pollution and deterioration of water quality are more prominent. The northern and eastern parts of Guangdong, on the other hand, have higher forest coverage and water quality by virtue of their favourable ecological foundation.

(2) How to show spatial justice

The spatial distribution of ecological quality reveals the contradiction between economic development and ecological protection. Despite its economic development, the PRD region's ecological quality has been challenged by urban expansion. In contrast, the northern part of Guangdong is rich in natural resources but lags behind in economic development. This spatial difference reflects **the uneven distribution of ecological resources and development rights**, which in terms of spatial justice means that the northern part of Guangdong lags far behind the PRD region in terms of economic gains and development opportunities, despite its superiority in natural resources.

5.5 Development Level of Green Industry and Technology

5.5.1 Results of Weights

System Level	Indicator Level	Weights
Development Level of Green Industry and Technology	Circular Economy Growth Rates	0.1578
	Green Industry Growth Rates	0.0251
	Environmental Protection Industry Growth Rates	0.0429
	Number of Green Patent Applications	0.3621
	Number of Green Patents Granted	0.3380
	Tertiary Industry Ratio	0.0741

(Table 5.7 Results of Weights of Development Level of Green Industry and Technology *Source:The Author*)

5.5.2 Results of Scores

ID	Name	Score	Rank
1	Guangzhou	0.536260463	2
2	Shenzhen	0.793616225	1
3	Zhuhai	0.156102803	7
4	Shantou	0.055782758	19
5	Foshan	0.19602101	5
6	Shaoguan	0.072680259	14
7	Heyuan	0.07735557	12
8	Meizhou	0.06677201	16
9	Huizhou	0.096797284	9
10	Shanwei	0.210639983	4
11	Dongguan	0.19458341	6
12	Zhongshan	0.210790388	3
13	Jiangmen	0.085993174	11
14	Yangjiang	0.065186659	17
15	Zhanjiang	0.071556402	15
16	Maoming	0.155556775	8
17	Zhaoqing	0.040495441	20
18	Qingyuan	0.08702346	10
19	Chaozhou	0.037236403	21
20	Jieyang	0.075236944	13
21	Yunfu	0.062842988	18

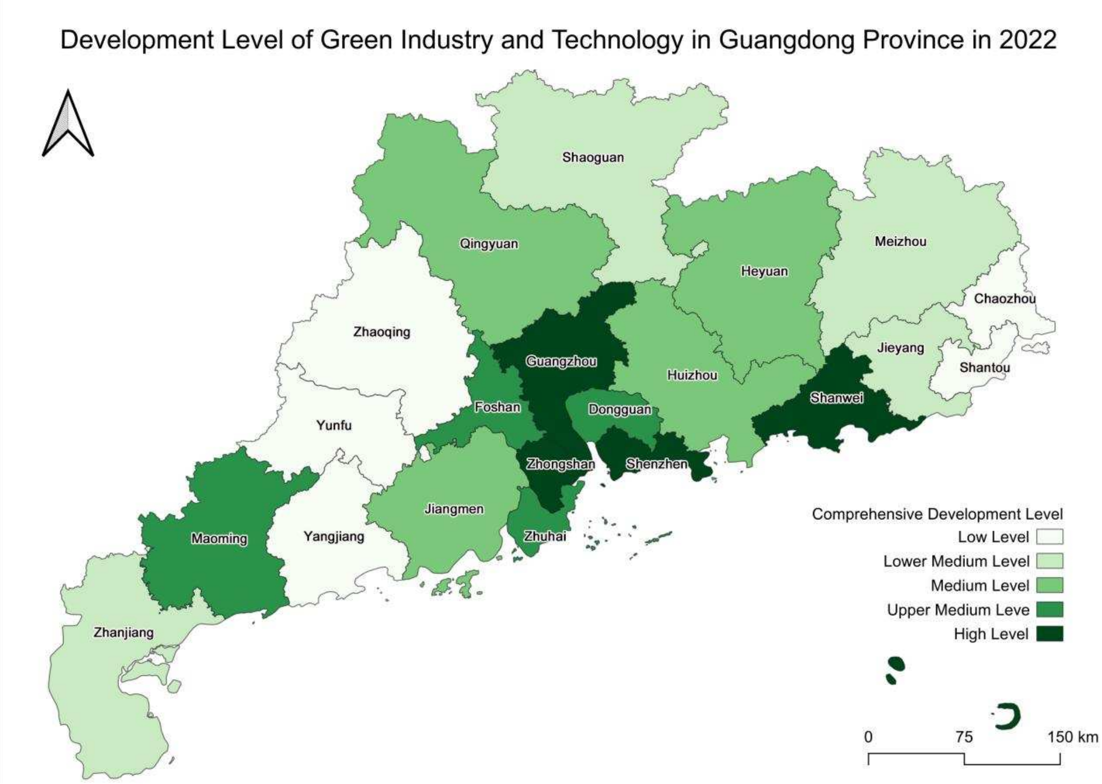
(Table 5.8 Results of Scores and Rank of Development Level of Green Industry and Technology *Source:The Author*)

The Green Industry and Science and Technology Development System measures **green patent applications**, the **growth rate of the circular economy** and the **growth rate of green industries**. Shenzhen is the most outstanding performer in this system .

- High-score areas(Shenzhen): Thanks to its strong scientific and technological innovation capacity, Shenzhen leads the province in terms of green patent applications and circular economy development. The number of **green patent applications** and the number of **patents granted in** Shenzhen account for most of the province's share, reflecting its leading position in promoting green technology development.

- Low-score areas(Eastern Guangdong): Shantou and Chaozhou, for example, scored lower due to a weaker green industry base and insufficient green technology innovation.

5.5.3 Spatial Justice Analysis-Spatial Differentiation Analysis



(Figure 5.4 Graduated Map of Green Industry and Technology *Source:The Author*)

(1) Spatial Distribution Characteristics

In the **green industry and technology development** system, Shenzhen, Guangzhou, Dongguan and other cities score high with their strong scientific and technological innovation ability and green industry foundation, while the eastern and northern regions of Guangdong score low, forming a typical **high-low spatial differentiation** phenomenon.

- **Shenzhen and Guangzhou**: The outstanding performance in indicators such as **the number of green patent applications** and **the growth rate of circular economy** shows their leading position in green technology innovation and industrial transformation. These cities are marked as dark-coloured areas in the map, showing their strengths in promoting green economy.

- **The eastern and northern regions of Guangdong**: such as Meizhou, Chaozhou and Shantou, scored lower due to their weaker industrial base and lack of green technology innovation. These regions are marked as light-coloured areas on the map, indicating their deficiencies in green industry development.

Main reasons: Differences in green industry and S&T development systems mainly stem from the gap between regions' capabilities in S&T innovation and industrial transformation. The PRD cities concentrate a large number of high-tech enterprises and research institutes, which receive policy support from the government, while the industrial structure of the eastern and northern regions of Guangdong is still dominated by traditional industries, with less application of green technologies.

(2) How to show spatial justice

The development of green technologies and industries varies significantly between regions, with the core cities in the PRD leading the development of green industries with their strong economic and technological foundations, while the eastern and northern Guangdong regions face the plight of insufficient innovation capacity. This **regional inequality in innovation resources** reflects the differences in the distribution of S&T resources and development opportunities in different regions, further exacerbating spatial justice issues.

5.6 **Level of Green Social Development and Policy Support**

5.6.1 Results of Weights

System Level	**Indicator Level**	**Weights**
Level of Green Social Development and Policy Support	Per Capita Public Green Space	0.1031
	Green Mobility Ratio	0.0398
	Public Transportation Usage Ratio	0.0975
	Fiscal Expenditure on Environmental Protection Ratio	0.2453
	Number of Digital Economy Policies	0.1816
	Environmental Concern Index	0.3327

(Table 5.9 Results of Weights of Level of Green Social Development and Policy Support *Source:The Author*)

5.6.2 Results of Scores

ID	Name	Score	Rank
1	Guangzhou	0.52491332	3
2	Shenzhen	0.672940214	1
3	Zhuhai	0.257305527	11

ID	Name	Score	Rank
4	Shantou	0.333891238	8
5	Foshan	0.512106681	4
6	Shaoguan	0.26288332	10
7	Heyuan	0.181505218	16
8	Meizhou	0.152039174	19
9	Huizhou	0.371073441	7
10	Shanwei	0.218214136	14
11	Dongguan	0.623163445	2
12	Zhongshan	0.456867318	5
13	Jiangmen	0.228620542	13
14	Yangjiang	0.249275029	12
15	Zhanjiang	0.38529574	6
16	Maoming	0.316457397	9
17	Zhaoqing	0.210298311	15
18	Qingyuan	0.168634634	17
19	Chaozhou	0.090073847	21
20	Jieyang	0.154286599	18
21	Yunfu	0.141349489	20

(Table 5.10 Results of Scores and Rank of Level of Green Social Development and Policy Support *Source:The Author*)

The Green Social Development and Policy Support System focuses on **the area of public green space**, **the proportion of green travelling** and **the proportion of fiscal expenditure on environmental protection**. In this system, Shenzhen and Dongguan score higher, while the less developed regions in eastern and northern Guangdong score lower.

- High-score areas (Shenzhen): Thanks to a high level of public green space planning and a vigorous green travelling policy, Shenzhen scored the highest in this system. The development of a green society is further facilitated by the government's financial expenditures and the support of digital economy policies.
- High-score areas (Meizhou, Chaozhou): These regions lack sufficient policy support for a green society, have more underdeveloped public infrastructures, and less fiscal expenditure on environmental protection, and thus have a weaker performance in the system.

5.6.3 Spatial Justice Analysis-Spatial Differentiation Analysis

(1) Spatial Distribution Characteristics

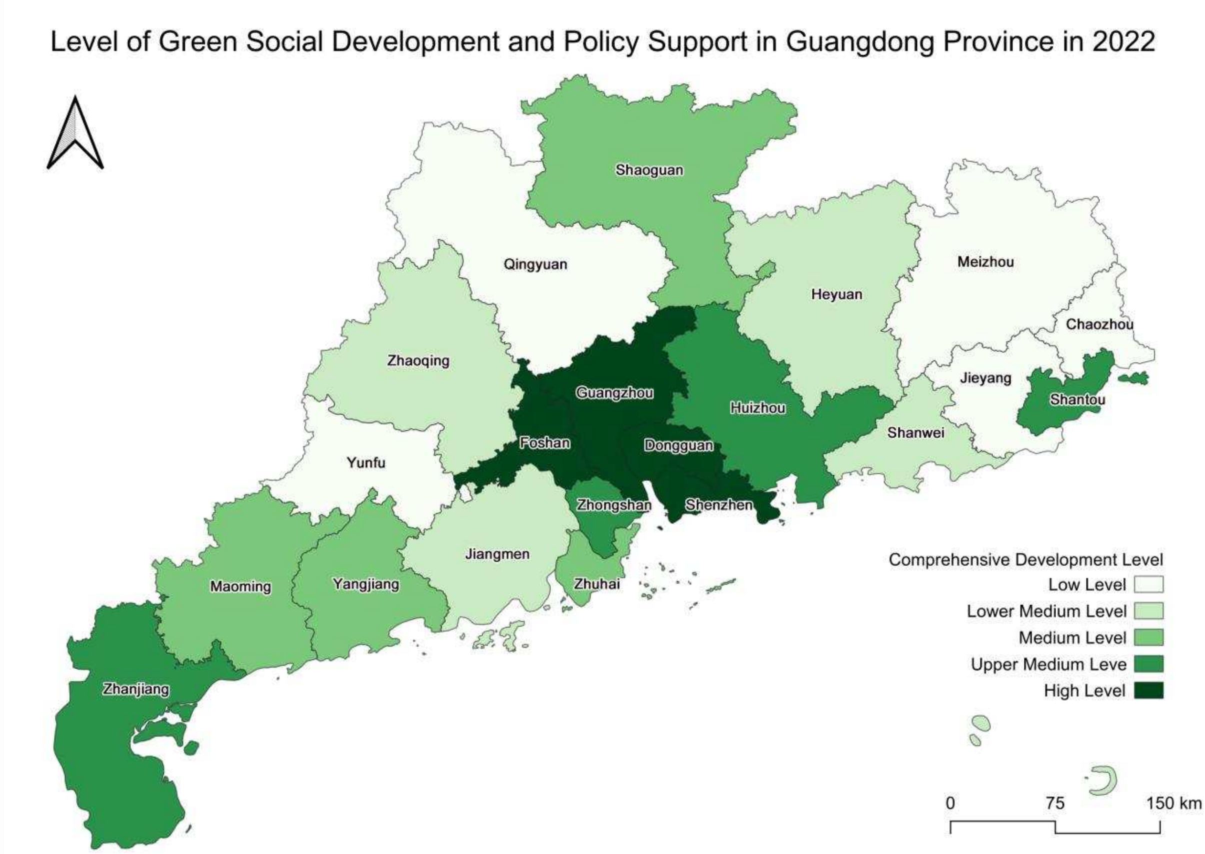
In the **Green Social Development and Policy Support** System, PRD cities such as Shenzhen and Dongguan scored higher, while eastern and northern Guangdong scored lower. This reflects the differences in policy support and social development in different regions.

- **Shenzhen and Dongguan**: These cities excel in indicators such as **the area of public green space**, **the proportion of green travelling** and **the proportion of financial expenditure on environmental protection**, showing strong policy support and a high level of social concern for green development. These cities are shown as dark-coloured areas in the map, highlighting the strength of policy support.
- **In the eastern and northern regions of Guangdong**: such as Chaozhou and Meizhou, the development of a green society and policy support is relatively lagging behind, especially in terms of insufficient investment in environmental protection financial expenditure and public infrastructure development, resulting in a lower score.

-**Main Reasons:**The strengths of the PRD cities in green social development are mainly due to strong government support and stronger environmental awareness in the community. In contrast, the eastern and northern regions of Guangdong lag behind in terms of public green space, green travelling and financial expenditure due to their weaker economic base and limited policy support.

(2) How to show spatial justice

The spatial differentiation of policy support and social development demonstrates the imbalance in **access to green policy resources** in different regions. Economically developed regions are not only able to promote green policies faster, but also attract more financial and technical support. The **uneven distribution of policy resources** further highlights the issue of spatial justice, as less developed regions face obstacles to the development of green societies due to insufficient policy support.



(Figure 5.5 Graduated Map of Level of Green Social Development and Policy Support
Source:The Author)

By visualising and analysing the spatial differentiation of the four system layers, it can be clearly seen:

- **PRD region** performs well in the **Resource Utilisation Efficiency**, **Green Industry Development** and **Policy Support** systems, forming high-value agglomerations. These regions benefit from their economic base, scientific and technological innovation and government support.
- **The eastern and northern regions of Guangdong** perform better in the **ecological environment quality** system, but lag behind in the **green industry development** and **policy support** system, showing spatial inequality between regions.

This spatial differentiation reveals the **spatial justice problem** in Guangdong's green transition, i.e., the unequal distribution of resources and policies exacerbates the development gap between regions. Therefore, future policies should pay more attention to less developed regions to enhance their capacity in green technology innovation and social infrastructure development.

5.7 Analysis of Coordination Development level of System-Coupling Coordination Degree

After assessing the individual performance of each system layer, this study further calculated the coupling co-ordination between system layers to measure the interaction and co-ordination between different systems.[118]

5.7.1 System Description

U1	U1	U1	U1
Efficiency Level of Resource and Energy Utilization	Ecological Environment Quality Level	Development Level of Green Industry and Technology	Level of Green Social Development and Policy Support

(Table 5.11 Four System Layers *Source:The Author*)

Coupling degree calculation formula:

$$C = \frac{4\sqrt[4]{U_1 \cdot U_2 \cdot U_3 \cdot U_4}}{U_1 + U_2 + U_3 + U_4}$$

where:
- C is the coupling degree, which indicates the coupling relationship between the four system layers.
- U1,U2,U3,U4 are the scores of the four system layers respectively.

Coordination formula:

$$T = \alpha_1 U_1 + \alpha_2 U_2 + \alpha_3 U_3 + \alpha_4 U_4$$

where α is the weight of each system layer, representing its relative importance. Usually, weight here is equal by default. As there are four systems, then the weight should be 0.25(the sum of weight should equal to 1).

Coupling Coordination Degree Equation:

$$D = \sqrt{C \cdot T}$$

5.7.2 Classification Based on the Coupling Coordination Degree

Referring to Zhang et al.'s study on the degree of coupling coordination, this research adopts the following classification criteria to determine the degree of coupling coordination.

Classification Based on the Coupling Coordination Degree		
Degree	**Level**	**Description**
0 - 0.3	Severe Imbalance	Little to no synergy between systems
0.3 - 0.5	Moderate Imbalance	Some degree of discord between systems
0.5 - 0.7	Initial Coordination	Presence of some synergistic development
0.7 - 0.9	Good Coordination	Systems are well-coordinated and consistent
0.9 - 1.0	High Coordination	Systems are highly coordinated and consistent

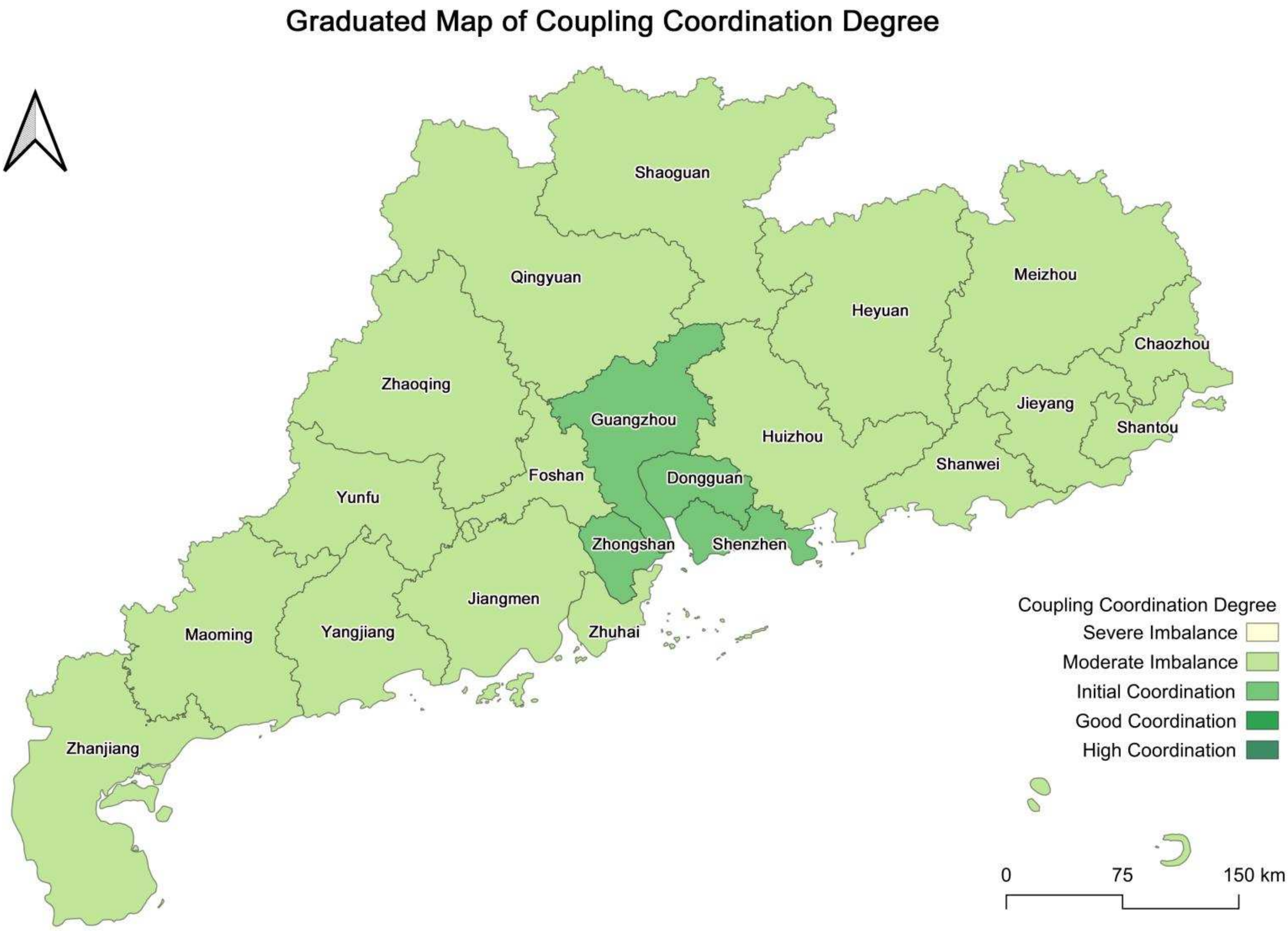
(Table 5.12 Classification Based on the Coupling Coordination Degree *Source:The Author*)

5.7.3 Results

ID	Name	Coupling Coordination Degree
1	Guangzhou	0.59
2	Shenzhen	0.65
3	Zhuhai	0.47
4	Shantou	0.44
5	Foshan	0.50
6	Shaoguan	0.40
7	Heyuan	0.39
8	Meizhou	0.40
9	Huizhou	0.43
10	Shanwei	0.47
11	Dongguan	0.53
12	Zhongshan	0.69
13	Jiangmen	0.42
14	Yangjiang	0.40
15	Zhanjiang	0.42
16	Maoming	0.49
17	Zhaoqing	0.38

ID	Name	Coupling Coordination Degree
18	Qingyuan	0.38
19	Chaozhou	0.37
20	Jieyang	0.46
21	Yunfu	0.40

(Table 5.13 Result of Coupling Coordination Degree *Source:The Author*)



(Figure 5.6 Graduated Map of Coupling Coordination Degree *Source:The Author*)

From the above table, we can get that the coupling coordination degree of **Zhongshan, Shenzhen, Dongguan, Guangzhou, Foshan and other cities** belongs to the preliminary coordination, which indicates that the synergy effect among their four system layers is better, the systems can cooperate better, and the green transition has formed the preliminary synergy. In contrast, the coupling co-ordination degrees of the eastern and northern regions of

Guangdong, such as **Chaozhou** and **Meizhou**, are **0.37** and **0.40** respectively, indicating lower system co-ordination and greater unevenness among the systems of green transition. Through these classifications, it can be seen that the major cities in the PRD (e.g. Shenzhen and Dongguan) have higher coupling coordination, while the coupling coordination in the eastern and northern Guangdong regions is relatively low, indicating that there is still much room for improvement in these regions at the level of multiple systems of green transition. From the hierarchical classification diagram, it can be seen that Shenzhen, Dongguan, Guangzhou and Zhongshan are all PRD cities with high coupling coordination, showing a clustering phenomenon.

5.7.4 Degree of Coupling Coordination and Spatial Justice

5.7.4.1 Relationship between the degree of coupling coordination and system synergistic development

The degree of coupling coordination reflects the interaction and coordination among the four systems (resource and energy use efficiency, ecological and environmental quality, green industry and scientific and technological development, green social development and policy support). A high degree of coupling coordination indicates that the systems interact better and can jointly promote the development of green transition. The results of the coupling coordination degree can be used to assess the coordination status of different systems in green transition in each region, thus assessing spatial justice.

(1) High coupling coordination degree and spatial justice

In regions with high coupling coordination degree, such as Shenzhen (0.65) and Dongguan (0.53), the synergistic effect among systems is stronger, indicating that these regions have balanced distribution and development of resources, policies, technologies and other elements in the process of green transition. This inter-system balance helps to promote common progress in the social, economic and ecological fields.

Regions with a high degree of coupled coordination usually benefit from the rational allocation of resources, the enhancement of scientific and technological innovation capacity and increased policy support. Through balanced development of policies, economy and environment, these regions comply with the basic principle of **spatial justice**, i.e., all members of the society can enjoy resources and opportunities equally in green development, and unequal distribution of resources is avoided.

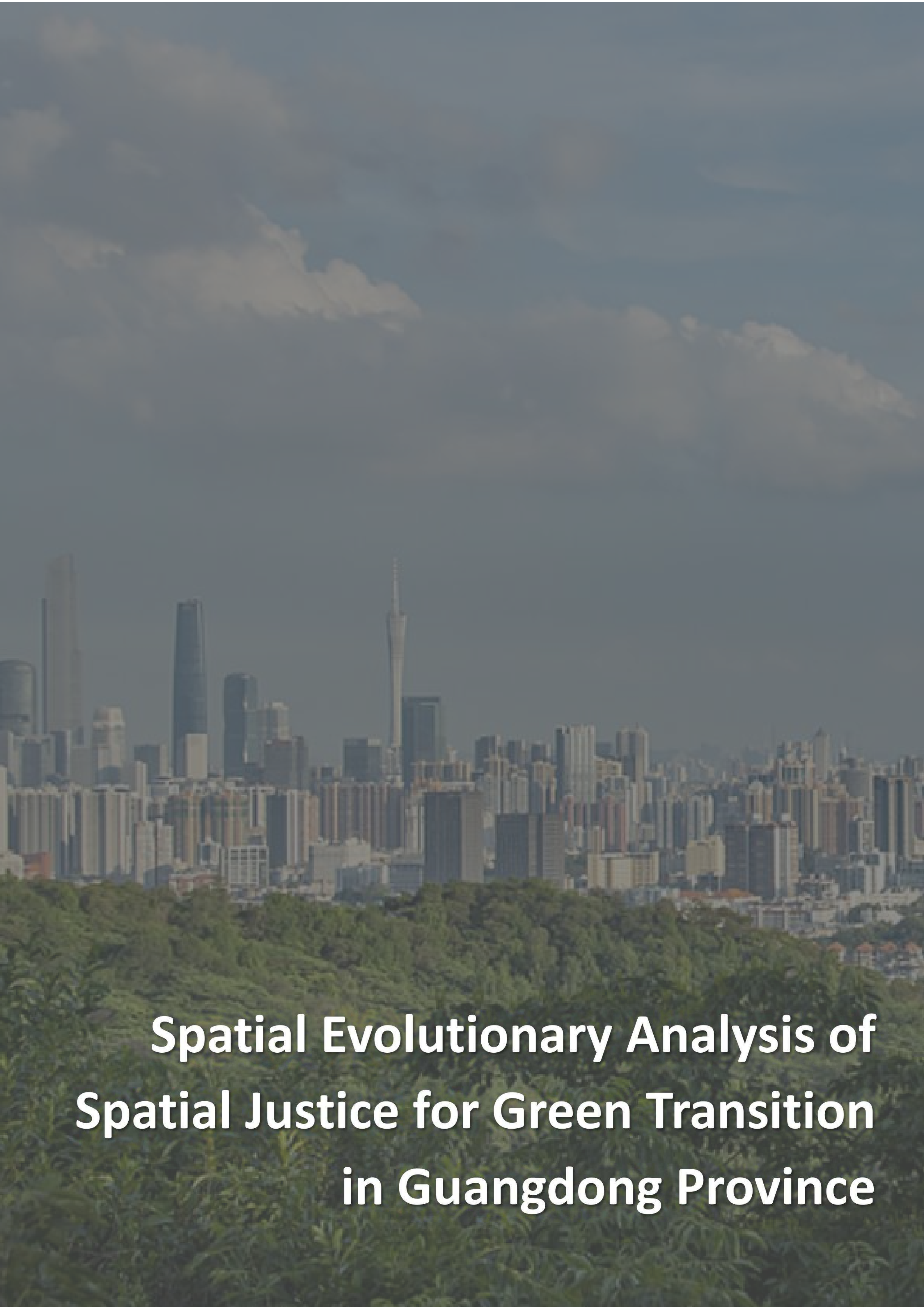
(2) Low coupling coordination degree and spatial injustice

On the contrary, in areas with low coupling coordination, such as Chaozhou (0.37) and Meizhou (0.40), the synergistic effect of the systems is poor, and the promotion of green transition is lagging behind. The low resource utilisation efficiency, more traditional industrial structure and insufficient policy support in these regions have led to imbalances between the systems. The poor synergy development of the systems indicates that these regions are unable to effectively integrate the available resources in the green transition, and it is difficult for science and technology innovation to develop in coordination with social and environmental needs.

From a spatial justice perspective, regions with low coupling coordination reflect the problem of unequal distribution of resources and technology. These regions have not been able to fully benefit from policy, financial and technical support, resulting in their green transition process lagging far behind that of developed regions. As a result, spatial justice is not fully reflected in these regions, especially the less developed regions lack the necessary support in green development and are unable to share the fruits of green economy with the developed regions.

5.7.4.2 Spatial Divergence of Coupling Coordination Degree

The spatial heterogeneity of the coupling coordination degree can reflect the **spatial inequality** of different regions in Guangdong Province in the process of green transition. There is a sharp contrast between the PRD region (e.g., Shenzhen and Dongguan) with a high coupling degree of coordination and the eastern and northern Guangdong (e.g., Chaozhou and Meizhou) with a low coupling degree of coordination, which implies that there is a significant gap between the developed regions and the less developed regions in the promotion of green transition.



Spatial Evolutionary Analysis of Spatial Justice for Green Transition in Guangdong Province

6 Spatial Justice Analysis-Spatial Auto-correlation Analysis

Spatial autocorrelation is an important tool for measuring the degree of geospatial aggregation of green transition systems, including global Moran's index and local Moran's index analyses. The global Moran index reflects the overall spatial correlation, and the local Moran index is used to identify the aggregation characteristics of specific areas.

6.1 Interpretation of Moran Index Principles

6.1.1 Global Moran Index[119]

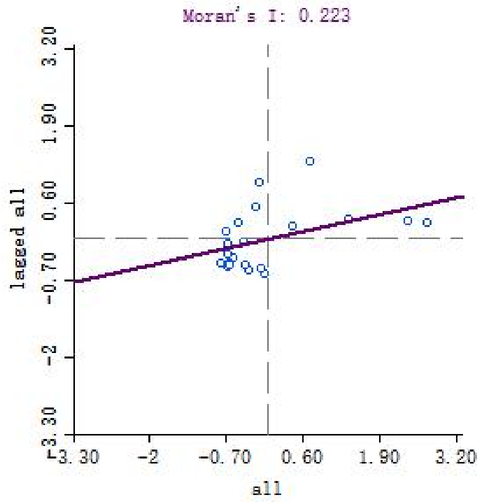
The global Moran index is used to measure the overall spatial autocorrelation, i.e., whether the level of green transition development has spatial aggregation characteristics within the province. The value of global Moran index is between [-1, 1], where:
I>0 indicates positive spatial autocorrelation, i.e., high or low values are clustered together and there is a significant spatial aggregation phenomenon.
I<0 indicates negative spatial autocorrelation, i.e., high and low values are alternately distributed, and there is no clustering effect.
I=0 indicates random distribution with no significant spatial pattern.
The results can be observed in the scatter plot.

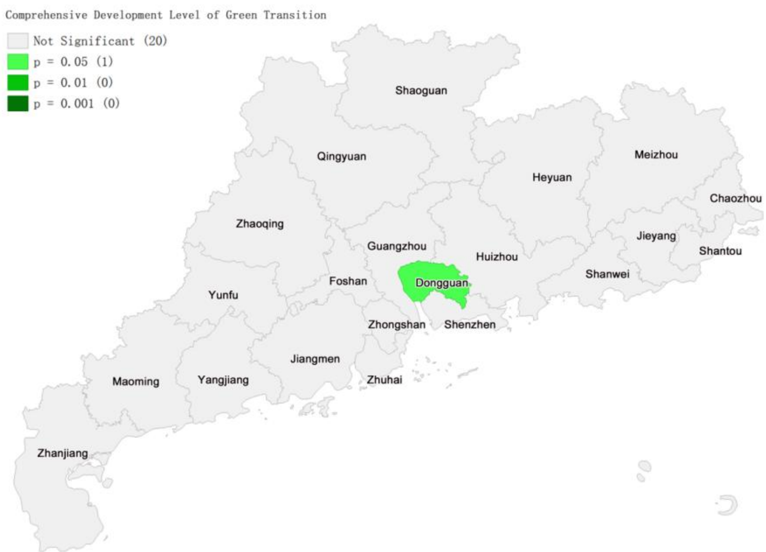
6.1.2 Local Moran Index[120]

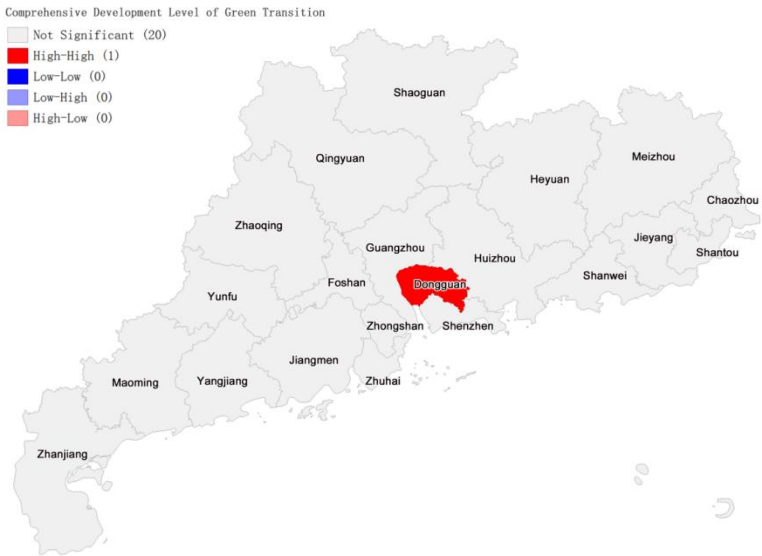
The Local Moran Index is used to analyse the spatial relationship of individual municipalities, helping to identify which areas belong to ‘high-high’ agglomeration (i.e., mutual agglomeration between high-level areas of green transition) and ‘low-low’ agglomeration (i.e., agglomeration between low-level areas), and which areas belong to ‘high-low’ agglomeration. ‘High-low’ heterogeneity (i.e. high level areas are neighbouring low level areas), etc.
The results can be observed in the saliency and agglomeration graph plots.

6.2 Global Moran Index and Local Moran Index Results

6.2.1 Comprehensive Development Level of Green Transition







[Figure 6.1 Results of Global and Local Moran's index of Comprehensive Development Level of Green Transition (From up to down) *Source:The Author*]

(1) Global Moran's index analysis.

- **Moran's I: 0.223** indicates that there is a weak positive spatial autocorrelation in the level of combined green transition development. This means that neighbouring regions have similar performance in green transition development levels, but this correlation is not strong.

- **Scatterplot Interpretation**: The x-axis indicates the combined green transition score, and the y-axis indicates the lagged green transition score. The positive slope of the purple line indicates the existence of positive spatial autocorrelation, and although a part of the regions' scores are close to the line, overall, the spatial clustering effect within the region is not strong.

(2) **Local Moran Index Significance :**

- The map shows the distribution of the significance of the combined level of green transition development. The green region (Dongguan) has a p-value of 0.05, indicating that the combined level of green transition in this region is statistically significant.

- All other regions are white, indicating that there is no significant spatial autocorrelation, that is, there is no obvious spatial clustering pattern between the level of green transition in these regions and their neighbouring regions.

(3) **Local Moran Index Cluster Maps.**

The map classifies the local spatial autocorrelation results into four cases:

-High-High (red, Dongguan): Indicates that Dongguan has a high combined level of green transition and that the surrounding areas also have a high level, forming an efficient cluster.

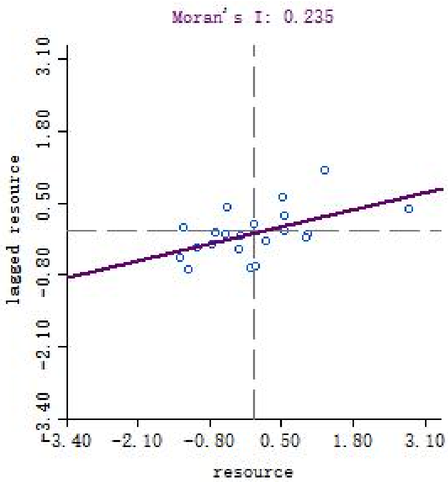
-Low-Low, Low-High and High-Low: No areas fall into these categories, meaning that no area exhibits low level clustering or mixed clustering (high level surrounded by low level or vice versa).

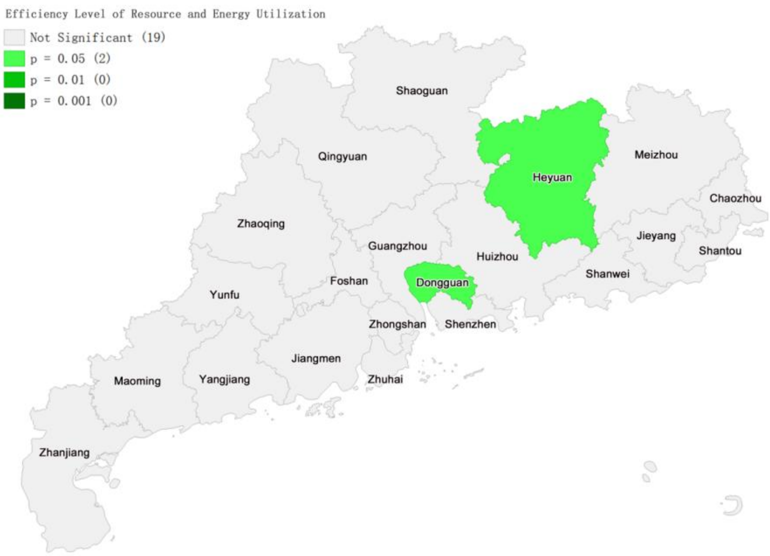
(4) **Spatial justice analysis.**

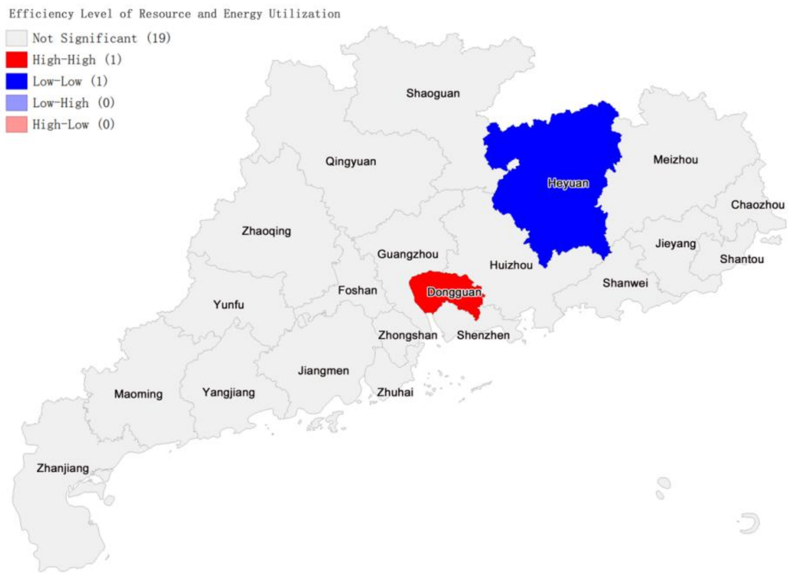
In the context of green transition, the map reveals the differences in the level of integrated development of green transition between regions. The results of the localised Moran Index show that Dongguan excels in green transition development, forming a significant 'high - high' cluster. This may reflect the region's superiority in green policies or better access to relevant resources.

- For other regions, the absence of significant clusters does not mean that spatial justice issues do not exist in these regions. In particular, in the absence of significant clusters, there may be an uneven distribution of policy resources.

6.2.2 Efficiency Level of Resource and Energy Utilization







[Figure 6.2 Results of Global and Local Moran's index of Efficiency Level of Resource and Energy Utilization (From up to down) *Source:The Author*]

(1) Global Moran's index analysis.

- **Moran's I: 0.235** shows that there is a weak positive spatial correlation between resource and energy efficiency levels. That is, efficient regions tend to be adjacent to neighbouring efficient regions, and inefficient regions are adjacent to neighbouring inefficient regions, but this correlation is not strong.

- **Scatterplot Interpretation**: The x-axis represents the Resource Utilisation Score and the y-axis represents the Lagging Resource Score. The positive slope of the purple line indicates a positive spatial autocorrelation, but the scatter distribution suggests that this autocorrelation is weak.

(2) Localised Moran Index Significance.

- This map shows the distribution of significance of resource and energy use efficiency levels. The green coloured regions (Dongguan and Heyuan) are statistically significant with a p-value of 0.05, indicating that the cluster effect in these regions is statistically significant.
- The other regions (white coloured parts) do not have significant spatial clustering effects, indicating that there is no significant correlation between the resource use efficiency of these regions compared to the neighbouring regions.

(3) **Local Moran Index Cluster Map.**

- This map divides regions into four categories:

o **High-High (blue, Heyuan)**: Regions with high resource and energy use efficiency form clusters with neighbouring regions that are equally efficient.

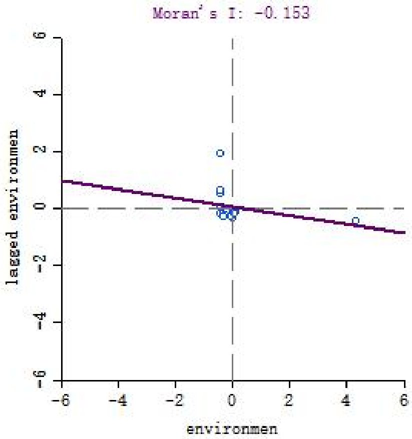
o **Low-Low (red, Dongguan)**: regions with low resource and energy use efficiency, clustered with equally inefficient neighbouring regions.

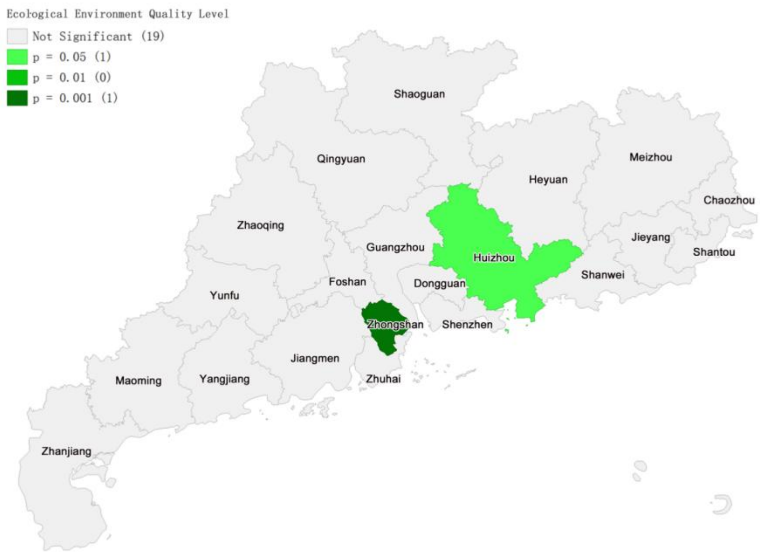
o **Low-High and High-Low**: No areas fall into these categories, indicating that no areas exhibit significant mixed clustering.

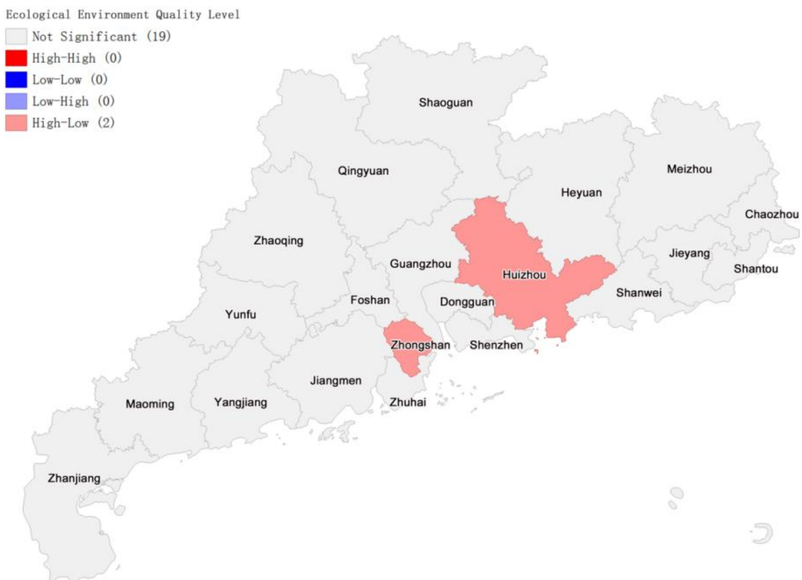
(4) **Spatial Justice Analysis.**

- At the heart of **spatial justice** is the equitable distribution of resources and opportunities across geographical areas. In this analysis, the local Moran Index reveals significant cluster effects in Dongguan and Heyuan. Heyuan's 'High-High' clustering means that the region excels in resource and energy efficiency, while Dongguan's 'Low-Low' clustering reveals a relative lag in efficiency. This difference may reflect imbalances in resource allocation and policy implementation, and Dongguan may need more support and policy intervention to improve its resource and energy use efficiency.

6.2.3 Ecological Environment Quality Level







[Figure 6.3 Results of Global and Local Moran's index of Ecological Environment Quality Level (From up to down) *Source:The Author*]

(1) Global Moran's index analysis.

- **Moran's I: -0.153** indicates that there is a weak negative spatial correlation between ecological quality levels. This means that high quality environmental areas may be adjacent to low quality environmental areas or vice versa. The negative correlation is present but not strong.
- **Scatterplot Interpretation**: The x-axis represents the ecological quality score and the y-axis represents the lagged ecological quality score. The negative slope of the purple line indicates that there is some negative spatial autocorrelation, but the distribution of the points indicates that this effect is not significant.

(2) Localised Moran index significance.

- This map shows the distribution of significance of ecological environmental quality. The p-values for the green and dark green areas (Huizhou and Zhongshan) are 0.05 and 0.001, respectively, indicating that the ecological quality of these areas is statistically significant. The ecological environmental quality of Huizhou and Zhongshan was significantly higher or lower than that of the surrounding areas, indicating a significant spatial clustering phenomenon.
- The other regions (white) are not statistically significant, indicating that there is no obvious spatial clustering of the ecological quality of these regions with their neighbouring regions.

(3) Localised Moran Index Cluster Map.

This map classifies the level of ecological quality into four categories:

-**High-Low (pink, Huizhou and Zhongshan)**: These areas have high ecological quality, but their neighbouring areas have low quality, forming a 'High-Low' spatial cluster. This suggests that Huizhou and Zhongshan are in a relatively advantageous position in terms of ecological environment, while their neighbouring areas perform poorly.

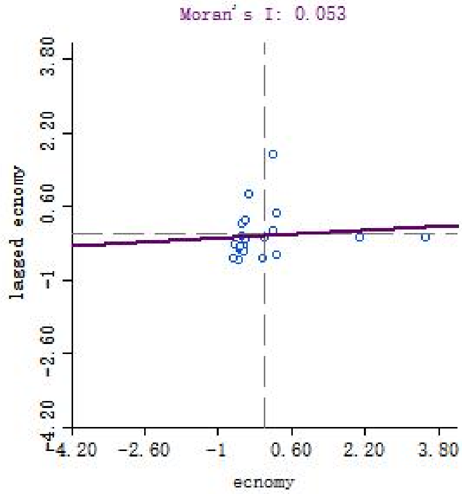
-**High-High, Low-Low, Low-High**: No areas fall into these categories, suggesting that there are no other significant clusters of high or low quality in Guangdong Province.

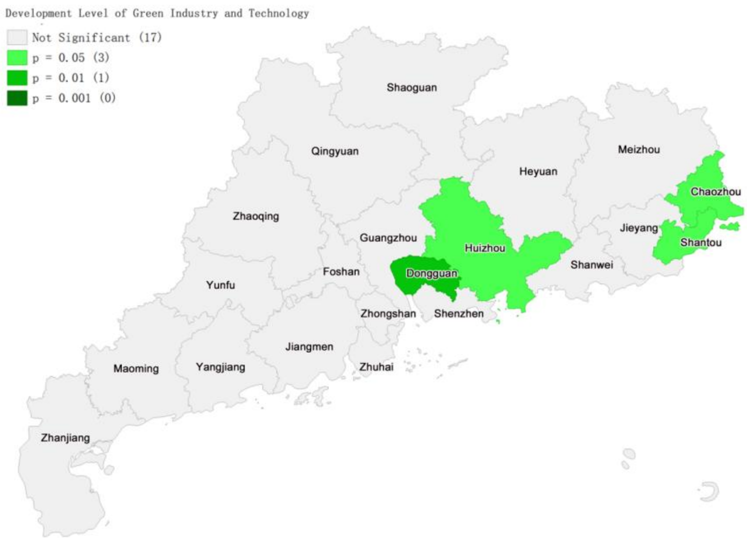
(4) **Spatial Justice Analysis.**

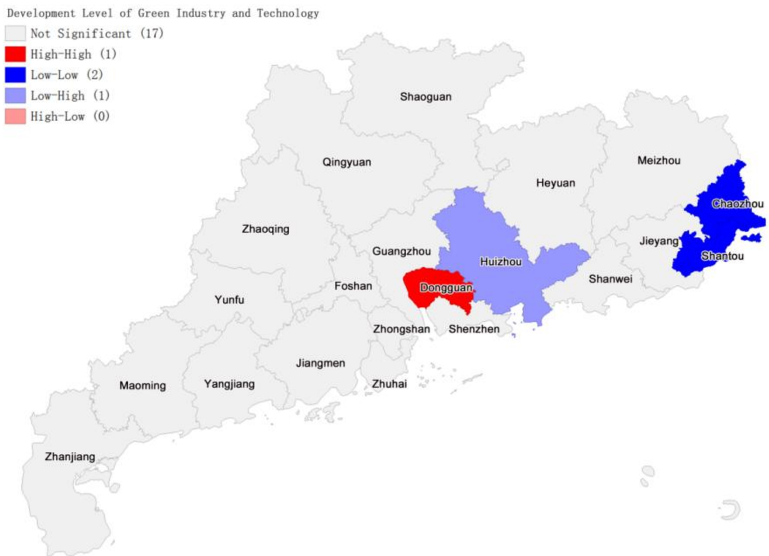
Spatial justice involves the equitable distribution of resources and environmental conditions. In the context of ecological quality, the 'high - low' clustering of Huizhou and Zhongshan suggests that these areas enjoy relatively high environmental quality, while their neighbours have low environmental quality.

This imbalance may reflect differences in resource allocation or policy implementation.

6.2.4 Development Level of Green Industry and Technology







[Figure 6.4 Results of Global and Local Moran's index of Development Level of Green Industry and Technology (From up to down) *Source:The Author*]

(1) Global Moran's index analysis.

- **Moran's I: 0.053** shows that the spatial autocorrelation of green industry and science and technology development level is very weak, and there is almost no significant spatial clustering effect. In other words, there is no significant spatial correlation between the green industry and technology development level of each region.

- **Scatterplot Interpretation**: The x-axis represents the score of green industry and science and technology development level, and the y-axis represents the lagged value. The slope of the purple line is very small, indicating that there is almost no significant spatial autocorrelation, and most of the points are clustered close to the origin, suggesting that the differences in scores among regions are small.

(2) Local Moran Index Significance.

- The map demonstrates the significance of the level of green industry and technology development. The p-values of the green regions (Dongguan, Huizhou, Shantou and Chaozhou) are 0.05 and 0.01, indicating that these regions are statistically significant, suggesting that there is a significant clustering effect of their green industry and science and technology development with the neighbouring regions.

- There is no significance in other regions (white part), and the level of green industry and science and technology development in these regions does not form obvious spatial clustering with the neighbouring regions.

(3) Local Moran Index Cluster Map.

This map divides the local spatial autocorrelation results into four categories:

-High-High (red, Dongguan): Indicates that Dongguan has a high level of green industry and science and technology development, and forms clusters with neighbouring regions with high levels of development.

-Low-Low (blue, Chaozhou and Shantou): Indicates that these regions have a low level of green industry and technology development and form clusters with neighbouring regions with low development levels, reflecting that the region is lagging behind in development.

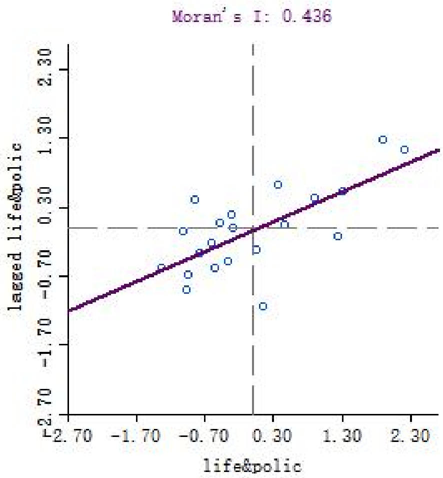
-Low-High (Huizhou): Huizhou shows a low-high cluster, implying that the region has a high level of development, but its neighbouring regions have a low level, and there is a clear spatial contrast.

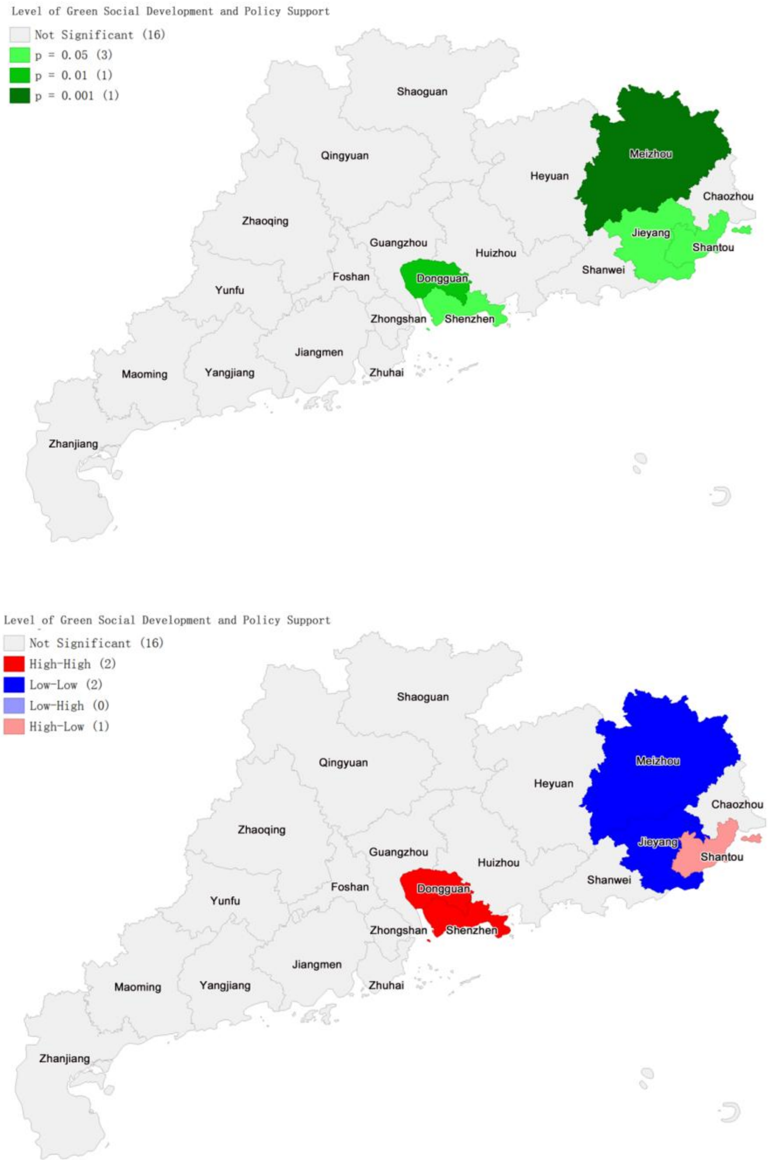
(4) Spatial Justice Analysis.

In terms of green industry and technological development, Dongguan is a 'high-high' cluster, indicating that the region has received more policy support or resources, forming a highly efficient industrial cluster.

In contrast, Shantou and Chaozhou are 'low-low' clusters, indicating the relative backwardness of these regions in terms of green industry and technology development. This phenomenon may reflect an imbalance in resource allocation and policy support.

6.2.5 Level of Green Social Development and Policy Support





[Figure 6.5 Results of Global and Local Moran's index of Level of Green Social Development and Policy Support (From up to down) *Source:The Author*]

(1) **Global Moran's Index Analysis**

-**Moran's I:** 0.436 indicates a strong spatial autocorrelation of green social development and policy support level, showing a clear spatial clustering effect. In other words, there is a significant spatial correlation between different regions in terms of green social development and policy support levels.

-**Scatterplot Interpretation:** The x-axis represents the score of green social development and policy support, while the y-axis shows the lagged values. The slope of the purple line is relatively steep, suggesting a significant spatial autocorrelation. The points are distributed along a positive diagonal, indicating that regions with high scores tend to cluster with neighboring regions that also have high scores.

(2) Local Moran Index Significance Analysis

- The map illustrates the significance of green social development and policy support levels. Green areas (such as Meizhou, Jieyang, Shenzhen, and Dongguan) display p-values of 0.05 and 0.01, showing statistical significance. This implies that these regions exhibit significant clustering effects in green social development and policy support with neighboring regions.

- Other areas (in white/gray) are not significant, indicating that these regions do not form obvious spatial clusters with neighboring regions in terms of green social development and policy support.

(3) **Local Moran Index Cluster Map**

This map categorizes the results of local spatial autocorrelation into four types:

-**High-High** (Red, Dongguan, Shenzhen): Indicates that these regions have high levels of green social development and policy support, and they form clusters with other regions that also have high levels.

-**Low-Low (**Blue, Meizhou, Jieyang): Indicates that these regions have low levels of green social development and policy support and form clusters with other regions that also have low levels, reflecting underdevelopment.

-**High-Low** (Pink, Shantou): Shantou shows a high-low cluster, implying that this region has a high level of development, but its neighboring areas have lower levels, creating a noticeable spatial contrast.

(4) Spatial Justice Analysis

Regarding green social development and policy support, Dongguan and Shenzhen fall under the "High-High" cluster, suggesting that these regions might have received more policy support or resources, forming efficient clusters of social development and policy support. Conversely, Meizhou and Jieyang are in the "Low-Low" cluster, indicating that these regions are relatively lagging in green social development and policy support. This phenomenon might reflect an imbalance in resource allocation and policy support.

Conclusion

7 Conclusion

7.1 Background and Purpose of the Study: Exploring the Path of Realising Spatial Justice in China's Green Transition

This study aims to explore how spatial justice can be achieved in China's green transition, especially in the context of the country's accelerated carbon-neutral process and the construction of an ecological civilisation that ensures the fairness of social resources and ecological welfare. Green transition is not only a change in economic and energy structure, but also a spatial justice issue involving social equity, fair distribution of resources and public participation. Guangdong Province is selected as a case study in this study not only because its economic dynamism and green industry development are representative, but also because the province's progress in green policy practice can provide valuable experience for other regions in China. Therefore, by analysing spatial justice in the green transition of Guangdong Province, this study provides empirical support and scientific guidance for achieving the goal of spatial justice in the country's green transition.

7.2 Research Methodology: Literature Review, Evaluation System Construction and Multidimensional Application of Spatial Analysis Methods

In order to comprehensively analyse the spatial justice situation in Guangdong Province in the process of green transition, this study obtains conclusions through the following multiple research methods:

Literature Review and Policy Analysis: By analysing relevant international and domestic literature on green transformation and spatial justice, clarifying the theoretical framework of green transition and spatial justice, and combining it with the context of China's Territorial Space Planning, the study clarifies the core evaluation dimensions of green transition, such as the efficiency of resource use, quality of ecological environment, and the level of development of green industries, which provides a strong theoretical foundation.

Evaluation System Construction: Based on the spatial justice issues in the green transition of Guangdong Province, this study designs a comprehensive evaluation index system. The system covers various aspects such as resource and energy use efficiency, ecological environment quality, green industry technology development, green social development and policy support, etc. The system is analysed using a combination of qualitative and quantitative methods, and the weight of each indicator is determined by entropy weighting method. The system is not only applicable to the evaluation of Guangdong Province, but also provides a reference model for the spatial justice of green transition in other provinces.

Spatial Analysis Approach: Using spatial autocorrelation analysis, we study the level of spatial justice in the green transition of 21 municipalities in Guangdong Province, particularly through global and local Moran indices, and analyse the spatial differences and evolutionary characteristics of the cities in Guangdong Province in terms of resource allocation, equitable participation and ecological welfare. This approach is able to reveal the spatial justice imbalances of different cities in the green transition process and demonstrate the spatial patterns of these differences.

7.3 Findings: Significant Spatial Justice Differences in the Green Transition of Guangdong Province

The results of the study show that there are significant differences in the level of spatial justice in green transition among cities in Guangdong Province. These differences are not only in terms of resource allocation and ecological protection efforts, but also in key areas such as public participation, green technology support and social welfare distribution. The results show that the performance on spatial justice dimensions between different regions can be categorised into the following levels：

Highly Developed Cities: Pearl River Delta cities such as Shenzhen, Dongguan and Guangzhou stand out in terms of resource allocation and ecological welfare. With strong economic power and policy support, these cities have invested significant resources in green industries, green energy use and public infrastructure development. In addition, these cities have better mechanisms for public participation and social welfare equalisation to ensure wide coverage of resources and ecological welfare. This resource agglomeration effect makes these cities' spatial justice performance in the green transition particularly significant, driving overall development within the region.

Moderately Developed Cities: Foshan, Huizhou, Jiangmen and other cities have achieved some success in resource and energy efficiency and ecological protection, but investment in policy support and technological innovation is still insufficient. The green transition in these cities relies mainly on infrastructure improvements and green industry development, but because of their relatively weak economic base, green technology innovation and equity in public services still need to be strengthened. Such cities reflect a common challenge in the green transition of many medium-development regions, namely insufficient policy and resource support, leading to certain limitations in the realisation of spatial justice.

Relatively underdeveloped Cities: Cities in eastern and northern Guangdong, such as Chaozhou, Meizhou, and Qingyuan, have large gaps in resource allocation, green innovation, and infrastructure development for green transition. The development of green industries in these areas is lagging behind, and the implementation of ecological protection and green social policies faces many challenges. The bottlenecks encountered by these underdeveloped regions in green transition reflect the imbalance in the transformation of industrial structure within the region and highlight their urgent need for green technology and policy support.

7.4 Policy Recommendations: Drawing on EU Experience to Promote Spatially Balanced Regional Green Transition in Guangdong Province[4]

In order to further promote spatial justice in the green transition, it is necessary to refer to the experiences of developed regions in the development of the green transition. The European Union has accumulated a wealth of experience in the green transition and has been particularly effective in promoting regional balance, spatial justice and public participation. As a multi-country regional organisation with unequal economic and development levels, the EU has narrowed the green development gap between different regions through a series of policy instruments, and also reached a high level of public participation and fairness in resource allocation. Referring to the EU's experience will help China and Guangdong Province to effectively address the challenges of unequal resource allocation, policy gaps, and insufficient public participation in the process of promoting green transformation. The EU has achieved a relatively balanced regional green transition through mechanisms such as cross-regional cooperation, financial support and community participation, which is particularly relevant to the green development of Guangdong Province, and can provide strong policy support and actionable practice models for less developed regions.

7.4.1 Establishing a cross-regional resource redistribution mechanism to support less developed regions

The EU redistributes resources across regions through mechanisms such as the European Regional Development Fund (ERDF), focusing on supporting green development and industrial innovation in less developed regions. Guangdong Province can learn from this model and focus on tilting funds and policy resources to less developed regions at the provincial level through financial transfers, resource redistribution, and special green funds. In particular, the allocation of resources can be combined with the industrial characteristics and green development potential of each region, and through financial and technological support for the development of green industries and ecological environmental protection in less developed regions, helping to achieve balanced development of green transition among regions.

7.4.2 Enhancing Residents' Support for Green Projects by Introducing Community Sharing and Benefit Guarantee Mechanisms

Community Benefit Agreements (CBAs) are widely used in green projects in the EU to safeguard the direct economic benefits of local residents in the projects and reduce resistance due to conflict of interest. Guangdong Province can introduce a community sharing mechanism in green projects to ensure that residents in less developed areas can directly benefit from the green industry. Through the establishment of a localised sharing economic model, combined with policy subsidies and other means, green projects are guaranteed to generate direct and long-term economic benefits for community residents. This benefit guarantee mechanism will not only increase residents' support for green projects, but also effectively promote the awareness of environmental protection among residents of underdeveloped regions, contributing to local sustainable development.

7.4.3 Optimising public participation to enhance policy responsiveness and residents' awareness of environmental protection

The EU attaches great importance to comprehensive public participation in the green transition to ensure policy transparency and public acceptance. On the basis of the existing mechanisms such as public consultation platforms and hearings, Guangdong Province can further enhance the depth and breadth of public participation through digital means and multi-party collaborative mechanisms. For example, a provincial ‘Green Transition

Participation' app could be developed to provide real-time updates on policy information and the progress of green projects, and a feedback channel could be set up to enable residents to directly participate in policy feedback. At the same time, it can work with schools and community organisations to carry out environmental education and green living promotion activities to encourage residents to actively participate in green actions.

7.5 Research Shortcomings and Future Prospects: Dynamic Improvement of Coverage and Public Participation

Although this study provides a detailed empirical analysis of the spatial justice issues of green transition in Guangdong Province, there are still deficiencies in the evaluation system and empirical coverage, which can be further explored in the following aspects in future studies:

7.5.1 Limitations of Data Coverage

This study takes Guangdong Province as the research object, which has certain specificities in terms of resource endowment and policy background. Therefore, in the future, a cross-regional comparative study can be conducted to analyse the development of spatial justice in different regions, so as to reveal the spatial imbalance in China's green transition in a more comprehensive way, and to establish a more universal spatial justice assessment system.

7.5.2 Dynamics and Sustainability of the Evaluation System

This study conducted spatial justice evaluation based on static data, but green transition is a long-term evolutionary process. Future research can study the dynamic evolution of spatial justice in greater depth through long-term tracking analyses and dynamic data support, so as to more accurately predict the sustainable development trend of spatial justice in the future, and provide empirical support for policy formulation.

7.5.3 Deepening Research on Public Participation

Future research should also further explore the role of public participation in green transition policies, especially how to more effectively safeguard the public's right to information and participation in green projects. For example, the practical effects of public participation in policy formulation, implementation and monitoring can be studied, so as to provide theoretical support for the construction of a more effective public participation mechanism.

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Annex

9 Annex

9.1 Calculation Process of Evaluation System

9.1.1 Entropy weighting method to calculate weights

(1) Original Data

Municipalities	Energy Consumption per Unit of GDP	Water Consumption per Unit of GDP(Cubic metres/10,000 yuan)	Electricity Consumption per Unit of GDP(kWh/10,000 yuan)	Land Use per Unit of GDP	Carbon Emissions	Forest Coverage Rates	Ecological Space Ratio	AQI Compliance Rate	Surface Water Quality Ratio	Industrial Solid Waste Comprehensive Utilization Rates	Population Density
Indicator Direction	-	-	-	-	-	+	+	+	+	+	+
Guangzhou	0.223283421	21.32529059	0.041788207	25.10	0.230838151	41.60%	10.57%	83.8	85.00%	95%	2588
Shenzhen	0.146876829	6.811231526	0.033155198	6.14	0.048300824	39.20%	6.80%	92.1	87.90%	92.17%	8889
Zhuhai	0.253002525	14.06517148	0.062101811	42.64	0.280280036	31.96%	6.67%	89.9	92.60%	96.85%	1436
Shantou	0.303422618	32.24586127	0.090765637	73.06	0.972914115	25.52%	6.50%	95.9	85.70%	93.77%	2514
Foshan	0.1161139	24.38891168	0.059764252	29.91	0.357962142	37.36%	10.09%	84.1	85.70%	90%	2515
Shaoguan	0.626813505	6.649930582	0.115210047	1177.34	2.232917171	74.52%	10.61%	92.1	84.90%	69.28%	155

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Municipalities	Energy Consumption per Unit of GDP	Water Consumption per Unit of GDP(Cubic metres/10,000 yuan)	Electricity Consumption per Unit of GDP(kWh/10,000 yuan)	Land Use per Unit of GDP	Carbon Emissions	Forest Coverage Rates	Ecological Space Ratio	AQI Compliance Rate	Surface Water Quality Ratio	Industrial Solid Waste Comprehensive Utilization Rates	Population Density
Heyuan	0.397915891	117.0274743	0.094996956	1209.18	0.742812086	73.20%	3.95%	96.2	84.10%	67.26%	182
Meizhou	0.437555971	143.3764082	0.096540115	1203.49	1.396210182	75%	15.07%	99.2	83.30%	98%	243
Huizhou	0.549366869	27.15	0.102372868	210.14	0.395576904	61.67%	20.98%	93.7	85.17%	84.52%	533
Shanwei	0.252182515	75.86882092	0.06272226	368.04	0.499209027	49%	6.65%	97.0	87.03%	98%	551
Dongguan	0.135688143	18.80304192	0.090859941	21.97	0.223040577	37.40%	14.27%	80.0	88.90%	90.78%	4242
Zhongshan	0.32206586	40.23377226	0.102390957	49.05	0.938804783	23.14%	8.22%	83.6	87.9	99.49%	2488
Jiangmen	0.266920704	69.43118461	0.05841408	252.69	1.374331886	45.12%	11.66%	81.9	87.20%	94.90%	506
Yangjiang	0.587837827	85.16528045	0.10777092	519.00	0.47577728	57.58%	5.22%	95.1	91.30%	98.84%	329
Zhanjiang	0.567021597	67.06967731	0.082700414	357.27	0.947687799	23.18%	12.77%	96.4	89.00%	94.27%	530
Maoming	0.456	41.6	0.043627704	293.29	0.419028039	55.70%	12.52%	97.3	86.70%	99.95%	545
Zhaoqing	0.310501201	64.69391148	0.086774868	550.51	0.505780942	67.40%	18.15%	86.0	86.37%	98.86%	277
Qingyuan	0.621425573	88.87702112	0.136834196	936.78	1.947007752	68.81%	18.65%	89.9	86.03%	92.93%	209
Chaozhou	0.50015857	47.405	0.095050692	240.66	0.158396006	59.69%	23.05%	96.2	85.70%	99.28%	815
Jieyang	0.234447093	5.926635681	0.111261528	232.91	0.373084644	50.89%	22.02%	96.2	80.35%	96.50%	1070
Yunfu	0.276636536	98.3286876	0.096143606	669.73	4.974995178	68.25%	19.19%	91.7	75.00%	83.61%	308

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Municipalities	Circular Economy Growth Rates	Green Industry Growth Rates	Environmental Protection Industry Growth Rates	Number of Green Patent Applications	Tertiary Industry Ratio	Number of Green Patents Granted	Urban Greening Coverage Ratio	Per Capita Public Green Space	Green Mobility Ratio	Public Transportation Usage Ratio	Fiscal Expenditure on Environmental Protection Ratio	Number of Digital Economy Policies	Environmental Concern Index
Indicator Direction	+	+	+	+	+	+	+	+	+	+	+	+	+
Guangzhou	-0.26%	-0.10%	-0.20%	7416	71.5	8912	44.67%	16.8	78.00%	23.80%	0.87%	0.002875629	111.890411
Shenzhen	-7.06%	21.90%	1.70%	11703	61.6	15359	43.09%	12.58	74.16%	50.11%	4.04%	0.002305397	104.3041096
Zhuhai	37.20%	-5.90%	17.10%	1282	53.8	1610	47.01%	22.25	65.00%	17.43%	2.04%	0.000976563	19.48493151
Shantou	12.09%	-0.01%	-40.00%	160	47.5	200	45.25%	15.3	73%	29%	2.93%	0.001592568	28.61917808
Foshan	7.71%	12.90%	20.70%	2151	42.1	3462	46.42%	18.19	70.20%	40.06%	1.30%	0.005185377	64.69589041
Shaoguan	-27.67%	19.20%	17.70%	125	50.0	249	43.19%	16.79	67.00%	30.00%	2.47%	0.001906275	8.378082192
Heyuan	10.52%	6.70%	16.00%	88	51.2	149	42.68%	15.45	60.00%	40.00%	1.49%	0.001102688	6.780821918
Meizhou	13.62%	-5.40%	0.30%	72	49.5	160	44.53%	19.24	50.00%	16.98%	0.86%	0.002380952	6.446575342
Huizhou	29.70%	-0.50%	10.50%	680	39.0	1406	42.43%	16.95	72.78%	49.20%	1.92%	0.002956029	26.0109589
Shanwei	629.10%	-49.30%	56.30%	84	48.7	104	44.52%	15.6	74.83%	23.70%	1.09%	0.003524364	5.180821918
Dongguan	17.20%	-4.10%	2.00%	2107	41.5	3834	48.81%	19.56	70.00%	23.00%	5.30%	0.00343428	57.28219178

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Municipalities	Circular Economy Growth Rates	Green Industry Growth Rates	Environmental Protection Industry Growth Rates	Number of Green Patent Applications	Tertiary Industry Ratio	Number of Green Patents Granted	Urban Greening Coverage Ratio	Per Capita Public Green Space	Green Mobility Ratio	Public Transportation Usage Ratio	Fiscal Expenditure on Environmental Protection Ratio	Number of Digital Economy Policies	Environmental Concern Index
Zhongshan	352.00%	7.40%	93.80%	695	48.1	1128	55.67%	15.05	65.00%	40.00%	3.25%	0.004562044	29.17534247
Jiangmen	15.24%	5.60%	15.10%	372	45.7	681	43.76%	20.79	65.00%	35.00%	0.74%	0.001705757	16.76164384
Yangjiang	17.53%	3.80%	22.90%	92	44.8	130	44.18%	25.79	65.00%	37.50%	1.04%	0.001467998	6.191780822
Zhanjiang	44.64%	-2.60%	33.50%	160	42.3	228	44.70%	17	65.00%	40.00%	1.17%	0.006354469	18.90684932
Maoming	335.41%	-1.70%	79.70%	101	45.7	156	44.15%	18.29	66.14%	40.00%	3.22%	0.001135396	10.05205479
Zhaoqing	-22.52%	-0.80%	-6.80%	140	40.4	234	41.99%	23.64	68.31%	31.30%	0.94%	0.000576037	12.7260274
Qingyuan	-28.44%	0.10%	117.10%	160	46.0	254	42.37%	14.87	70.49%	35.00%	1.20%	0.001119284	7.567123288
Chaozhou	-37.07%	-58.80%	47.59%	38	42.8	73	42.47%	14.17	72.66%	5.10%	1.04%	0.001066585	7.24109589
Jieyang	19.10%	-5.85%	-12.20%	58	55.0	98	44.21%	15.11	74.83%	6.69%	2.05%	0.000789141	8.865753425
Yunfu	-56.30%	47.10%	9.90%	77	48.6	114	40.85%	17.98	74.83%	6.69%	1.11%	0.001877934	2.668493151

(2) Data Nomalisation

city	Energy Consumption per Unit of GDP	Water Consumption per Unit of GDP(Cubic metres/10,000 yuan)	Electricity Consumption per Unit of GDP(kWh/10,000 yuan)	Land Use per Unit of GDP	Carbon Emissions	Forest Coverage Rates	Ecological Space Ratio	AQI Compliance Rate	Surface Water Quality Ratio	Industrial Solid Waste Comprehensive Utilization Rates	Population Density
Guangzhou	0.7902	0.8880	0.9167	0.9842	0.9630	0.3560	0.3466	0.1979	0.0011	0.8571	0.2786
Shenzhen	0.9398	0.9936	1.0000	1.0000	1.0000	0.3097	0.1492	0.6302	0.0015	0.7620	1.0000
Zhuhai	0.7320	0.9408	0.7208	0.9697	0.9529	0.1701	0.1424	0.5156	0.0020	0.9052	0.1467
Shantou	0.6332	0.8085	0.4443	0.9444	0.8123	0.0459	0.1335	0.8281	0.0012	0.8110	0.2701
Foshan	1.0000	0.8657	0.7434	0.9802	0.9371	0.2742	0.3215	0.2135	0.0012	0.6956	0.2702
Shaoguan	0.0000	0.9947	0.2086	0.0265	0.5566	0.9907	0.3487	0.6302	0.0011	0.0618	0.0000
Heyuan	0.4482	0.1917	0.4035	0.0000	0.8590	0.9653	0.0000	0.8438	0.0010	0.0000	0.0031
Meizhou	0.3706	0.0000	0.3886	0.0047	0.7264	1.0000	0.5822	1.0000	0.0010	0.9403	0.0101
Huizhou	0.1516	0.8456	0.3324	0.8304	0.9295	0.7430	0.8916	0.7135	0.0012	0.5280	0.0433
Shanwei	0.7336	0.4911	0.7148	0.6992	0.9085	0.4987	0.1414	0.8854	0.0014	0.9403	0.0453
Dongguan	0.9617	0.9063	0.4434	0.9868	0.9645	0.2750	0.5403	0.0000	0.0016	0.7195	0.4679
Zhongshan	0.5967	0.7504	0.3322	0.9643	0.8193	0.0000	0.2236	0.1875	1.0000	0.9859	0.2671
Jiangmen	0.7047	0.5380	0.7564	0.7951	0.7308	0.4238	0.4037	0.0990	0.0014	0.8455	0.0402

city	Energy Consumption per Unit of GDP	Water Consumption per Unit of GDP(Cubic metres/10,000 yuan)	Electricity Consumption per Unit of GDP(kWh/10,000 yuan)	Land Use per Unit of GDP	Carbon Emissions	Forest Coverage Rates	Ecological Space Ratio	AQI Compliance Rate	Surface Water Quality Ratio	Industrial Solid Waste Comprehensive Utilization Rates	Population Density
Yangjiang	0.0763	0.4235	0.2803	0.5737	0.9132	0.6641	0.0665	0.7865	0.0019	0.9660	0.0199
Zhanjiang	0.1171	0.5552	0.5221	0.7081	0.8174	0.0008	0.4618	0.8542	0.0016	0.8262	0.0429
Maoming	0.3345	0.7405	0.8990	0.7613	0.9248	0.6278	0.4487	0.9010	0.0013	1.0000	0.0447
Zhaoqing	0.6194	0.5724	0.4828	0.5475	0.9071	0.8535	0.7435	0.3125	0.0013	0.9667	0.0140
Qingyuan	0.0106	0.3965	0.0000	0.2264	0.6146	0.8806	0.7696	0.5156	0.0013	0.7853	0.0062
Chaozhou	0.2480	0.6982	0.4030	0.8051	0.9777	0.7048	1.0000	0.8438	0.0012	0.9795	0.0756
Jieyang	0.7683	1.0000	0.2467	0.8115	0.9341	0.5351	0.9461	0.8438	0.0006	0.8945	0.1048
Yunfu	0.6857	0.3277	0.3925	0.4484	0.0000	0.8698	0.7979	0.6094	0.0000	0.5002	0.0175

city	Circular Economy Growth Rates	Green Industry Growth Rates	Environmental Protection Industry Growth Rates	Number of Green Patent Applications	Tertiary Industry Ratio	Number of Green Patents Granted	Urban Greening Coverage Ratio	Per Capita Public Green Space	Green Mobility Ratio	Public Transportation Usage Ratio	Fiscal Expenditure on Environmental Protection Ratio	Number of Digital Economy Policies	Environmental Concern Index

Guangzhou	0.0818	0.5543	0.2534	0.6325	1.0000	0.5782	0.2578	0.3195	1.0000	0.4155	0.0273	0.3980	1.0000
Shenzhen	0.0718	0.7620	0.2654	1.0000	0.6970	1.0000	0.1511	0.0000	0.8629	1.0000	0.7222	0.2993	0.9305
Zhuhai	0.1364	0.4995	0.3635	0.1066	0.4569	0.1006	0.4157	0.7320	0.5357	0.2739	0.2853	0.0693	0.1540
Shantou	0.0998	0.5551	0.0000	0.0105	0.2636	0.0083	0.2969	0.2059	0.8250	0.5254	0.4794	0.1759	0.2376
Foshan	0.0934	0.6771	0.3864	0.1811	0.0971	0.2217	0.3758	0.4247	0.7214	0.7767	0.1226	0.7977	0.5679
Shaoguan	0.0418	0.7365	0.3673	0.0075	0.3411	0.0115	0.1579	0.3187	0.6071	0.5532	0.3780	0.2302	0.0523
Heyuan	0.0975	0.6185	0.3565	0.0043	0.3771	0.0050	0.1235	0.2173	0.3571	0.7754	0.1639	0.0911	0.0377
Meizhou	0.1020	0.5043	0.2565	0.0029	0.3246	0.0057	0.2483	0.5042	0.0000	0.2639	0.0248	0.3124	0.0346
Huizhou	0.1255	0.5505	0.3215	0.0550	0.0000	0.0872	0.1066	0.3308	0.8136	0.9798	0.2574	0.4119	0.2137
Shanwei	1.0000	0.0897	0.6130	0.0039	0.2995	0.0020	0.2476	0.2286	0.8868	0.4132	0.0764	0.5102	0.0230
Dongguan	0.1072	0.5165	0.2673	0.1774	0.0789	0.2460	0.5371	0.5284	0.7143	0.3977	1.0000	0.4946	0.5000
Zhongshan	0.5957	0.6251	0.8517	0.0563	0.2815	0.0690	1.0000	0.1870	0.5357	0.7754	0.5489	0.6898	0.2427
Jiangmen	0.1044	0.6081	0.3507	0.0286	0.2081	0.0398	0.1964	0.6215	0.5357	0.6643	0.0000	0.1955	0.1290
Yangjiang	0.1077	0.5911	0.4004	0.0046	0.1789	0.0037	0.2247	1.0000	0.5357	0.7198	0.0647	0.1544	0.0323
Zhanjiang	0.1473	0.5307	0.4679	0.0105	0.1043	0.0101	0.2598	0.3346	0.5357	0.7754	0.0930	1.0000	0.1487
Maoming	0.5715	0.5392	0.7619	0.0054	0.2076	0.0054	0.2227	0.4322	0.5764	0.7754	0.5432	0.0968	0.0676
Zhaoqing	0.0493	0.5477	0.2113	0.0087	0.0432	0.0105	0.0769	0.8372	0.6539	0.5821	0.0429	0.0000	0.0921
Qingyuan	0.0407	0.5562	1.0000	0.0105	0.2154	0.0118	0.1026	0.1734	0.7318	0.6643	0.1013	0.0940	0.0449
Chaozhou	0.0281	0.0000	0.5575	0.0000	0.1198	0.0000	0.1093	0.1204	0.8093	0.0000	0.0657	0.0849	0.0419
Jieyang	0.1100	0.5000	0.1770	0.0017	0.4937	0.0016	0.2267	0.1915	0.8868	0.0353	0.2863	0.0369	0.0567
Yunfu	0.0000	1.0000	0.3176	0.0033	0.2974	0.0027	0.0000	0.4088	0.8868	0.0353	0.0797	0.2253	0.0000

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(3)Calculation of information entropy and coefficient of variation

city	Energy Consumption per Unit of GDP	Water Consumption per Unit of GDP(Cubic metres/10,000 yuan)	Electricity Consumption per Unit of GDP(kWh/10,000 yuan)	Land Use per Unit of GDP	Carbon Emissions	Forest Coverage Rates	Ecological Space Ratio	AQI Compliance Rate	Surface Water Quality Ratio	Industrial Solid Waste Comprehensive Utilization Rates	Population Density
Guangzhou	-0.1900	-0.1755	-0.2113	-0.1861	-0.1611	-0.1097	-0.1212	-0.0660	-0.0076	-0.1570	-0.2138
Shenzhen	-0.2111	-0.1883	-0.2223	-0.1879	-0.1651	-0.0993	-0.0655	-0.1513	-0.0094	-0.1452	-0.3640
Zhuhai	-0.1811	-0.1820	-0.1825	-0.1844	-0.1600	-0.0636	-0.0632	-0.1322	-0.0123	-0.1627	-0.1423
Shantou	-0.1651	-0.1652	-0.1327	-0.1813	-0.1439	-0.0225	-0.0601	-0.1806	-0.0081	-0.1513	-0.2099
Foshan	-0.2189	-0.1727	-0.1860	-0.1856	-0.1582	-0.0909	-0.1149	-0.0699	-0.0081	-0.1365	-0.2100
Shaoguan	0.0000	-0.1885	-0.0771	-0.0118	-0.1108	-0.2147	-0.1217	-0.1513	-0.0075	-0.0215	0.0000
Heyuan	-0.1310	-0.0590	-0.1242	0.0000	-0.1494	-0.2114	0.0000	-0.1828	-0.0070	0.0000	-0.0068
Meizhou	-0.1148	0.0000	-0.1210	-0.0027	-0.1334	-0.2158	-0.1716	-0.2029	-0.0065	-0.1668	-0.0183
Huizhou	-0.0594	-0.1701	-0.1083	-0.1670	-0.1574	-0.1801	-0.2226	-0.1642	-0.0077	-0.1127	-0.0587
Shanwei	-0.1814	-0.1179	-0.1815	-0.1492	-0.1550	-0.1386	-0.0628	-0.1884	-0.0089	-0.1668	-0.0608
Dongguan	-0.2139	-0.1778	-0.1325	-0.1864	-0.1613	-0.0911	-0.1635	0.0000	-0.0101	-0.1397	-0.2825

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city	Energy Consumption per Unit of GDP	Water Consumption per Unit of GDP(Cubic metres/10,000 yuan)	Electricity Consumption per Unit of GDP(kWh/10,000 yuan)	Land Use per Unit of GDP	Carbon Emissions	Forest Coverage Rates	Ecological Space Ratio	AQI Compliance Rate	Surface Water Quality Ratio	Industrial Solid Waste Comprehensive Utilization Rates	Population Density
Zhongshan	-0.1588	-0.1574	-0.1083	-0.1837	-0.1447	0.0000	-0.0885	-0.0633	-0.0241	-0.1719	-0.2085
Jiangmen	-0.1768	-0.1257	-0.1880	-0.1624	-0.1339	-0.1240	-0.1346	-0.0385	-0.0090	-0.1556	-0.0554
Yangjiang	-0.0347	-0.1062	-0.0959	-0.1305	-0.1556	-0.1676	-0.0349	-0.1748	-0.0115	-0.1697	-0.0319
Zhanjiang	-0.0486	-0.1284	-0.1480	-0.1505	-0.1445	-0.0007	-0.1474	-0.1842	-0.0101	-0.1532	-0.0583
Maoming	-0.1068	-0.1560	-0.2089	-0.1578	-0.1569	-0.1616	-0.1446	-0.1904	-0.0087	-0.1735	-0.0601
Zhaoqing	-0.1627	-0.1312	-0.1404	-0.1263	-0.1549	-0.1963	-0.1999	-0.0927	-0.0085	-0.1698	-0.0239
Qingyuan	-0.0067	-0.1013	0.0000	-0.0665	-0.1188	-0.2001	-0.2041	-0.1322	-0.0083	-0.1481	-0.0122
Chaozhou	-0.0859	-0.1500	-0.1241	-0.1637	-0.1627	-0.1742	-0.2376	-0.1828	-0.0081	-0.1712	-0.0891
Jieyang	-0.1867	-0.1891	-0.0873	-0.1646	-0.1579	-0.1454	-0.2303	-0.1828	-0.0045	-0.1614	-0.1127
Yunfu	-0.1738	-0.0882	-0.1218	-0.1098	0.0000	-0.1986	-0.2086	-0.1480	0.0000	-0.1085	-0.0287

city	Circular Economy Growth Rates	Green Industry Growth Rates	Environmental Protection Industry Growth Rates	Number of Green Patent Applications	Tertiary Industry Ratio	Number of Green Patents Granted	Urban Greening Coverage Ratio	Per Capita Public Green Space	Green Mobility Ratio	Public Transportation Usage Ratio	Fiscal Expenditure on Environmental Protection Ratio	Number of Digital Economy Policies	Environmental Concern Index
Guangzhou	-0.0840	-0.1456	-0.1043	-0.3546	-0.2968	-0.3420	-0.1464	-0.1273	-0.1884	-0.1207	-0.0269	-0.1733	-0.3316
Shenzhen	-0.0764	-0.1792	-0.1078	-0.3625	-0.2482	-0.3652	-0.1009	0.0000	-0.1717	-0.2135	-0.2700	-0.1437	-0.3231
Zhuhai	-0.1214	-0.1357	-0.1343	-0.1419	-0.1944	-0.1321	-0.1988	-0.2170	-0.1248	-0.0896	-0.1561	-0.0492	-0.1136
Shantou	-0.0972	-0.1458	0.0000	-0.0244	-0.1360	-0.0195	-0.1607	-0.0932	-0.1668	-0.1418	-0.2158	-0.0991	-0.1529
Foshan	-0.0927	-0.1662	-0.1400	-0.1995	-0.0660	-0.2189	-0.1868	-0.1544	-0.1527	-0.1830	-0.0864	-0.2602	-0.2580
Shaoguan	-0.0505	-0.1754	-0.1352	-0.0185	-0.1615	-0.0254	-0.1041	-0.1271	-0.1360	-0.1468	-0.1869	-0.1200	-0.0508
Heyuan	-0.0956	-0.1566	-0.1325	-0.0117	-0.1723	-0.0127	-0.0871	-0.0969	-0.0935	-0.1828	-0.1066	-0.0608	-0.0393
Meizhou	-0.0988	-0.1366	-0.1052	-0.0084	-0.1563	-0.0142	-0.1427	-0.1726	0.0000	-0.0872	-0.0249	-0.1479	-0.0367
Huizhou	-0.1145	-0.1450	-0.1234	-0.0890	0.0000	-0.1197	-0.0782	-0.1304	-0.1653	-0.2109	-0.1457	-0.1771	-0.1424
Shanwei	-0.3533	-0.0377	-0.1890	-0.0109	-0.1482	-0.0059	-0.1425	-0.1005	-0.1747	-0.1202	-0.0606	-0.2022	-0.0265
Dongguan	-0.1024	-0.1389	-0.1084	-0.1970	-0.0563	-0.2324	-0.2311	-0.1778	-0.1517	-0.1170	-0.3132	-0.1985	-0.2410
Zhongshan	-0.2936	-0.1577	-0.2298	-0.0905	-0.1422	-0.1014	-0.3138	-0.0869	-0.1248	-0.1828	-0.2333	-0.2408	-0.1551
Jiangmen	-0.1004	-0.1549	-0.1310	-0.0544	-0.1154	-0.0675	-0.1215	-0.1968	-0.1248	-0.1656	0.0000	-0.1069	-0.1001
Yangjiang	-0.1027	-0.1520	-0.1434	-0.0124	-0.1037	-0.0100	-0.1334	-0.2580	-0.1248	-0.1744	-0.0533	-0.0902	-0.0347
Zhanjiang	-0.1280	-0.1414	-0.1590	-0.0244	-0.0697	-0.0229	-0.1471	-0.1315	-0.1248	-0.1828	-0.0703	-0.2907	-0.1108

city	Circular Economy Growth Rates	Green Industry Growth Rates	Environmental Protection Industry Growth Rates	Number of Green Patent Applications	Tertiary Industry Ratio	Number of Green Patents Granted	Urban Greening Coverage Ratio	Per Capita Public Green Space	Green Mobility Ratio	Public Transportation Usage Ratio	Fiscal Expenditure on Environmental Protection Ratio	Number of Digital Economy Policies	Environmental Concern Index
Maoming	-0.2881	-0.1430	-0.2155	-0.0142	-0.1152	-0.0137	-0.1325	-0.1562	-0.1313	-0.1828	-0.2319	-0.0636	-0.0619
Zhaoqing	-0.0574	-0.1445	-0.0915	-0.0211	-0.0351	-0.0237	-0.0611	-0.2343	-0.1430	-0.1519	-0.0387	0.0000	-0.0782
Qingyuan	-0.0494	-0.1460	-0.2510	-0.0244	-0.1182	-0.0260	-0.0759	-0.0821	-0.1542	-0.1656	-0.0750	-0.0622	-0.0451
Chaozhou	-0.0369	0.0000	-0.1781	0.0000	-0.0773	0.0000	-0.0796	-0.0624	-0.1647	0.0000	-0.0539	-0.0576	-0.0427
Jieyang	-0.1043	-0.1358	-0.0803	-0.0053	-0.2038	-0.0049	-0.1342	-0.0884	-0.1747	-0.0179	-0.1564	-0.0298	-0.0542
Yunfu	0.0000	-0.2117	-0.1224	-0.0095	-0.1475	-0.0075	0.0000	-0.1505	-0.1747	-0.0179	-0.0625	-0.1182	0.0000

9.2 Calculation of Coupling and Coordination Degree

City	U1-Efficiency Level of Resource and Energy Utilization	U2-Ecological Environment Quality Level	U3-Development Level of Green Industry and Technology	U4-Level of Green Social Development and Policy Support	Coupling degree	Coordination degree	Coupling Coordination Degree
Guangzhou	0.5913	0.0729	0.6421	0.5249	0.7583	0.4578	0.5892
Shenzhen	0.9761	0.0690	0.7063	0.6729	0.6980	0.6061	0.6504

City	U1-Efficiency Level of Resource and Energy Utilization	U2-Ecological Environment Quality Level	U3-Development Level of Green Industry and Technology	U4-Level of Green Social Development and Policy Support	Coupling degree	Coordination degree	Coupling Coordination Degree
Zhuhai	0.5063	0.0735	0.2570	0.2573	0.8143	0.2735	0.4719
Shantou	0.5050	0.0695	0.1287	0.3339	0.7602	0.2593	0.4440
Foshan	0.5895	0.0750	0.1718	0.5121	0.7409	0.3371	0.4997
Shaoguan	0.1143	0.1264	0.1688	0.2629	0.9466	0.1681	0.3989
Heyuan	0.1456	0.1096	0.1847	0.1815	0.9789	0.1554	0.3900
Meizhou	0.1773	0.1642	0.1594	0.1520	0.9984	0.1632	0.4037
Huizhou	0.2916	0.1445	0.0809	0.3711	0.8495	0.2220	0.4343
Shanwei	0.3951	0.0988	0.2958	0.2182	0.8892	0.2520	0.4733
Dongguan	0.6602	0.0912	0.1662	0.6232	0.7295	0.3852	0.5301
Zhongshan	0.4979	0.8500	0.2756	0.4569	0.9238	0.5201	0.6932
Jiangmen	0.3939	0.0724	0.1377	0.2286	0.8316	0.2082	0.4161
Yangjiang	0.2328	0.0993	0.1154	0.2493	0.9219	0.1742	0.4007
Zhanjiang	0.2833	0.0861	0.0986	0.3853	0.8179	0.2133	0.4177
Maoming	0.3819	0.1256	0.2138	0.3165	0.9199	0.2594	0.4885
Zhaoqing	0.3331	0.1229	0.0504	0.2103	0.8055	0.1792	0.3799
Qingyuan	0.1288	0.1370	0.1460	0.1686	0.9949	0.1451	0.3800
Chaozhou	0.3440	0.1548	0.0717	0.0901	0.8247	0.1652	0.3691
Jieyang	0.4346	0.1481	0.2169	0.1543	0.9034	0.2385	0.4642

Politecnico di Torino

City	U1-Efficiency Level of Resource and Energy Utilization	U2-Ecological Environment Quality Level	U3-Development Level of Green Industry and Technology	U4-Level of Green Social Development and Policy Support	Coupling degree	Coordination degree	Coupling Coordination Degree
Yunfu	0.2466	0.1340	0.1475	0.1413	0.9680	0.1674	0.4025