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Analysis of Regional Carbon Emission Decoupling Coupling in China Based on ArcGIS Analysis-Empirical Evidence From Urban-Rural Integration in Fujian Province

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China's ambitious measures for developing a low-carbon economy led to the "double carbon" target initiation. Under this national goal, reaching peak carbon emissions by 2030 is desired. This should not come at the cost of economic growth; which means carbon emissions can be reduced while economic growth can be achieved simultaneously. To realise this strategic reform, the first pilot ecological civilisation zone in Fujian Province of China was initiated; its outcome is set to be the responsible case for such initiations aiming at increased low-carbon economy development. Therefore, it is essential to investigate the relationship between carbon emissions and economic growth based on the evidence. Hence, we applied a model that combines the Tapio and Coupled coordination. Combining the Tapio and the coupled coordination models allows us to analyse carbon emissions and economic growth in Fujian Province over 20 years, i.e., 2001–2020. First, we divided the urban-rural integration process into four stages following China's Five-Year Plan (FYP): T1 (2001–2005), T2 (2006–2010), T3 (2011–2015), and T4 (2016–2020). Second, ArcGIS mapping was used to represent the spatial evolution pattern of low-carbon economic development in Fujian Province. We observed that the low-carbon economy in Fujian Province had reached a point where the economic growth rate has already exceeded its carbon emission growth rate and is currently in a weak decoupling state. In addition, there observed a bifurcation pattern between carbon emissions and economic growth, especially in the coastal cities that are out of balance, whereas the inland cities are being coordinated. Overall, it is observed that the concept of ecological civilisation is crucial for China to achieve the "double carbon goal," and it is high time to create accelerating measures that guide the integration of urban and rural areas in the future with appropriate infrastructure.

Keywords: China, Fujian; carbon emissions, urban-rural integration, decoupling model, coupled coordination model

1 INTRODUCTION

1.1 Background

In the ninth meeting of the 2021s Central Finance and Economics Commission, China proposed incorporating "carbon neutrality and carbon peaking" measures as part of the overarching design of ecological civilisation (Wang et al., 2021). This incorporation insists on reducing carbon emissions and following a path of low-carbon sustainable development (Wang et al., 2021). But there lies the biggest macroscopic challenge as China's economy continues to develop at high speed. On the other side, the energy demand for the "high carbon" structure has not yet reached saturation. On top of it, the phenomenon of industrial and urban-rural incoordination in economic development is highly seen. So, all these issues collectively made the carbon emission reduction task a more challenging one. The concept of urban-rural integration has been around since the last century. China released the Blue Book on Urban-Rural Integration, in which the achievements of the integration process have been summarised and discussed from the perspective of urban-rural planning, industrial layout, infrastructure development (primarily the critical services like energy, healthcare, road etc.) and public services (Baoxin et al., 2019). Also, the new development path of "four synchronisations" (industrialisation, informatisation, urbanisation, and agricultural modernisation) heavily dependent on energy is discussed. So, the aim was to integrate the urban and rural areas to promote economic, environmental, and urban-rural development in coordination. However, in such complex approaches, understanding the synergies would be better. Therefore, the critical issue is the relationship between carbon emissions and economic growth as well as urban-rural integration. At the same time, exploring synergistic ways to promote high-level economic development and an ecological environment are also crucial, especially when implementing the new development concept in line with sustainable economic principles.

1.2 Literature Review

To understand the problem's complex nature, we conducted a literature survey on the four aspects that are deemed necessary for the investigated concept. These four include the relationship between carbon emissions and economic growth, decoupling analysis, the impact of energy infrastructure on carbon emissions, and urbanisation on carbon emissions.

1.2.1 The Relationship Between Carbon Emissions and Economic Growth

When we looked at the literature exploring the relationship between carbon emissions and economic growth, there has been considerable research on China's and China's contiguous regions, such as the Jin-Shaan-Menggu region 2), the Yellow River basin region 3), and the Yangtze River economic belt 4). All the studies by (Wu et al., 2019; Mo and Wang., 2021; Tian and Lin., 2021) have concluded that the relationship between the two gradually tends toward low-carbon economic development, providing a scientific theoretical basis for adopting emission reduction measures to reach the peak in each region. In another study, Zhao et al. (2022) argued that carbon emissions and economic growth are closely related and generally do not cross over in the long run; this view was also supported by (Myszczyszyn and Suproń, 2021) study of carbon emissions and economic growth in V4 countries (namely Czech Republic, Hungary, Poland, and Slovakia). However, there is still a degree of dependence of economic growth on carbon emissions.

1.2.2 Decoupling Analysis of Carbon Emissions

Peng et al. (2011) looked at the spatial and temporal decoupling of China's economic growth and carbon emissions at the national and regional levels. They concluded that China would remain in a weak state of decoupling for a long time, and low-carbon emission reduction technology has yet to impact the economy as a whole practically (Peng et al., 2011). Wang B et al. (2021) used the Mann-Kendall (MK) trend test to identify the characteristics of China's provincial carbon emissions from 2000 to 2018 and classified them into high and low types. Also, their empirical study showed that China's carbon emissions generally showed a spatial pattern of "high in the east, low in the west, high in the north and low in the south" (Wang et al., 2021). From the perspective of counties, Ji and Xue., 2022 investigated the decoupling of carbon emissions in Jiangsu Province, China, and concluded that economic growth and carbon emission reduction did not always happen at the same time. However, the decoupling effect of carbon emissions in counties gradually increased over time Ji and Xue., 2022. Liu et al. (2021), enriched Energy-Economy-Environment (3E) system theory. They then analysed the coupling relationship of carbon emission reduction and economic growth and environmental protection with China's national conditions after clarifying the coupling mechanism of carbon emission reduction-economic growth-environmental protection in provincial areas. Based on clarifying the coupling mechanism, Liu et al. (2021) assessed the degree to which carbon emission reduction, economic growth, and environmental protection are coupled and coordinated in the Chinese provinces. Also, the coupling and coordinated comprehensive evaluation index system of "provincial carbon emission-economic growth-environmental protection" was constructed and found that the degree of coupling and coordination of the 3E system is "high in the southeast and low in the middle and west" (Liu et al., 2021).

1.2.3 Impact of Energy Infrastructure on Carbon Emissions

Usman et al. (2021) looked at the 15 highest carbon-emitting countries from the context of economic inclusion over renewable and non-renewable energy projects. In the analysis, Usman et al. (2021) observed a strong dependency on the cross-sectors; then, only such projects will help in reducing environmental degradation and boost economic growth. Usman and Makhdum., 2021, in another study, investigated taking the data from the year 1990–2018 and observed a dynamic linkage between ecological footprint, agriculture value-added, forest area, non-renewable and renewable energy use, and financial development in BRICS-T countries (Brazil, Russia, India, China, South Africa, and Turkey). Likewise, Balsalobre-Lorente et al. (2022) investigated the relationship between economic complexity and environmental degradation in the countries of the PIIGS (Portugal, Ireland, Italy, Greece, and Spain). They found a unidirectional causality link between the energy infrastructure and the amount of emission mitigated. Huang et al., 2022 investigated the moderating effect of ICT and renewable energy and human capital in E-7 (developing countries) and G-7 (developed countries). The observed effect was significantly positive, highlighting a high chance of reducing ecological footprint levels in E-7 and G-7 countries due to this moderating effect.

1.2.4 Impact of Urbanisation on Carbon Emissions

The urbanisation process will inevitably have an impact on increasing the use of energy, resulting in the emission of large amounts of greenhouse gases such as CO_2 (Haouraji et al., 2021; Mata et al., 2021; Pang et al., 2021). Ding et al. (2021) analysed the impact of 182 prefecture-level cities in China on carbon emissions during rapid urbanisation. They found that urban construction increases the growth of carbon emissions (Ding et al., 2021). Liu et al. (2022) found that under China's new urbanisation scenario, the population-land-economic urbanisation (PLEU) coupling coordination degree has an inverted U-shaped effect on carbon emissions and gradually tends to decrease as the PLEU coupling coordination degree is high to a certain degree (Liu et al., 2022). In their study of 283 cities in China, Zhou et al. (2021) evaluated the impact of multidimensional urbanisation on carbon emissions efficiency, finding that multidimensional urbanisation exhibits spatial heterogeneity characteristics for carbon emissions efficiency and carbon emission efficiency is gradually enhanced through the process of multidimensional urbanization. Xiao, (2012) used factor analysis to measure rural carbon emissions in Hubei Province in the process of urban-rural integration and concluded that urban-rural integration is positively related to rural carbon emissions. Shi et al. (2021) used the Epsilon Based Measure (EBM) super-efficiency model, kernel density estimation, and Global Malmquist-Luenberge (GML) index analysis to study the efficiency of urban-rural integration development in the Yangtze River Delta and its dynamic evolution characteristics. They concluded that economically developed areas of the Yangtze River Delta have lower efficiency of urban-rural integration than economically less developed areas, the polarisation of urban-rural integration development has serious consequences, and redundancy of carbon emissions negatively affect urban-rural integration development (Shi et al., 2021).

Based on the literature review carried out in the above paragraphs, it can be understood that the current studies on the Spatio-temporal coupling relationship between carbon emissions and economic growth are mostly focused on large regions such as national provinces or regional integration. In contrast, the studies on the relationship between urban-rural integration and carbon emissions and economic development, the impact of "four synchronisations," and energy infrastructure are diverse. Their general laws and policy inspirations on carbon emissions and economic growth are more macroscopic, which may not lead to an effective decision. For the diversified characteristics of economic development in provincial areas, especially in distinct regions at the prefecture level, further research is needed on micro-level comparisons.

Therefore, this paper pays special attention to integrating low-carbon transition into the whole process of national economic development requirements, followed by analysing the changes in carbon emissions during different economic development stages in the urban-rural integration process. To realise this strategic reform, the first pilot ecological civilisation zone in Fujian Province of China was analysed as the responsible case aiming to increase low-carbon economy development. We applied the Tapio decoupling model and the coupled coordination model to study the data of Fujian Province and nine prefectures in Fujian Province. ArcGIS method was used to describe the decoupling relationship and spatial-temporal coupling evolution characteristics between carbon emissions and economic growth in Fujian Province to provide a scientific basis and policy inspiration for the smooth promotion of carbon emission reduction in Fujian Province.

The manuscript is structured in five sections; **Section 2** discusses the data collection and methods considered for the analysis. In **section 3**, results are presented and discussed. **Section 4** presented the policy insights, followed by conclusions in **section 5**.

2 DATA COLLECTION AND METHODS

2.1 Data Collection

Carbon emissions and gross domestic product (GDP) are the two key data needed for the investigation. The required data on carbon emissions is collected using the China Carbon Accounting Database (https://www.ceads.net.cn). However, we noticed some missing data; for which we used an approach to estimate the reduction target of carbon emissions intensity based on the 13th 5-year plan of Fujian Province. As we all know, the economic growth is expressed by the GDP; hence the GDP values of prefecture-level cities in Fujian Province over the years. The GDP data are all from the 2002 to 2021 Fujian Statistical Yearbook and the statistical yearbooks of prefecture-level cities to avoid the impact of inflation caused by price fluctuations. The real GDP of each region is converted from the nominal GDP of 2001–2020 to the constant price GDP of 2020, with 2001 as the base period. At the same time, given the lag between carbon emissions and economic growth, ensuring authenticity was critical (Wu et al., 2019). To ensure the authenticity of the Spatio-temporal coupling relationship, this paper took 5 years as a stage [divided into four periods: $T_{1\ (2001–2005)}$, $T_{2\ (2006–2010)}$, $T_{3\ (2011–2015)}$, and $T_{4\ (2016–2020)}$].

Each period also coincides with the national 5-year plan period. This model enables us to examine the decoupling relationship between greenhouse gas emissions and economic growth at different stages of economic development, both by examining the decoupling relationship and the Spatio-temporal relationship.

TABLE 1 | Decoupling elasticity and degree.

Category	Degree of decoupling	△C	△G	Unhooking elasticity
Decoupling	Strong decoupling	<0	>0	E < 0
	Weak decoupling	>0	>0	0 ≤ E < 0.8
	Decline decoupling	<0	<0	E > 1.2
Connect	Expansion link	>0	>0	0.8 ≤ E ≤ 1.2
	Recession link	<0	<0	0.8 ≤ E ≤ 1.2
Negative decoupling	Dilated negative decoupling	>0	>0	E > 1.2
	Weak negative decoupling	<0	<0	0 ≤ E < 0.8
	Strong negative decoupling	>0	<0	E < 0

TABLE 2 | Coupling coordination value and grade division.

Coupling coordination value interval	Level	Degree of coupling coordination
(0.0~0.1)	1	Extremely maladjusted
[0.1~0.2)	2	Severe maladjustment
[0.2~0.3)	3	Moderate disorder
[0.3~0.4)	4	Mild disorder
[0.4~0.5)	5	On the verge of disorder
[0.5~0.6)	6	Barely coordinated
[0.6~0.7)	7	Primary coordination
[0.7~0.8)	8	Intermediate coordination
[0.8~0.9)	9	Good coordination
[0.9~1.0)	10	Quality coordination

2.2 Research Methods

2.2.1 Tapio Decoupling Model

Tapio decoupling elasticity model considered in this study is a further supplement and improvement to the decoupling index model of the Organization for Economic Cooperation and Development (OECD). This model effectively alleviates the calculation deviation caused by the highly sensitive or extreme selection of the initial and final values of the OECD index model and exceedingly improves the objectivity and accuracy of decoupling relationship measurement and analysis (Chen et al., 2022).

The economic growth and carbon dioxide emissions can be calculated using **Eq. 1**.

$$E(c_i, g_i) = \frac{\triangle C_i / C_{iBase}}{\triangle G_i / G_{iBase}} = \frac{(C_{iEnd} - C_{iBase}) / C_{iBase}}{(G_{iEnd} - G_{iBase}) / G_{iBase}} \tag{1}$$

where, $E(c_i, g_i)$ represents the decoupling elasticity of economic growth and carbon emissions in the i^{th} period; $\triangle C_i$ and $\triangle G_i$ respectively represent the changes in carbon emissions and economic growth in the period i; C_{iEnd} and G_{iEnd} represents the end of C_i and the end of G_i respectively represent the carbon emission and the economic growth value at the end of the i^{th} period; C_{iBase} and G_{iBase} represents respectively represent the carbon emissions and economic growth values of the base period in the i^{th} period.

Generally, the decoupling elasticity state is divided into three categories and eight degrees (see **Table 1**). When the decoupling elasticity E is less than 0, that is, when the rate of change in carbon emissions is negative while the rate of economic expansion is positive, this is an ideal condition for sustainable development of a low-carbon economy, namely, maximised economic benefits while minimising resource consumption (Zhang, 2016).

2.2.2 Coupled Coordination Model

The coupling coordination model can reflect the overall "efficacy" and "synergy" of multiple systems and determine whether the multiple systems are mutually reinforcing at a high level of mutually restricting at a low level. **Table 2** provides a breakdown of the reference coupling coordination degree.

While establishing the coupling and coordination model, it is essential to acknowledge that both positive and negative effects of carbon emissions and economic growth exist in developing a low-carbon economy. Additionally, all original data should be normalised to make the research results more scientific and objective. After eliminating the difference, the data is changed into the same dimensional value, so the variable x_{ijt} is set to represent the sample value of the index j of district i in the period t; The maximum value is a_{ijt}; while the minimum value is b_{ijt} of the index j in the region i at the time period t (Jiang et al., 2017). The processing formula is as follows:

$$\text{GDP has a positive effect}: u_{ijt} = \frac{x_{ijt} - b_{ijt}}{a_{ijt} - b_{ijt}} \tag{2}$$

$$CO_2 \text{ has a negative effect}: u_{ijt} = \frac{a_{ij} - x_{ijt}}{a_{ijt} - b_{ijt}} \tag{3}$$

where, u_{ij} is represented as the degree of contribution to the efficiency of low-carbon economic construction, and the value range is [0,1]. When $u_{ij} = 0$ means that the system has the worst effect on the construction of a low-carbon economy; When $u_{ij} = 1$ means that the system has the best effect on low-carbon economy development.

In light of this, **Eq. 4** represents the coupling coordination model of carbon emissions and economic growth:

$$D = \sqrt{C * S} \overset{Among}{\Rightarrow} \begin{cases} c = \sqrt[2]{\dfrac{U_1 U_2}{(U_1 + U_2)^2}} \\ s = aU_1 + bU_2 \end{cases} \tag{4}$$

where the notations D, C, and S, represent the degree of coupling coordination, the degree of coupling, and the measure of economic growth system-wide. a and b are the weight

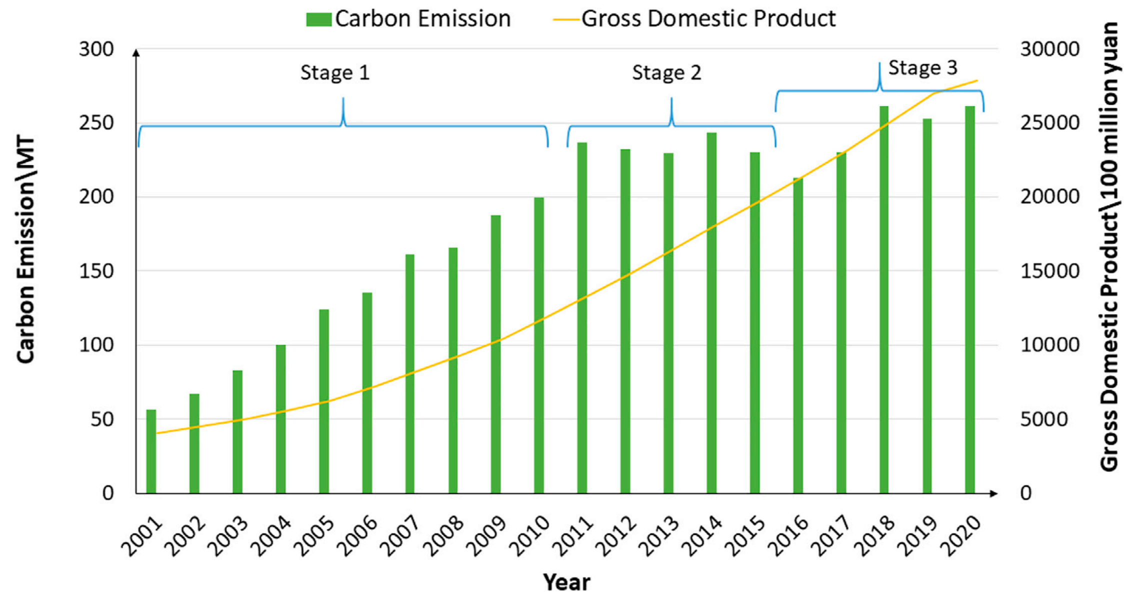

FIGURE 1 | The trend of Carbon Emissions and GDP of Fujian Province from 2001 to 2020.

coefficients of carbon emissions and economic growth. Referring to the existing literature document by (Tian and Lin, 2021), the importance of carbon emissions and economic growth is usually placed in the same position, so the values of a and b are 0.5.

3 RESULTS AND DISCUSSION

3.1 Analysis of the Trend of Total Carbon Emissions and Gross Domestic Product Changes

The trend of carbon emissions and GDP of Fujian Province from 2001 to 2020 is shown in **Figure 1**. From this, it can be understood that the total carbon emissions show a fluctuating upward trend.

Combined with the Fujian Province's development characteristics, it can roughly be divided into three stages: 2001–2010 is the first stage, carbon emissions continue to rise, the overall layout of China in this period is still the core of GDP growth, urbanisation rate is faster. The same is true for Fujian Province, where the influx of labour from the countryside to the cities accelerated the development of the industry. Industrial development at this time was relatively rough. Agriculture also used a lot of machinery, chemical fertilisers, pesticides, plastic films, etc., resulting in significant carbon emissions at this stage. 2011–2015 is the second stage, where carbon emissions fluctuated and slightly decreased in total. In 2011, Fujian Province issued the "Fujian Urban System Plan (2010–2030)," which set the near, medium, and long term planning period and formulated a complete development strategy for urban-rural integration. During this period, the ecological construction in Fujian Province has continued to increase, with joint efforts to control carbon emissions and absorb and transform carbon pollution. At the same time, the urbanisation rate of Fujian Province reaches 62.7%, the mileage of highways and railroads increases rapidly, and the construction and formation of a modern transportation network increase the total carbon emissions. In contrast, the pilot work of county-level urbanisation is focused on Fujian Province in 2014, accelerating the development of urban-rural integration ideas, thus making the industry more coordinated. Hence, the carbon emissions show a fluctuating trend of first decreasing, then increasing and then decreasing. The third stage is from 2016 to 2020, in which the economic strength of Fujian Province has achieved more remarkable development and the high quality of economic development while focusing on ecological and environmental management and carbon emission control has slowed down the growth rate of carbon emissions. In this stage, Fujian Province is gradually realising a more comprehensive policy system of urban-rural combination and has also made certain efforts in social security, compulsory education, urban-rural water supply integration, etc. The development of urban-rural integration makes urban-rural industries more coordinated, urban-rural residents' lives happier, and economic development more efficient, which reduces the waste of resources and slows down the growth rate of carbon emissions.

3.2 Analysis of How Carbon Emission is Decoupled From Economic Growth

The decoupling elasticity between carbon emission and economic increase of nine prefecture-level cities in Fujian Province from 2001 to 2020 is calculated according to **Eq. 1** and shown in **Table 3**.

TABLE 3 | Decoupling elasticity index of prefecture-level cities in Fujian Province from 2001 to 2020.

	T_1			T_2			T_3			T_4		
	C_1	G_1	E_1	C_2	G_2	E_2	C_3	G_3	E_3	C_4	G_4	E_4
Fuzhou	0.624	0.564	1.105	0.392	0.678	0.578	–0.010	0.508	–0.020	0.124	0.339	0.366
Xiamen	0.694	0.820	0.847	0.440	0.610	0.722	–0.065	0.436	–0.149	0.116	0.322	0.362
Putian	0.553	0.637	0.867	0.470	0.769	0.612	0.125	0.558	0.224	0.097	0.293	0.331
Sanming	0.626	0.449	1.393	0.422	0.701	0.602	–0.096	0.484	–0.199	0.112	0.305	0.368
Quanzhou	0.650	0.629	1.034	0.371	0.678	0.547	–0.063	0.501	–0.126	0.117	0.312	0.374
Zhangzhou	0.572	0.495	1.156	0.398	0.702	0.567	0.073	0.551	0.132	0.030	0.215	0.138
Nanping	0.613	0.514	1.193	0.373	0.669	0.557	–0.116	0.476	–0.245	0.025	0.219	0.114
Longyan	0.633	0.495	1.279	0.420	0.722	0.581	–0.092	0.488	–0.188	0.103	0.313	0.328
Ningde	0.586	0.480	1.220	0.398	0.741	0.537	–0.034	0.526	–0.065	0.082	0.318	0.258

After analysing the results from **Table 3**, it is evident that in the period of $T_{1\ (2001–2005)}$, the prefecture-level cities in Fujian Province show two decoupling states of expansion, i.e., negative decoupling and expansion connection. However, the observed growth rate of carbon emissions was too fast, except for Xiamen. The decoupling elasticity of Xiamen and Putian is 0.847 and 0.867, respectively. The decoupling elasticity of the other seven prefecture-level cities is greater than 1, and the growth rate of carbon emissions exceeds the growth rate of economic growth. During this period, Fujian Province, as a coastal port province, grasped the improvement opportunity of Chinese accession to WTO. Also, a large number of rural population flocked to cities, which accelerated the urbanisation rate, which led to industrial emissions and waste generated by heavy industries such as petrochemicals and metallurgy and steel making a pronounced increase. As a result, the overall carbon emissions increased.

In the period of $T_{2\ (2006–2010)}$, the decoupling status of Fujian prefecture-level cities has been significantly better than that of $T_{1\ (2001–2005)}$. The decoupling elasticity of all prefecture-level cities has exceeded the critical value of 0.8, reaching the weak decoupling status. It can be seen that the task of optimising the quality of ecological protection and environment launched in Fujian Province in the 11th Five-Year Plan has been quite effective. The growth rate of carbon emissions has slowed down. In contrast, the economy has grown at a high rate, and all prefecture-level cities have achieved the provincial targets for saving energy and reducing carbon emissions. In Fujian Province, urbanisation has accelerated since this period. However, the government has also been conducting waste and sewage treatment, which to a certain extent reduced the problem of the rapid increase in carbon emissions brought about by rapid urbanisation. Fujian Province has also been committed to agricultural forestry issues during this period, improving rural productivity and promoting the coordinated development of urban and rural areas.

In the period $T_{3\ (2011–2015)}$, Putian City and Zhangzhou City are in a highly weak decoupling; in the short term, seven prefecture-level cities are in a strong decoupling state and have reached the most desirable state of low-carbon economic development by maintaining positive economic development while the growth rate of carbon emissions is in a negative value. Ningde, Sanming, and Longyan have the most obvious improvement in decoupling elasticity, from negative decoupling in $T_{1\ (2001–2005)}$ to strong decoupling in $T_{3\ (2011–2015)}$. It is mainly due to the "12th Five-Year Plan" period that Fujian Province accelerated the construction of ecological provinces, strengthened the development and application of new technologies, new equipment, new products for energy conservation and emission reduction, and effectively controlled the total emissions of sulfur dioxide and other major pollutants. During this period, Fujian Province has put forward a clear vision of urban-rural integration, so it has carried out environmental construction and protection, public service facilities construction, etc. During this time, the concept of urban-rural integration has gradually taken root in people's hearts. Also, the domestic waste has been reasonably disposed of, energy-saving and emission reduction in industry, and more collaborative development among industries, further reducing carbon emissions. It is noteworthy that in this development stage, Fujian Province specifies that the carbon emission intensity should be reduced by 17.5% (Lin, 2012), resulting in a significant decrease in the GDP growth rate of each prefecture-level city in the $T_{3\ (2011–2015)}$ period compared with the $T_{2\ (2006–2010)}$ period. Accordingly, the concept of sustainable and green development has begun to take shape in the 12th Five-Year Plan period. The concept of green and high-quality, sustainable development took shape during the 12th Five-Year Plan period, avoiding the pursuit of high economic increase at the expense of the ecological environment.

In the $T_{4\ (2016–2020)}$ period, China has transitioned from a fast-growing to a high-quality development stage, emphasising the organic combination of ecological civilisation construction and economic development to achieve sustainable economic and social improvement (Ma, 2019). "During the 13th Five-Year Plan period, the decoupling elasticity index of Fujian Province has rebounded in all prefecture-level cities, with an average increase of 0.36 units compared with the $T_{3\ (2011–2015)}$ period, but it is still in a fragile decoupling state, and the low-carbon economic development trend is relatively stable. The increase in urbanisation rate and the increase in domestic waste, etc., in Fujian Province during this period, together with its promotion of the whole industrial chain of the petrochemical industry, are the main reasons for the rebound in carbon emissions. However, the urban-rural integration in Fujian Province has progressed during this period. The policy system of urban-rural integration is gradually improved, the concept of coordinated urban-rural

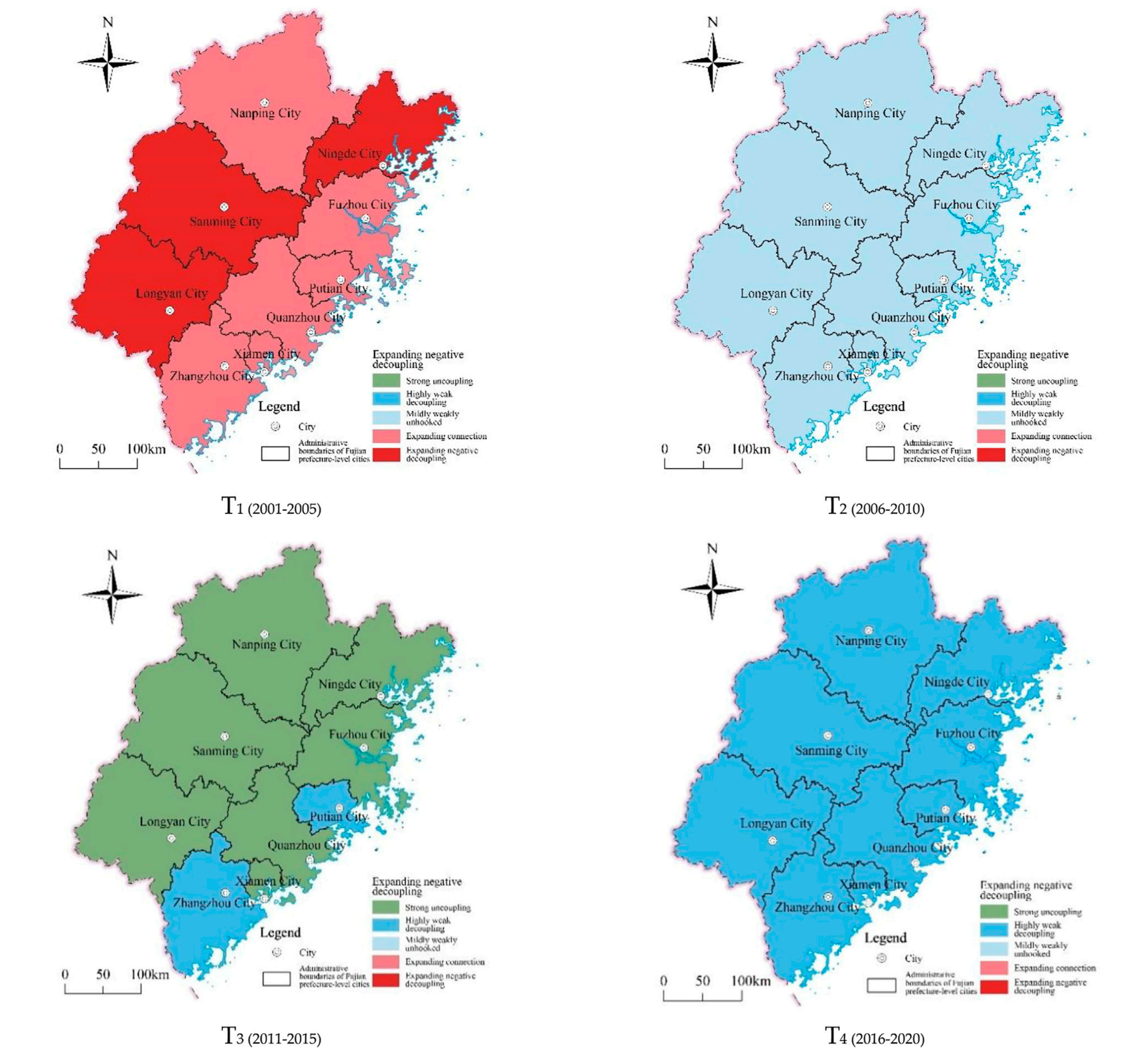

FIGURE 2 | Spatial distribution of decoupling status between carbon emissions and economic growth of prefecture-level cities in Fujian Province.

development is gradually popularised, and the industrial and agricultural increasing urban-rural integration is more coordinated. In addition, the government is committed to environmental construction and reasonable treatment of domestic waste while strengthening other areas. These include the total energy consumption and intensity constraints and supporting the optimisation of the development of the regional carbon emission rate to prioritise reaching the peak. As a result, from a comprehensive view of Fujian Province's decoupling seem still in a better state. Also, the optimisation and integration of industry make the GDP growth rate more than twice the growth rate of carbon emissions. From the spatial perspective, the decoupling index of prefecture-level cities in Fujian Province gradually tends to be in an overall good state through the polarisation between the east and west with an expanding negative decoupling state and the north and south with an expanding connected state. The differences between regions gradually decrease, see **Figure 2**.

3.3 The Coupling and Coordination Degree of Economic Growth and Carbon Emissions: A Correlation Analysis

The coupling and coordination degree of carbon emission and economic growth in Fujian Province from 2001 to 2020 is mainly on the verge of dissonance and barely coordinated. In general, the

TABLE 4 | The degree of coupling and coordination between carbon emissions and economic growth in Fujian Province between 2001 and 2020.

Prefecture-level city	$T_{1\ (2001–2005)}$	$T_{2\ (2006–2010)}$	$T_{3\ (2011–2015)}$	$T_{4\ (2016–2020)}$
Fuzhou city	◆	○	○	△
Xiamen city	△	○	△	△
Putian city	◆	○	○	△
Sanming city	◆	○	◆	◇
Quanzhou city	◆	○	△	△
Zhangzhou city	◆	○	○	△
Nanping city	△	○	△	◇
Longyan city	◆	○	◆	○
Ningde city	◆	○	△	△

Note: Mild disorder ◆, Impending disorder △, Reluctant coordination ○, Primary coordination ◇.

coupling and coordination degree of carbon emissions and economic growth in Fujian Province has experienced a change from mostly dissonance to mostly coordination in the past 20 years, reflecting that most regions in Fujian Province have controlled carbon emissions to a certain extent while promoting economic growth. **Table 4** takes 5 years as an observation period and divides the coupling coordination degree of each prefecture-level city in Fujian into four observation periods over 20 years. This explains the differentiated characteristics of the coupling coordination degree of each prefecture-level city in Fujian Province in different observation periods.

In the first observation period, the degree of coupling coordination in Fujian Province was out of balance, among which seven cities reached a mild level of dissonance, while Xiamen and Nanping did not reach a mild level of dissonance but were on the verge of dissonance; the possible reason was that the economic development of Fujian Province was still dominated by rough and labour-intensive manufacturing industries. The greenhouse gases produced in the production process were not effectively controlled. In the second observation period, Fujian Province changed its development concept and focused on developing environmental industries while upgrading traditional manufacturing industries so that the coupling and coordination between carbon emissions and economic growth in the whole Fujian Province reached a barely coordinated level in this period. In the third observation period, the degree of coupling and coordination decreases in most regions of Fujian Province, and the degree of coupling in Sanming and Longyan even reaches a slight disorder. During this period, the economic strength of Fujian Province continues to increase, and the regional GDP grows rapidly. However, high energy-consuming industries still dominate, and high-tech new industries are not yet mature. Each prefecture-level city's coupling and coordination degree in Fujian Province is steadily increasing in the fourth observation period. Compared with other regions, the coupling and coordination degree of Sanming City, Nanping City, and Longyan City, located in the mountainous area of northwestern Fujian Province, increases, and the coupling and coordination degree of Sanming City and Nanping City reaches the primary coordination.

To show the coupling and coordination between carbon emissions and economic growth in Fujian Province and the regional differentiation characteristics, the results are plotted based on each of the coupling and coordination degrees in the four observation periods and the natural interruption point method as shown in **Figure 3**. The prospect of the regional differentiation characteristics presents the state of polarised distribution, "coastal-inland". The degree of coupling and coordination between carbon emissions and economic growth of inland cities in Fujian Province is better than that of coastal cities. Specifically, the coupling degree of Xiamen and Nanping does not reach the disorder degree in the period 2001-2020. Compared with the other eight regions, the development process of the coupling and coordination degree of Sanming City, although it has experienced two decreases to the mild disorder level, is now located at the top of Fujian Province.

3.4 Discussion

Based on the analysed results in **sections 3.1–3.3**, a discussion was carried out to clearly understand the relationship between carbon emission and economic growth in different stages of urban-rural integration. In addition, the discussion is extended to shred some views on green economy rebound possible.

3.4.1 Relationship Between Carbon Emission and Economic Growth

In the $T_{1\ (2001–2005)}$ period, there was no urban-rural integration planning in Fujian Province during the 10th Five-Year Plan period. The ecological construction planning focused on agricultural production pollution control, domestic waste treatment, water resources protection, soil erosion control, etc. At the same time, more attention was paid to urbanisation during this period. Even though the transformation of traditional industries was proposed, it mainly focused on improving technology and machinery and equipment levels without focusing on the coordination between urban and rural industries. So, the transformation measures could not do a good job in controlling the carbon emissions of heavy industries and manufacturing industries in the industrialisation process. Therefore, during the 10th Five-Year Plan, the rapid economic development was accompanied by a significant increase in carbon emissions. The decoupling between regional carbon emissions and economic growth in nine prefecture-level cities in Fujian Province was mainly an expansionary link, and the coupling coordination was mainly in a mild disorder.

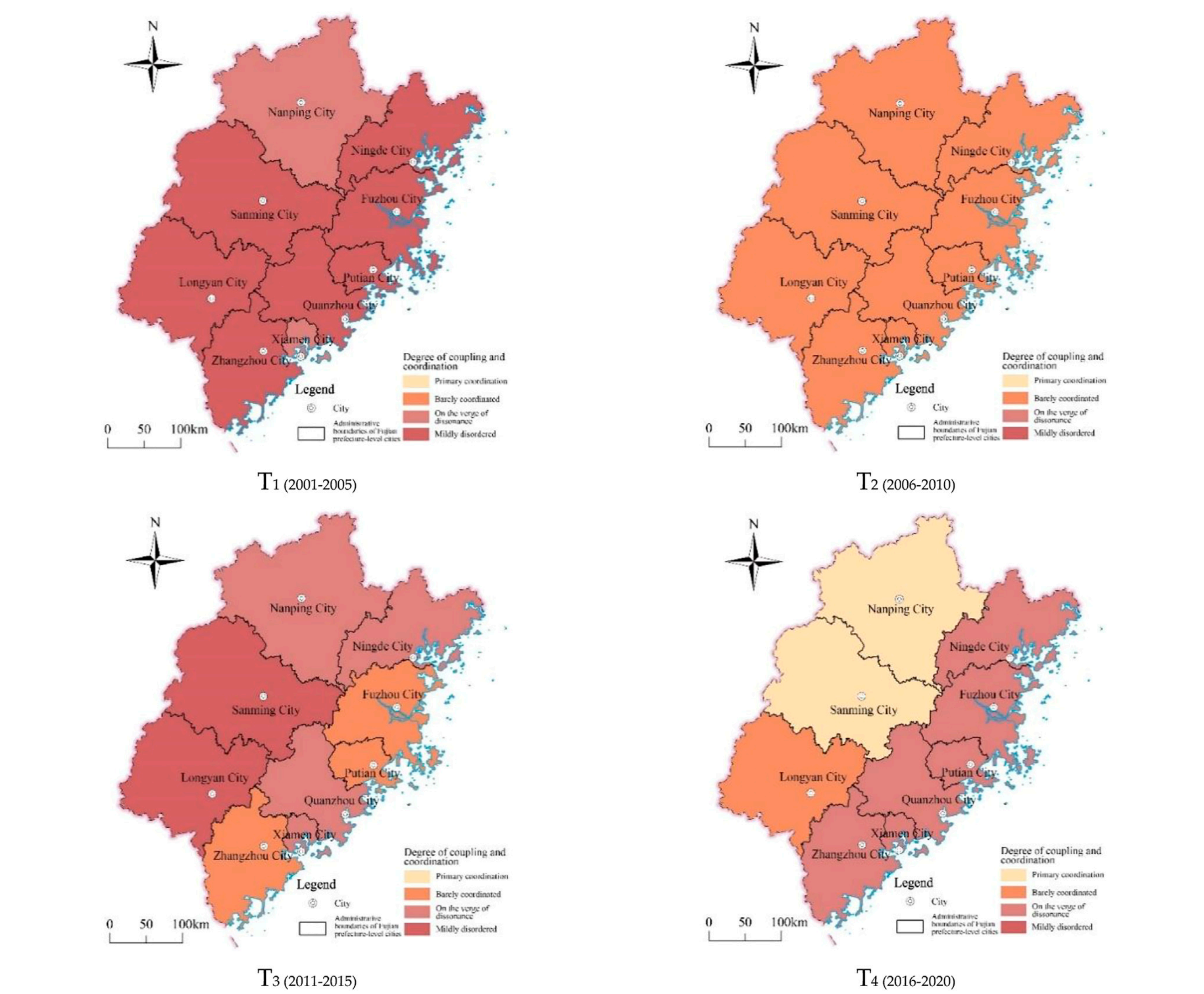

FIGURE 3 | Spatial distribution of coupling coordination degree between carbon emissions and economic growth in prefecture-level cities of Fujian Province.

During the $T_{2\ (2006–2010)}$ period, Fujian Province changed its development concept and focused on the development of environmental industries while upgrading traditional industries. "During the 11th Five-Year Plan period, Fujian Province accelerated the development of urbanisation and industrialisation, focusing on the industrialisation process and strengthening transportation construction, and on the other hand, made special plans for the environmental protection industry, built environmental protection industry bases, and developed purification devices and other projects in terms of solid, liquid and gas pollution control. The agricultural and forestry land reform has been carried out, promoting environmental protection. According to the result, the economy develops while the carbon emission is barely taken control. The decoupling between regional carbon emissions and economic growth in nine prefecture-level cities in Fujian Province is mildly decoupled. The coupling coordination is mainly barely coordinated.

In $T_{3\ (2011–2015)}$, Fujian Province accelerated the construction of an ecological province, strengthened the development and application of new technologies, equipment, and products for energy conservation and emission reduction, and effectively controlled the total emissions of major pollutants such as sulfur dioxide. During this period, Fujian Province began to plan the blending of urban and rural development, and promote the coordinated construction of cities, so that the industry in Fujian Province could be better optimised and upgraded; during the "12th Five-Year Plan" period, Fujian Province continued to optimise the energy structure, providing energy security for the further development of the low-carbon economy. "In the 12th Five-Year Plan, when planning the development of the three leading industries and manufacturing industries, more attention is paid to upgrading low energy consumption and low pollution technology and equipment transformation, controlling the layout of carbonintensive industries, and improving the coordination between industries. Meantime, the investment in scientific and technological study and development of low-carbon industries is increased, and low-carbon industries are vigorously developed. In addition, while focusing on the integrated improvement of urban and rural areas, the concept of green low-carbon consumption is vigorously promoted to reduce the consumption of high-carbon products and stimulate the production and consumption of low-carbon products.

$T_{4\ (2016–2020)}$ period, during the 13th Five-Year Plan period in Fujian Province, the policy system of urban-rural integration will be gradually improved. The planning of ecological and environmental governance and low-carbon development will be further refined in terms of environmental protection and carbon emission reduction, proposing to take the initiative to control carbon emissions, increase the carbon emissions control of key industries such as petrochemicals and manufacturing, and implement demonstration projects of near-zero carbon emission zones. In the high-quality, coordinated development of the economy, while focusing on ecological and environmental governance and carbon emission control, higher demand for carbon emission intensity reduction has been put forward. The carbon emission intensity in Fujian Province in 2020 has decreased by nearly 20% compared with that in 2015. The low-carbon development in Nanping and Sanming cities, in particular, has been effective. Agriculture and forestry in Fujian Province have also been reformed in this stage. The application of pesticides and fertilisers has been reduced. The development of urban-rural integration has been more effective in dealing with domestic waste, social security, and environmental protection concepts. The growth rate of carbon emissions has gradually slowed down while the overall economic development.

3.4.2 Green Economy Rebound Effects

Green economy rebound effects may occur when the firms aim for greater efficiency. As a result, resources might become cheaper especially in the economic terms. Such progress may affect the demand having a direct influence on the brown products. Such effects are known as macro-level rebound effects. In our study, there is a possibility for variety of rebound effects. The one could be related to investments. For instance, the difference in the projected investment's composition from the capital stock's initial composition may have unexpected indirect consequence on the green growth. As a result, the economic outcomes would vary. In the four stages of urban-rural integration, such effect is mildly observed if we look at it theoretically. The other could be related to employment that is created during and after urban and rural integration. Generally, green growth is assumed to provide more employment opportunity than the conventional due to the involved operations in the value chain. However, if the governing body can be able to provide or not by satisfying the employment regulations will be a big question and can be considered as a potential rebound. On the other side, the improvements in energy efficiency for the related energy infrastructure may have influence on the resource consumption (e.g., patterns, type, technology and others). So, by conducting a macroeconomic relationship between resource consumption and investment for urban-rural integration and the outcome may be analyzed to exactly quantify the possible rebound effects.

4 POLICY INSIGHTS

Based on the observed results, it is clear that China needs immediate measures to build a low carbon economy. So, the following six policy inspirations are proposed to accelerate the development of China's regional low-carbon economy.

First, promote the integration of urban and rural areas to reduce the wastefulness caused by the uneven development of urban and rural areas through coordinated development of urban and rural areas and strengthen the carbon sequestration capacity of ecosystems. We should make full use of the natural ecological pattern of "eight mountains, one water, and one field" in Fujian Province, promote the integrated protection of mountains, water, forests, fields, lakes, grasses, and sands, improve forest quality, continuously increase forest area and storage volume, and give full play to the carbon absorption and sequestration capacity of the forest system (Fan, 2021).

Second, adhere to the reduction principle and deepen the reform of energy structure. Rapid technological progress has promoted the development of renewable energy and renewable power generation as well as energy technology efficiency (Chen, 2022), strengthening technological innovation and effective energy use (Lu et al., 2021), shorting energy demand, and increasing renewable energy applications on the demand side and supply side, respectively (Xu et al., 2022), giving full play to the leading role of scientific and technological innovation, implementing green low-carbon cycle technological innovation and technology research and development actions, improving the research and development of demand-side and production-side technological innovation. Promote the development and application of clean energy, green energy, renewable energy, and other related low-carbon technologies, control fossil energy consumption, gradually realise the replacement of low-carbon energy for high-carbon, and realise resource conservation and carbon emission reduction from the source. Also, focus on developing the remanufacturing industry and strengthening the comprehensive utilisation of resources. While expanding the supply and consumption of green, low-carbon products, it should also uphold the concept of waste recycling and reuse to realise the saving and replacement of primary resources and form a green production and lifestyle, which can reduce carbon emissions generated by primary resources mining, smelting, processing, and other links.

Third, promote the development of industrial integration and innovation of green, low-carbon industries. On the one hand, we can construct smart cities and smart industries through the application of technological innovation to promote energy saving and emission reduction in industrial production and build a more green and efficient industrial chain; on the other hand, the development of green finance is a driving force to achieve carbon neutrality (Wang et al., 2022). Fujian Province should focus on its geographical advantages and policy orientation to build forest banks, establish carbon trading markets, develop green industries, and optimise forestry industries to coordinate economic development and environmental protection.

Fourth, we should strengthen the coordinated development between industries and between urban and rural areas. The integrated development of urban and rural areas is for our country's overall planning and coordinated development. In its process, we should build a good social and market environment through policy politics, etc., so that urban and rural populations, resources, technology, etc. can be integrated, and in the market can take each other's needs, so that urban and rural areas can develop in a coordinated manner. In terms of environmental coordination, the amount of carbon sequestered by forests and crops can be increased through better construction of villages. The amount of carbon emitted in the process of agro-industrial production can be reduced through research on energy-saving and emission reduction technologies.

Fifth, the "two mountains" concept of "green water and green mountains are the silver and golden mountain" should be fully implemented in urban-rural integration. We should strengthen the promotion of the concept of ecological construction, resource conservation, and environmental protection, reduce pollution in all areas when ensuring the combined development of urban and rural areas, reduce the use of chemical fertilisers, pesticides, and mulch in agriculture, and accelerate the integration of modern scientific and technological achievements with the whole process of ecological resource development, promote the ecologicalization of science and technology, explore potential ecological, economic resources, stimulate the internal driving force of green development, and form new green development methods such as carbon sink economy, forestry, forest recreation, etc. Forest recreation and other new green development methods continuously promote ecological restoration and treatment. At the same time, they accelerate the realisation of ecological resources' value and make us realise the outcome of coordinated development of economic, social, and ecological benefits.

Sixth, build a city cluster system to build urban integration better. The urban cluster relationship between coastal cities and inland cities is constructed through regional relationships, transportation networks, policy measures, and industrial chains. Thus, the urban economy can be developed in a more coordinated way, and the process can promote the high-quality development of the overall economy of Fujian Province by reasonably optimising the market and industry, etc. At the same time, due to the difference in geographical conditions, through the coordination between cities, we can improve the local economic development; for example, more hilly and mountainous areas can pay more attention to the protection of mountains and forests to improve the carbon sequestration capacity. In contrast, coastal ports and economically developed areas can optimise industries to improve the quality of economic development, increase the employment rate, etc.

5 CONCLUSION

In conclusion, this study revealed that carbon emissions and regional GDP in Fujian Province show an upward trend. The carbon emissions are observed to have slight fluctuations. The economic development pattern, industrial structure (that includes energy), industrialisation process, urbanisation development, and other factors can affect the rate of increase in carbon emissions. The decoupling state and the degree of coupling and coordination between carbon emissions and economic growth in each prefecture-level city of Fujian Province have different characteristics at different times, resulting from the combined effect of economic development pattern, industrial structure, and technology development level. At the present stage, the carbon emission and economic growth in Fujian Province have reached a high degree of weak decoupling. The coupling and coordination degrees are more obviously different between coastal and inland, with inland cities reaching the coupling and coordination state and coastal cities relatively poor. We believe that proposed policy insights could help China develop a low carbon economy.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All the authors have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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