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Research on the Coupling and Coordination Relationship between Digital Economy and Green Development in Guangdong Province

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Abstract: Green development enabled by the digital economy is an important engine for economic growth. The article empirically investigates the spatial and temporal evolution of the coupling and coordination between the digital economy and green development by constructing an index system of the digital economy and green development, and by selecting the panel data of 21 prefectural cities in Guangdong Province in the period of 2012-2022. The study finds that, in terms of external spatial distribution, there is a large gap between the level of digital economy and green development in each city, and the development is not balanced; the gap between the two major coupling levels in each city is more obvious, presenting an uneven pattern of "center-edge". In terms of intra-city development, the level of coupling and coordination between the digital economy and green development of each city from 2012 to 2022 shows an upward trend, reaching the level of primary coordination to good coordination, but the overall level is still not high, and there is still a certain gap from realizing high-quality coordination. Accordingly, in order to promote the interconnection of digital economy and green development, the article puts forward a series of policy recommendations to promote the deep integration of industrial digitization and greening among cities, adhering to the innovation-driven, and facilitating the coordinated development based on the differentiated resources of cities.

Keywords: Digital economy, Green development, Coupled coordination, Spatio-temporal evolution.

1. Introduction

The digital economy and green development have become the twin engines for promoting economic growth in China, and our economy is currently in a critical period of transformation of old and new growth momentum. However, in the process of green transformation and development, it still faces problems such as insufficient new kinetic energy, high pressure on resources and environment, prominent high-pollution and high-energy-consumption industries, and unreasonable industrial structure. Green development is a low-carbon and high-efficiency development model, which has become the ballast of China's sustainable socio-economic development. Digital technology relying on data, algorithms and arithmetic power has the characteristics of resource intensification and high output efficiency. The digital economy can improve the efficiency of resource and energy utilization, promote the transformation and upgrading of industrial structure, reduce pollution emissions, and help realize green transformation.

As a large province with a digital economy, Guangdong's digital economy will reach 6.41 trillion yuan in 2022, with a growth rate of 8.6%, ranking at the forefront of the country. Guangdong continues to take the digital economy as a new kinetic energy and a new engine to lead the high-quality development of the economy, and strives to promote the construction of a strong digital economy province, but Guangdong's traditional manufacturing industry accounts for a large proportion of the economy, resulting in green ecology and environmental governance and other problems are still prominent. A large number of facts show that the digital economy and green development have a logical correlation mechanism that promotes each other: on the one hand, the digital economy itself is a low-carbon recycling economy, which can promote the upgrading of the industrial structure through technological empowerment, improve the efficiency of resource allocation, and provide digital kinetic energy for green development; on the other hand, the green development stimulates the demand for the digital economy among enterprises and individuals, expands the application scenarios of the digital economy, enriches the business forms of the digital economy, and realizes a new momentum for the digital economy and environmental management. the industry of digital economy, and realizes the expansion of the scale of digital economy. Therefore, how to realize the integration of digital economy and green development has become an important issue at present. Therefore, the article takes Guangdong Province as an example, clarifies the internal logical connection between digital economy and green development, analyzes the coupled and coordinated relationship between digital economy and green development, and has important theoretical and practical significance for realizing the benign interaction between digital economy and green development.

2. Lierature Reviewt

Research on digital economy. Scholars mainly focus on the following aspects: first, the concept and characteristics of the digital economy, different research scholars have defined the concept and characteristics of the digital economy from a variety of perspectives. The digital economy is an economic activity that takes digitized information (including data elements) as the key resource, uses modern information networks as the carrier, is driven by digital technological innovation as the traction, and manifests itself in a series of new modes and business forms [1], on the basis of combing through the connotations of previous scholars' definitions related to the digital economy, summarizes and summarizes the four major endogenous characteristics of the digital economy. They are: the non-competitive nature of

information products, the zeroing of the marginal cost of information, the online absence of digital markets, and the emergence of big data as a key input. The second is the measurement aspect of the development level of digital economy. Academic research on the measurement of the level of digital economic development is quite a lot, mainly from the national and regional levels, [3] constructed the evaluation index system of the level of digital economic development from the three dimensions of digital infrastructure, digital industry development and digital economic environment. Third, the research aspect of the economic and social economic effects of the digital economy. Scholars mainly study the impact of the digital economy on economic growth, industrial structure upgrading and other aspects. [4] The development of the digital economy mainly empowers the high-quality development of the economy by enhancing the quality of the entire supply system and improving total factor productivity. [5] studied the effect and internal mechanism of digital economy development on industrial structure upgrading through instrumental variable method, double difference method, mediation effect model, etc., and found that the development of digital economy has a positive role in promoting industrial structure upgrading.

Relevant research on green development. It mainly focuses on the internal logic, influencing factors and indicator measurement of green development. First, the internal logic of green development, scholars explain the connotation concept and logic of green high-quality development, and sort out the problems in the process of green development [6, 7]. Second, the influencing factors of green development, scholars have mainly discussed green development from two perspectives: economic transformation and environmental factors. Under the perspective of economic transformation, fiscal decentralization and environmental regulation have the role of promoting green development in regions with green total factor productivity growth [8], and factors such as R&D investment, foreign direct investment, financial development, and industrial structure are conducive to promoting the upgrading of industrial structure, enhancing regional economic efficiency and thus promoting green development [9]. Under the perspective of environmental factors, energy efficiency plays a positive role in promoting regional green development, and regional temperature, vegetation cover and other conditions affect the level of green development [10, 11] Third, the green development level measurement aspect. [12] constructed a three-stage DEA model to measure the dynamic efficiency of urban green development, and introduced labor, capital, energy, land and water resources as input variables into the index system. [13] consider the green development efficiency of non-desired outputs to characterize the level of urban green development, focusing mainly on the green development status of resource-based cities in the Yellow River Basin.

Regarding the related research on the impact of digital economy on green development, the development of digital economy has penetrated into all segments and stages, and scholars have carried out more extensive research on the impact of digital economy on regional innovation capacity, industrial structure optimization, and high-quality development of the economy, etc. However, as a kind of convergent economy, the driving role of digital economy on green development cannot be ignored. Most scholars explore the impact of digital economy development on it in terms of green low-carbon, high-quality development, industrial structure transformation, green economic performance, and green total factor productivity [14-16], or they use dynamic and static spatial Durbin models, double-difference methods, coupled coordination, and super-efficient SBM to explore the digital economy development impact on it [17-19].

By combing through the existing literature, it can be seen that scholars have conducted relatively comprehensive studies on the impact of digital economy on green development and the measurement of the level indicators of the two, but the research on the interaction between the two still needs to be expanded and deepened. First, the relationship between digital economy and green development is not only a single functional relationship, clarifying the interactive relationship between the two will provide useful reference for the development of economic quality. Second, Guangdong, as the front-runner of China's digital economy and green development, has typical representativeness as the research object, and can provide reference for the Guangdong-Hong Kong-Macao Greater Bay Area and China's digital economy and green development. Therefore, based on the above analysis, the article takes Guangdong Province as an example to deeply explore the dynamic evolution process of the coupled and coordinated relationship between digital economy and green development, with a view to providing reference for the high-quality development of China's economy.

3. Research Design

3.1. Indicator Construction

The level of digital economy and green development is affected by many factors, drawing on the concept of indicator selection in existing studies [20-22], combining with the actual development of Guangdong Province, and taking into account the principles of indicator selection such as systematicness, comprehensiveness, scientificity, and accessibility, we constructed the evaluation index system of the digital economy and green development as shown in Table 1. For the digital economy evaluation index system, based on the two dimensions of digital industrialization and industrial digitization, five sub-indicators are selected for evaluation; for the green development evaluation index system, from the three dimensions of green production, green life, green governance, a total of six indicators are selected for evaluation.

Table 1. Digital economy and green development indicator system

Index system	First-order index	Secondary index	Attribute
The digital economy	Internet penetration	Internet users per 100 population	+
	Number of Internet-related workers	Percentage of employees in computer services and software	+
	Internet-related outputs	Total telecommunication services per capita	+
	Number of mobile Internet users	Cell phone subscribers per 100 population	+
	Digital Finance for Inclusive Development	China Digital Inclusive Finance Index	+
Green development	Green production	Industrial sulfur dioxide emissions per unit of GDP (t/million yuan)	-
		Growth rate of energy consumption per unit of GDP (%)	+
	Green Living	Greening coverage of built-up areas (%)	+
		Green space per capita (square meters per person)	+
	Green governance	Municipal sewage treatment rate (%)	+
		Rate of harmless treatment of municipal domestic waste (%)	+

3.2. Data Sources

This article takes 21 prefecture-level cities in Guangdong Province as the research object to explore the relationship between digital economy and green development. According to the availability of data, the time span of the study is selected as 2012-2022. The raw data for all the evaluation indicators of digital economy and green development are mainly from China Environmental Statistics Yearbook, China Urban Statistics Yearbook, China Energy Statistics Yearbook, Guangdong Statistics Yearbook, as well as the statistical yearbooks and bulletins of each prefectural-level city. The data of some cities are missing in some years, and the interpolation method is used to complete the data. The interpolation method was used to complete the data.

3.3. Research Methods

3.3.1. Entropy value method

Due to the differences in dimensions and units of measurement between the data of the indicators, the data of the indicators are standardized in order to eliminate the influence of the scale and ensure the accuracy of the indicators:

$$\text{Positive index: } X'_{ij} = \frac{X_{ij} - X_{j\min}}{X_{j\max} - X_{j\min}}$$

$$\text{Negative index: } Y'_{ij} = \frac{X_{j\max} - X_{ij}}{X_{j\max} - X_{j\min}}$$

Where X'_{ij} and Y'_{ij} denotes normalized values; X_{ij} denotes the raw values of the indicator; and X_{jmax} and X_{jmin} denotes the maximum and minimum values of the raw data of the indicator during the evaluation period.

3.3.2. Coupling coordination degree model

Since the traditional coupling coordination degree model C value will be unevenly distributed, which will lead to a reduction in the effectiveness of the results, this paper draws on the research method of Wang Shujia et al. (2021) to construct the following coupling coordination degree model:

$$C = \left\{ \frac{U_1 * U_2}{\left[\frac{U_1 * U_2}{2} \right]^2} \right\}^{\frac{1}{2}}$$

$$T = \alpha_1 U_1 + \beta U_2$$

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

Where U1, U2 refers to the comprehensive level of digital economy and green development respectively; C is the degree of coupling, D is the degree of coupling coordination, the two take the value of the range of (0, 1), in which the larger D is, indicating that the development trend of the coordination of the two is good; T is the comprehensive coordination index of the two; α and β are the coefficients of the weights to be determined and α + β = 1, taking into account that the two subsystems are of equal importance, it is taken that α = β = 0.5. Further referring to the study of [23], the coupling coordination degree is categorized into the following grades, as shown in Table 2.

Table 2. Criteria for classifying the degree of coupling coordination

Level of coordination	Degree of coupling coordination	Stage of coupling coordination
1	[0,0.15]	Serious dissonance
2	[0.15,0.25]	Moderate dissonance
3	[0.25,0.45]	Slight dissonance
4	[0.45,0.55]	Dissonance-harmonization transition phase
5	[0.55,75]	Junior coordination
6	[0.75,0.85]	Good coordination
7	[0.85,1]	Highly coordinated

4. Empirical Analysis

4.1. Analysis of Digital Economy and Green Development Level

The entropy method is used to calculate the comprehensive level index of digital economy and green development of 21 prefecture-level cities in Guangdong Province, which is shown in Table 3.

Table 3. Comprehensive level of digital economy development in Guangdong Province

Province	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean
Shenzhen	0.526	0.470	0.685	0.687	0.686	0.629	0.792	0.738	0.739	0.860	0.948	0.706
Guangzhou	0.523	0.522	0.581	0.596	0.752	0.740	0.701	0.698	0.846	0.788	0.826	0.688
Maoming	0.088	0.079	0.051	0.240	0.229	0.162	0.239	0.229	0.321	0.271	0.369	0.207
Shaoguan	0.143	0.143	0.155	0.119	0.198	0.256	0.229	0.185	0.285	0.233	0.312	0.205
Yunfu	0.051	0.076	0.175	0.137	0.124	0.206	0.328	0.203	0.308	0.271	0.364	0.204
Dongguan	0.038	0.132	0.138	0.204	0.245	0.203	0.219	0.237	0.246	0.224	0.329	0.201
Foshan	0.077	0.090	0.199	0.161	0.224	0.185	0.195	0.284	0.159	0.237	0.321	0.194
Jiangmen	0.083	0.046	0.154	0.119	0.187	0.206	0.142	0.273	0.236	0.311	0.367	0.193
Zhuhai	0.091	0.088	0.167	0.131	0.201	0.192	0.294	0.250	0.186	0.237	0.255	0.190
Zhanjiang	0.117	0.094	0.086	0.227	0.282	0.188	0.202	0.181	0.216	0.281	0.208	0.189
Chaozhou	0.071	0.103	0.191	0.137	0.144	0.117	0.163	0.235	0.305	0.329	0.271	0.188
Zhaoqing	0.094	0.071	0.126	0.112	0.233	0.226	0.206	0.218	0.209	0.318	0.221	0.185
Huizhou	0.074	0.103	0.206	0.189	0.215	0.115	0.174	0.189	0.277	0.236	0.238	0.183
Shanwei	0.061	0.103	0.129	0.116	0.106	0.216	0.265	0.292	0.195	0.329	0.206	0.183
Shantou	0.067	0.116	0.183	0.181	0.090	0.207	0.176	0.262	0.202	0.192	0.324	0.182
Qingyuan	0.052	0.048	0.093	0.237	0.142	0.246	0.207	0.218	0.187	0.258	0.279	0.179
Zhongshan	0.093	0.027	0.099	0.176	0.179	0.164	0.231	0.162	0.208	0.301	0.256	0.172
Heyuan	0.046	0.111	0.132	0.110	0.123	0.163	0.204	0.234	0.281	0.188	0.295	0.172
Jieyang	0.035	0.075	0.105	0.160	0.211	0.187	0.147	0.252	0.194	0.227	0.258	0.168
Meizhou	0.054	0.073	0.165	0.098	0.172	0.133	0.142	0.214	0.179	0.313	0.282	0.166
Yangjiang	0.043	0.020	0.093	0.120	0.150	0.161	0.128	0.239	0.213	0.239	0.265	0.152
Mean	0.116	0.123	0.186	0.203	0.233	0.234	0.256	0.276	0.285	0.316	0.343	

As can be seen from Table 1, the overall level of digital economy development in Guangdong Province from 2012 to 2022 shows a rising trend year by year, with the average index rising from 0.116 to 0.343, an average increase of 1.97 times during the 11-year period, and the scale of digital economy development has increased, with significant effects, realizing a substantial improvement. In terms of urban space, the development of digital economy within Guangdong Province is uneven, and there is a large gap between regions. Shenzhen and Guangzhou's digital economy development level is significantly ahead of other cities' digital economy development level, and the average index of Shenzhen and Guangzhou's digital economy development level in 2022 will be 0.706 and 0.689. This is mainly because Guangzhou and Shenzhen, as the two core-level cities in Guangdong Province, have a unique geographic location and superior policy environment. Specifically, Guangzhou and Shenzhen have attracted many high-tech enterprises, and the open and superior market environment has laid a good foundation for the transformation of digital economy achievements. Secondly, the many high-tech enterprises in Guangzhou and Shenzhen have attracted many digital talents, providing a source of living water for the development of digital economy. Maoming, Shaoguan, Yunfu, Dongguan, four cities of the digital economy development level is relatively close to the level of 0.20 or so. In particular, Dongguan's digital economy has developed rapidly, jumping from 0.038 to 0.2 in 2012, which is the greatest progress in digital economic development strength among all cities.

According to Table 4, it can be seen that the green development index of Guangdong Province from 2012 to 2022 shows a rising trend, which indicates that the 21 prefecture-level cities in Guangdong Province have achieved some success in carrying out green transformation and development work, and the gap in the level of green development between cities is relatively small, but the overall trend of Zhuhai, Foshan, Dongguan, Huizhou and the three cities is flat, and the overall level of green development in 2022 will be 0.543, 0.531 , 0.514, 0.492, which is closely related to the leading industries and development strategies of the above cities. Among them, Foshan and Dongguan have an industrial pattern dominated by manufacturing and processing industries. Among them, the industrial pattern of Foshan and Dongguan, which is dominated by manufacturing and processing trade, inhibits the space for green development to a certain extent. Shaoguan and Qingyuan's relatively low level of green development is mainly due to the acceptance of a large number of heavy industries and high-energy-consuming production capacity transferred from the Pearl River Delta region, which has a certain inhibiting effect on green development.

Table 4. Comprehensive level of green development in Guangdong Province

Province	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean
Shenzhen	0.312	0.496	0.505	0.514	0.578	0.596	0.618	0.648	0.679	0.715	0.768	0.584
Guangzhou	0.282	0.438	0.478	0.556	0.588	0.626	0.646	0.652	0.678	0.689	0.690	0.575
Zhuhai	0.321	0.534	0.549	0.577	0.544	0.546	0.574	0.567	0.584	0.580	0.592	0.543
Foshan	0.355	0.412	0.509	0.529	0.542	0.550	0.566	0.579	0.585	0.593	0.616	0.531
Dongguan	0.421	0.399	0.408	0.480	0.551	0.566	0.568	0.522	0.535	0.568	0.635	0.514
Zhanjiang	0.360	0.423	0.438	0.442	0.731	0.539	0.490	0.519	0.549	0.581	0.580	0.514
Huizhou	0.390	0.424	0.456	0.462	0.501	0.501	0.608	0.521	0.537	0.514	0.500	0.492
Jiangmen	0.356	0.435	0.461	0.448	0.482	0.525	0.504	0.543	0.553	0.555	0.543	0.491
Yangjiang	0.410	0.373	0.347	0.379	0.489	0.488	0.532	0.605	0.583	0.535	0.629	0.488
Zhaoqing	0.376	0.466	0.468	0.452	0.466	0.538	0.500	0.519	0.543	0.465	0.528	0.484
Zhongshan	0.453	0.470	0.476	0.450	0.497	0.493	0.389	0.524	0.457	0.520	0.569	0.482
Meizhou	0.395	0.344	0.394	0.410	0.473	0.536	0.571	0.547	0.560	0.483	0.489	0.473
Heyuan	0.405	0.426	0.447	0.432	0.433	0.448	0.482	0.479	0.427	0.547	0.497	0.457
Shantou	0.355	0.391	0.398	0.423	0.459	0.453	0.477	0.484	0.506	0.521	0.503	0.452
Maoming	0.370	0.374	0.389	0.369	0.445	0.469	0.517	0.506	0.495	0.492	0.522	0.450
Yunfu	0.504	0.345	0.300	0.389	0.436	0.437	0.463	0.487	0.504	0.478	0.531	0.443
Shaoguan	0.303	0.336	0.361	0.366	0.430	0.508	0.501	0.530	0.498	0.480	0.522	0.440
Shanwei	0.405	0.368	0.431	0.459	0.414	0.403	0.441	0.463	0.496	0.450	0.503	0.439
Jieyang	0.493	0.298	0.313	0.306	0.405	0.491	0.421	0.471	0.480	0.521	0.589	0.435
Qingyuan	0.418	0.435	0.442	0.386	0.312	0.451	0.497	0.455	0.457	0.429	0.421	0.428
Chaozhou	0.463	0.417	0.329	0.326	0.347	0.377	0.418	0.413	0.487	0.504	0.505	0.417
Mean	0.388	0.410	0.424	0.436	0.482	0.502	0.513	0.525	0.533	0.534	0.559	

4.2. Analysis of Coupling Coordination Between Digital Economy and Green Development

Based on the coupling coordination degree model elaborated in the previous section, the coupling degree and the mean value of the coupling coordination degree of digital economy and green development of 21 prefecture-level cities in Guangdong Province are calculated. The results are shown in Tables 5 and 6:

Table 5. Coupling value of digital economy and green development in Guangdong Province.

Province	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean
Guangzhou	0.954	0.996	0.994	0.993	0.975	0.978	0.989	0.990	0.970	0.979	0.973	0.981
Shenzhen	0.967	1.000	0.988	0.990	0.988	0.993	0.973	0.979	0.976	0.968	0.934	0.978
Shaoguan	0.933	0.915	0.917	0.862	0.929	0.944	0.928	0.876	0.962	0.938	0.968	0.925
Chaozhou	0.678	0.796	0.964	0.913	0.910	0.851	0.899	0.962	0.973	0.978	0.954	0.898
Foshan	0.767	0.766	0.943	0.886	0.946	0.894	0.903	0.959	0.842	0.920	0.965	0.890
Yunfu	0.577	0.770	0.965	0.878	0.831	0.933	0.985	0.911	0.971	0.961	0.982	0.888
Maoming	0.789	0.759	0.640	0.977	0.947	0.874	0.930	0.926	0.977	0.957	0.985	0.887
Shantou	0.730	0.839	0.930	0.916	0.739	0.928	0.888	0.955	0.903	0.887	0.976	0.881
Shanwei	0.676	0.826	0.841	0.802	0.805	0.953	0.968	0.974	0.900	0.988	0.908	0.876
Dongguan	0.554	0.864	0.870	0.915	0.923	0.882	0.896	0.926	0.929	0.901	0.948	0.874
Zhanjiang	0.860	0.771	0.742	0.947	0.896	0.875	0.910	0.876	0.900	0.938	0.882	0.872
Huizhou	0.732	0.794	0.926	0.908	0.917	0.780	0.833	0.883	0.948	0.929	0.935	0.871
Zhaoqing	0.800	0.677	0.817	0.798	0.943	0.913	0.910	0.913	0.896	0.982	0.913	0.869
Qingyuan	0.626	0.600	0.757	0.971	0.927	0.956	0.911	0.936	0.908	0.968	0.979	0.867
Jieyang	0.496	0.803	0.868	0.949	0.949	0.894	0.876	0.953	0.906	0.919	0.921	0.867
Jiangmen	0.783	0.586	0.866	0.815	0.898	0.900	0.828	0.944	0.916	0.960	0.981	0.862
Zhuhai	0.829	0.698	0.846	0.777	0.888	0.878	0.947	0.922	0.856	0.907	0.917	0.860
Heyuan	0.603	0.811	0.840	0.805	0.831	0.885	0.914	0.939	0.979	0.873	0.967	0.859
Meizhou	0.653	0.761	0.913	0.789	0.884	0.799	0.798	0.899	0.857	0.977	0.963	0.845
Zhongshan	0.753	0.457	0.754	0.899	0.883	0.865	0.967	0.850	0.927	0.964	0.925	0.840
Yangjiang	0.588	0.443	0.816	0.854	0.848	0.864	0.791	0.901	0.885	0.924	0.913	0.802
Mean	0.731	0.759	0.867	0.888	0.898	0.897	0.907	0.927	0.923	0.944	0.947	

Table 6. Coupling harmonization degree value of digital economy and green development in Guangdong Province.

Province	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean
Guangzhou	0.954	0.996	0.994	0.993	0.975	0.978	0.989	0.990	0.970	0.979	0.973	0.981
Shenzhen	0.967	1.000	0.988	0.990	0.988	0.993	0.973	0.979	0.976	0.968	0.934	0.978
Shaoguan	0.933	0.915	0.917	0.862	0.929	0.944	0.928	0.876	0.962	0.938	0.968	0.925
Chaozhou	0.678	0.796	0.964	0.913	0.910	0.851	0.899	0.962	0.973	0.978	0.954	0.898
Foshan	0.767	0.766	0.943	0.886	0.946	0.894	0.903	0.959	0.842	0.920	0.965	0.890
Yunfu	0.577	0.770	0.965	0.878	0.831	0.933	0.985	0.911	0.971	0.961	0.982	0.888
Maoming	0.789	0.759	0.640	0.977	0.947	0.874	0.930	0.926	0.977	0.957	0.985	0.887
Shantou	0.730	0.839	0.930	0.916	0.739	0.928	0.888	0.955	0.903	0.887	0.976	0.881
Shanwei	0.676	0.826	0.841	0.802	0.805	0.953	0.968	0.974	0.900	0.988	0.908	0.876
Dongguan	0.554	0.864	0.870	0.915	0.923	0.882	0.896	0.926	0.929	0.901	0.948	0.874
Zhanjiang	0.860	0.771	0.742	0.947	0.896	0.875	0.910	0.876	0.900	0.938	0.882	0.872
Huizhou	0.732	0.794	0.926	0.908	0.917	0.780	0.833	0.883	0.948	0.929	0.935	0.871
Zhaoqing	0.800	0.677	0.817	0.798	0.943	0.913	0.910	0.913	0.896	0.982	0.913	0.869
Qingyuan	0.626	0.600	0.757	0.971	0.927	0.956	0.911	0.936	0.908	0.968	0.979	0.867
Jieyang	0.496	0.803	0.868	0.949	0.949	0.894	0.876	0.953	0.906	0.919	0.921	0.867
Jiangmen	0.783	0.586	0.866	0.815	0.898	0.900	0.828	0.944	0.916	0.960	0.981	0.862
Zhuhai	0.829	0.698	0.846	0.777	0.888	0.878	0.947	0.922	0.856	0.907	0.917	0.860
Heyuan	0.603	0.811	0.840	0.805	0.831	0.885	0.914	0.939	0.979	0.873	0.967	0.859
Meizhou	0.653	0.761	0.913	0.789	0.884	0.799	0.798	0.899	0.857	0.977	0.963	0.845
Zhongshan	0.753	0.457	0.754	0.899	0.883	0.865	0.967	0.850	0.927	0.964	0.925	0.840
Yangjiang	0.588	0.443	0.816	0.854	0.848	0.864	0.791	0.901	0.885	0.924	0.913	0.802
Mean	0.731	0.759	0.867	0.888	0.898	0.897	0.907	0.927	0.923	0.944	0.947	

As shown in Table 5, the mean value of the coupling degree and the mean value of the coupling coordination degree of the digital economy and green development of 21 cities in Guangdong Province in 2012-2022 show an upward trend, and the mean value of the coupling degree grows from 0.731 to 0.947, which indicates that the tightness of the interconnection and interaction between the digital economy and the green development has been enhanced. The mean value of the coupling coordination degree increased from 0.427 to 0.641, an increase of 50.11%, indicating a good trend of coordinated development of the two systems. However, in terms of the current degree of coupling coordination, Guangdong Province is still far from realizing a high level of coupling coordination. Specifically, the coupling coordination degree of the region was mildly dysfunctional during 2012-2013, and the average value of annual coupling coordination degree increased to 0.525 in 2014-2015, entering the dysfunctional-coordinated transition stage. The reason for this is that the early manufacturing industry adopted a rough development mode, which made the environment damaged by pollution. As one of the pillar industries in Guangdong Province, the manufacturing industry is in the green transition period, but the implementation of green development policies is insufficient and the digital economy infrastructure is poor, resulting in a dislocation-coordination transition state. The average value of the coupling coordination degree exceeds 0.55 mainly from 2016, starting to enter the primary coordination stage.

Overall, in recent years, the digital economy of Guangdong Province has been developing rapidly, and the enhancement of the strength of the development of the digital economy drives the enhancement of the level of green development, and in turn, the enhancement of the level of green development helps the enhancement of the strength of the digital economy, and the two promote each other and develop together, and the digital economy and the green development of Guangdong Province are gradually showing a coordinated development trend.

Table 6 shows that the coupling degree of 21 cities in Guangdong Province from 2012 to 2022 shows an overall fluctuating upward trend. Shaoguan, Zhuhai and some other cities show a “U” - shaped development trend, and the development trend is relatively slow in 2013-2016.After 2016, the coupling degree accelerates, and the coupling trend becomes better year by year. In 2019, all the cities reach the highly coupled stage, which indicates that with the development of the time series, the digital economy system and the green development system within each city system begin to promote and check each other. The main reason for this is that Guangdong Province is committed to accelerating the development of high-tech industries and strategic emerging industries, and many major scientific and technological achievements have reached the world's advanced level. In terms of green development, cities have actively responded to policy requirements, continued to reduce the emission of major pollutants, significantly improved the level of energy conservation and environmental protection, and made new progress in promoting the construction of an ecological civilization, thus making a positive contribution to the digital economy and green development.

Further analyzing the coupling and coordination degree of digital economy and green development in Guangdong, the coupling and coordination degree of digital economy and green development in 21 cities in Guangdong Province shows an imbalanced pattern of “high in the middle - high at the edge”, but the overall trend is good. Specifically, “Guangzhou-Shenzhen” has become the key core circle of the coupled development of the two systems in the province, and the coupling degree of coordination is over 0.75, which is in the stage of good coupling coordination. This is closely related to its superior geographical location, rich resources, diversified industrial structure, convenient transportation and policy support. Under the radiation drive of the core city, the economic interaction of neighboring cities is enhanced, and the spillover effect is obvious. Dongguan, Zhuhai, Zhanjiang

coupling coordination degree value are more than 0.55, in the basic coupling coordination stage. Zhongshan, Huizhou, Jiangmen, Shaoguan, Qingyuan, Zhaoqing, Jieyang, Shanwei and other 16 cities have also entered the dysfunctional-coordinated transition stage coupling stage, mainly because on the one hand due to geographic location, transportation accessibility is low, the attraction of technical talent and foreign enterprises is weak, the development of the digital economy is relatively slow, and these areas rely on resource-consuming industries, green weaknesses are prominent, industrial ecology is still to be improvement; on the other hand, these regions, as green ecological barriers, can realize a good interaction between digital economy and green development through the implementation of digital economy and green development policies, improving the efficiency of resource utilization, and the spillover effect of core cities.

5. Conclusions and Recommendations

This paper constructs an evaluation index system for digital economy and green development, and measures and analyzes the comprehensive development level of digital economy and green development of 21 cities and municipalities in Guangdong Province from 2012-2022 from both temporal and spatial perspectives. This paper also reveals the temporal and spatial evolution characteristics of the coupling degree and coupling coordination degree of the two systems. The results show that: 1) Characteristics of the comprehensive development level: there is a big gap between the development level of digital economy and green development level of each city, and the development level of digital economy in Shenzhen and Guangzhou is far ahead of their green development level. The digital economy development level of all other cities lags behind the green development level, showing obvious regional differences. 2) Coupling characteristics: the coupling degree of digital economy and green development in each city can be roughly divided into two stages: a stable development stage before 2016 and an accelerated development stage after 2016, with the coupling degree increasing year by year, indicating that the functions of the two systems within the city are deepening.3) Coordination characteristics: the coupling degree of digital economy and green development in each city shows " high in the middle - low at the edge". The coupling degree of digital economy and green development of each city shows the unbalanced pattern of "high in the middle - low at the edge", and "Guangzhou, Shenzhen, Zhuhai and Dongguan" has become the core circle of the coupling development of the two systems in the province. From 2012 to 22 years, the D value of the degree of coordination between digital economy and green development of each city showed an upward trend, showing a good development trend. The D-value of "Guangzhou-Shenzhen" exceeds 0.7, which is in a good state of coordination. Dongguan, Zhuhai, Zhanjiang coupling degree of coordination value of more than 0.55, in the basic coupling coordination stage. The other cities are in the dysfunctional-coordination stage.

Based on the above findings, this paper puts forward the following policy recommendations:

(1) Given the significant differences between cities in the degree of coupling between digital economy and green development and their coordination levels, cities should comprehensively assess their own strengths and weaknesses, adopt a comprehensive planning, scientific layout, and localized approach, and implement differentiated development strategies with regional characteristics. Focus on strengthening the leading role of Guangzhou, Shenzhen and the Pearl River Delta (PRD) city clusters, and fully utilize the leading position of these cities in the digital economy and green development. By strengthening cooperation and exchanges with other cities, it can drive the development of neighboring cities, narrow the digital divide in the region, and effectively exert its spatial spillover effect.

(2) For regions such as eastern Guangdong, western Guangdong and northern Guangdong, the foundation of the digital economy in these places is relatively weak and traditional industries dominate. Therefore, the government needs to provide specific policy support for the digital economy and green development in these regions. It should actively guide enterprises to adopt digital technologies and carry out multifaceted, chain-wide transformation and upgrading of their traditional businesses, so as to facilitate their digital and intelligent transformation. In addition, the Government needs to encourage enterprises to adopt the concepts of green production, green manufacturing and green consumption, so as to turn green development into spontaneous actions and long-term strategies for enterprises. Through these measures, the optimization of the economic structure of these regions can be promoted and sustainable development can be achieved.

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References

[1] CHEN Xiaohong, LI Yangyang, SONG Lijie, et al. Theoretical system and research outlook of digital economy. Management World, 2022, Vol.38(02), p.208-224+13-16.

[2] Zhang Wenkui. Endogenous characteristics and industrial organization of digital economy. Management World, 2022, Vol.38(07), p.79-90.

[3] HE Di, ZHAO Xianzhuo, QI Qi. A study on the measurement of the development level of China's digital economy, spatio-temporal pattern and regional differences. Industrial Technology and Economics,2023,Vol.42(03),p.54-62.

[4] Ren Baoping. Research on Modernized Governance System of Digital Economy Enabling High-Quality Development. Academia, 2022, (12), p.24-30.

[5] Jiao Shuaitao, Sun Qiubi. Mechanism of linkage between digital economy development and consumption upgrading and its empirical research. Industrial Technology and Economics, 2021, Vol.40(12), p.84-93.

[6] WANG Dan, GONG Xiaoying. Digital technology boosting green high-quality development-theoretical interpretation and practical path. Technical Economics and Management Research, 2024, (07), p.14-17.

[7] WEI Lili, HOU Yuqi. Digital Economy Enabling Green Development, p. Theoretical Change, Internal Logic and Realization Path. Journal of Shaanxi Normal University (Philosophy and Social Science Edition), 2023, Vol.52(03), p.94-106.

[8] ZHU Ruirui, WANG Keliang, ZHANG Fuqin. FDI, fiscal pressure and green total factor productivity. Resources and Industry, 2023, Vol.25(06), p.77-90.

[9] HU Ridong, TANG Jinfeng, SONG Hongyan. Environmental regulation, green technology innovation and green total factor productivity in manufacturing industry. Industrial Technology and Economics, 2023, Vol.42(07), p.113-122.

[10] ZHANG Xiaoyu, LU Hanglin, ZHENG Pengfei. Measurement and trend analysis of energy utilization efficiency in the Yellow River Basin under the perspective of green development--Based on the study of convergence and spatial dynamic evolution. Journal of Henan Normal University (Natural Science Edition), 2023, Vol.51(02), p.45-55.

[11] Di Yaxiao, Li Xiaoxing, Zhang Ge, et al. Exploring the use of sensory image data regulation to promote high-quality green and low-carbon development mode under the goal of "dual carbon". Environmental Engineering, 2023, Vol.41(S2), p.924-926+936.

[12] Fu Jinpeng. Spatial agglomeration and the efficiency of urban green development-an empirical analysis based on Liaoning Province and Jiangsu Province. Urban Issues, 2022, (08), p.62-72.

[13] Yue L, Yan Huizhen. Impact of technological progress on green development of resource-oriented cities in the Yellow River Basin. Science Research, 2023, Vol.41(09), p.1615-1626+1637.

[14] Eddie Zhuang, Ziwei Wu. Digital Economy Enabling Green Development in the Yangtze River Economic Belt, p. Mechanisms, Heterogeneity and Strategies. Regional Economic Review, 2024, (04), p.85-93.

[15] CAI Lihui, SUN Lingyu, GAO Ziwang, et al. Multidimensional impact of digital economy on urban green development. Statistics and Decision Making, 2024, Vol.40(10), p.106-111.

[16] YU Luyao, ZHOU Tao, GAO Yang. Digital economy, green technology innovation and urban green development efficiency - an analysis based on spatial correlation perspective. Industrial Technology and Economics, 2023, Vol.42(12), p.65-73.

[17] Cai Chengzhi, Zhang Lin. Spatial spillover effects of the impact of digital economy on China's agricultural green development-an analysis based on static and dynamic spatial Durbin models. Ecological Economy, 2024, Vol.40(06), p.108-116.

[18] TIAN Ze, ZHANG Hanqi, XU Xingwu, et al. Study on carbon emission effects and influencing factors of digital economy for urban green development. Industrial Technology and Economics, 2024, Vol.43(07), p.70-80.

[19] JI Xinlong, LIU Qin. Spatio-temporal evolution and obstacle degree analysis of coupled coordination of digital economy and green development. East China Economic Management, 2024, Vol.38(07), p.77-90.

[20] ZHAO Tao, ZHANG Zhi, LIANG Shangkun. Digital Economy, Entrepreneurial Activity and High-Quality Development-Empirical Evidence from Chinese Cities. Management World, 2020, Vol.36(10), p.65-76.

[21] ZHU Help, ZHANG Mengfan. Construction and empirical evidence of green development evaluation index system. Statistics and Decision Making, 2019, Vol.35(17), p.36-39.

[22] WANG Yong, LI Haiying, YU Hai. Spatial pattern of green development in Chinese provinces and its evolution characteristics. China Population-Resources and Environment, 2018, Vol.28(10), p.96-104.

[23] LI Dapeng, XIA Antao. Spatio-temporal characteristics and influencing factors of coupled coordination of science and technology innovation and green development in Hunan. Journal of Central South Forestry University of Science and Technology (Social Science Edition), 2020, Vol.14(06), p.50-56+65.