Original Research

Research on the Decoupling Relationship between CO$_2$ Emissions and Economic Growth in Zhejiang Province

Xiang Chen[1], Yi Li[2,3]*, Yongliang Yang[1]**

[1]School of Economics and Management/Zhejiang Academy of Ecological Civilization, Zhejiang Sci-Tech University, Hangzhou 310018, China
[2]East China Sea Institute/Collaborative Innovation Center of Port Economy, Ningbo University, China
[3]Fashion Department of International United Faculty between Ningbo University and University of Angers/Faculty of Tourism and Culture, Ningbo University, China

Abstract

Carbon peaking and carbon neutrality are public commitments made by the Chinese government to the world, and they are also the inherent requirements for achieving high-quality economic development in China's Provinces. On the basis of the data on Zhejiang Province from 2007 to 2019, this study employs the Tapio decoupling analysis method and the environmental Kuznets curve (EKC) model to represent speed decoupling and quantity decoupling. Moreover, this research examines the decoupling relationship between Zhejiang Province's carbon dioxide (CO$_2$) emissions and economic growth. The analysis draws the following outcomes. (1) During the sample period, Zhejiang's economic aggregate and carbon emissions continued to grow, and the economic growth rate was significantly higher than the growth rate of CO$_2$ emissions. (2) The speed decoupling of CO$_2$ emission and economic growth in Zhejiang Province was in good condition, with weak decoupling at the provincial level and weak decoupling and strong decoupling at the city level. (3) The EKC of Zhejiang Province was in the shape of an inverted "N". From 2007 to 2019, Zhejiang's per capita GDP was between the two inflection points. Moreover, no quantity decoupling occurred between CO$_2$ emissions and economic growth.

Keywords: CO$_2$ emissions, economic growth, Zhejiang Province, Tapio decoupling, EKC

Introduction

In the 21st century, addressing global climate change has attracted international attention [1-3]. A global consensus has been made to reduce greenhouse gas emissions, develop a low-carbon economy, and achieve sustainable development. According to estimations by the Carbon Dioxide Information Analysis Center (CDIAC), since 2007, China has surpassed the United States to become the largest carbon emitter in the world [4, 5]. Hence, it is also responsible for reducing its carbon dioxide (CO$_2$) emissions [6].

*e-mail: liyi1@nbu.edu.cn
**e-mail: royyang@zju.edu.cn

To achieve carbon peaking and even carbon neutrality, the CO_2 emissions per unit of the GDP must be significantly reduced. Such goals will force China's energy structure and industrial structure to adjust and optimize continuously and drive the strong growth of clean energy and green industries [7].

Zhejiang is a top economic Province in China and has experienced rapid economic growth [8]. In 2020, Zhejiang's GDP reached 6.46 trillion yuan, an increase of 344.53% compared with 2007, with an average annual growth rate of 7.42%. In addition, its total GDP accounted for 6.36% of the country's total, thus ranking fourth among all Provinces. Assuming that Zhejiang is an independent economy, it will become the 18th largest economy in the world. The GDP of Zhejiang Province in 2020 is between Turkey, which ranks 17th, and the Netherlands, which ranks 18th.

At the same time, Zhejiang is also a major province of energy consumption and carbon emissions [9]. In 2019, Zhejiang Province's energy consumption totaled 224 million tons of standard coal, thus accounting for 4.6% of the national total. This energy consumption resulted in approximately 560 million tons of CO_2 emissions. Departments of the Zhejiang government also attach great importance to energy transformation and energy efficiency improvement [8]. Zhejiang Province has enacted a number of low-carbon development policies to curb the growth of carbon emissions. These policies taken by the government on the environment have resulted in remarkable results in the energy transition of Zhejiang Province [10]. On the one hand, the level of clean energy has improved. In 2019, Zhejiang's power terminal energy consumption accounted for 38.3%, which was 12.8% higher than the national average. On the other hand, the energy consumption per unit of the GDP has declined. Zhejiang's energy consumption per 10,000 yuan of the GDP has dropped from 0.77 tons of standard coal in 2007 to 0.36 tons of standard coal in 2019. Under the background of carbon peaking and carbon neutrality, studying the decoupling state between CO_2 emissions and economic growth in Zhejiang Province will help clarify the current situation of CO_2 emissions and economic growth in Zhejiang Province.

The measurement methods of the decoupling state between CO_2 emissions and economic growth include quantity decoupling and speed decoupling. Among them, "quantity decoupling" means that CO_2 emissions tend to stabilize or decline with economic growth. The "speed decoupling" means that the rate of CO_2 emissions is slower than economic growth during the same period. The most commonly used method to represent quantity decoupling is environmental Kuznets curve (EKC) theory. EKC theory was first proposed by Grossman and Krueger [11]. This method is used to describe the relationship between environmental pollution and economic growth, that is, pollutant emissions increase first and then decrease with the accumulation of economic growth. It presents an inverted "U" shape relationship, which is used to measure quantity decoupling. Scholars have tested and enriched EKC theory by using some environmental indicators in different countries or regions. Tenaw et al. [12] and Wang et al. [13] conducted empirical studies on environmental data from 20 sub-Saharan African countries and energy consumption data from 29 provinces in mainland China. The researchers concluded that the EKC theory is valid. Besides, Behnaz et al. [14] found a similar conclusion by using Malaysia's data for the years from 1980 to 2009. However, Mehmood et al. [15] found no such inverted "U" shape relationship between CO_2 emissions and economic growth in all countries. Furthermore, Wang et al. [16] found that CO_2 emission intensity and per capita GDP exhibits an "N" shape relationship in China. Meanwhile, Iqbal et al. [17] pointed out that a "U" shape relationship between the two in Pakistan.

After Tapio [18] proposed the decoupling elasticity index, scholars have also widely used this method to study the decoupling relationship at the national and industry levels to represent speed decoupling. For example, Guo and Chen [19] used China as a research sample and applied the Tapio decoupling method to analyze the impact of environmental regulations on CO_2 emissions. The study found that China's environmental regulations can effectively decrease CO_2 emissions and reach the expected emission targets. Wu et al. [20] studied the relationship between CO_2 emissions and world economic growth based on decoupling theories, and research results show that developed countries have stronger decoupling and developing countries have weaker decoupling. In addition, scholars have also examined in detail the relationship between CO_2 emissions and economic growth in the construction [21], transportation [22], agriculture [23], and textile industries [24].

Previous studies on the decoupling of carbon emissions and economic growth have mostly focused on the national level, such as Sino-US trade [25], developed and developing countries [26], African countries [27], and European countries [28]. The main contribution of this paper is to divide decoupling into "speed decoupling" and "quantity decoupling", and to study the decoupling relationship between carbon emissions and economic growth at the provincial level. On the basis of the data of Zhejiang Province and 11 prefecture-level cities from 2007 to 2019, this study employs the Tapio decoupling analysis method and EKC model to measure the CO_2 emissions at the Zhejiang level and the prefecture city level. Moreover, this work examines the decoupling relationship between Zhejiang's CO_2 emissions and economic growth. Corresponding policy recommendations based on the research conclusions, this study also provides theoretical and empirical support for Zhejiang Province to take the lead in achieving carbon peaking.

Materials and Methods

Carbon Emissions Calculation

Given that the Zhejiang Provincial Bureau of Statistics does not have direct monitoring data on carbon emissions and the academic community has not yet formed a unified standard for calculating CO_2 emissions, this study indirectly measures CO_2 emissions on the basis of energy consumption [29]. Some cities in Zhejiang Province have announced the detailed consumption of various types of energy, whereas some cities have only announced the total energy consumption. For the former cities, the carbon emissions coefficient method is used to calculate their carbon emissions. The specific calculations of the formula are as follows:

$$TC = \sum E_i \lambda_i \xi_i \qquad (1)$$

In Formula (1), i represents the type of energy, including raw coal, cleaned coal, coke, gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas, natural gas, heat, and electricity. TC means the total carbon emissions. E_i denotes the energy consumption of energy i. λ_i represents the conversion coefficient to standard coal of energy i, and ξ_i is the CO_2 emission coefficient of energy i. The specific conversion coefficient and CO_2 emission coefficient are presented in Table 1.

For cities that have only announced their total energy consumption, the CO_2 emission coefficients per ton of standard coal are calculated as 2.720 and 2.277 through the Kaya carbon emissions identity method and the carbon chemical combustion formula method, respectively [30]. Considering the carbon content, sulfur, nitrogen, and other elements of standard coal; incomplete combustion; and other factors, this study takes the arithmetic average of the two as 2.499, which is the CO_2 emission coefficient per ton of standard coal. The amount of carbon emissions can be obtained by multiplying the energy consumption of cities in Zhejiang Province by the CO_2 emission coefficient per ton of standard coal (unit: ten thousand tons). The formula for calculating carbon emissions is as follows:

$$TC = TE \times 2.499 \qquad (2)$$

In Formula (2), TE represents the total energy consumption of the city, which is calculated by tons of standard coal.

Tapio Decoupling Theory

The decoupling analysis method mainly uses the elasticity index to measure the degree of decoupling. In the field of resource and environmental economy, decoupling represents the fracture of the coupling relationship between environmental pollutant emissions and GDP. With reference to the Tapio decoupling model [18], this study conducts a decoupling analysis between the CO_2 emissions and economic growth of Zhejiang Province from 2007 to 2019. The result is expressed by the decoupling elasticity index.

$$e = \frac{\%\Delta TC}{\%\Delta GDP} = \frac{TC_{t+i}/TC_t}{GDP_{t+i}/GDP_t} \qquad (3)$$

Table 1. Conversion coefficient and CO_2 emission coefficient for different energy sources.

Energy	Conversion Coefficient (λ)	CO_2 Emission Coefficient (ξ)
Raw coal	0.7143 kgce/kg	2.492 kgc/kgce
Cleaned coal	0.9000 kgce/kg	2.631 kgc/kgce
Coke	0.9714 kgce/kg	2.977 kgc/kgce
Gasoline	1.4714 kgce/kg	1.988 kgc/kgce
Kerosene	1.4714 kgce/kg	2.051 kgc/kgce
Diesel	1.4571 kgce/kg	2.167 kgc/kgce
Fuel oil	1.4286 kgce/kg	2.219 kgc/kgce
Liquefied petroleum gas	1.7143 kgce/kg	1.828 kgc/kgce
Natural gas	1.2150 kgce/cu.m	2.162 kgc/kgce
Heat	0.03412 kgce/MJ	3.212 kgc/kgce
Electricity	0.1229 kgce/KW-h	6.113 kgc/kgce

Note: Conversion coefficient for standard coal come from the 2019 China Energy Statistics Yearbook. The CO_2 emission coefficient refers to Cao et al. [31].

Table 2. Types of relationships for the Tapio decoupling model.

Decoupling Types	Carbon Emissions Change (%ΔTC)	GDP Change (%ΔGDP)	Elastic Index (e)
Strong decoupling	<0	>0	(-∞, 0)
Weak decoupling	>0	>0	(0, 0.8)
Recessive decoupling	<0	<0	(1.2, +∞)
Expansive coupling	>0	>0	(0.8, 1.2)
Recessive coupling	<0	<0	(0.8, 1.2)
Expansive negative decoupling	>0	>0	(1.2, +∞)
Weak negative decoupling	<0	<0	(0, 0.8)
Strong negative decoupling	>0	<0	(-∞, 0)

In Formula (3), e is the decoupling elasticity index, %ΔTC denotes the change rate of carbon emissions, and %ΔGDP is the change rate of the gross national product. Among them, Tapio elastic decoupling states can be divided into eight types according to the coefficients of %ΔTC, %ΔGDP, and e, and the difference between positive and negative. The ideal degrees of decoupling are strong decoupling, weak decoupling, recession decoupling, expansion coupling, recession coupling, expansion negative decoupling, weak negative decoupling, and strong negative decoupling. The specific classification method is shown in Table 2.

Econometric Methods Employed for EKC Hypothesis

This study refers to the practice of Lv et al. [32] and introduces the cubic term of the per capita GDP (PGDP). According to the significance and positive and negative value of each coefficient, we can determine its relationship with carbon emissions. The econometric model is set as:

$$lnTC_{it} = \alpha_0 + \beta_1 y_{it} + \beta_2 (y_{it})^2 + \beta_3 (y_{it})^3 + \gamma X_{it} + \mu_i + \varepsilon_{it} \qquad (4)$$

Equation (4) describes the EKC relationship between carbon emissions and economic performance, where i is the city and t is the year. $lnTC_{it}$ is the carbon emissions of city i in year t, and y_{it} is the actual PGDP of city i in year t. PGDP is an effective tool to understand the macroeconomic performance of a country or region, and it is also a reasonable macroeconomic indicator to measure the living standards of the people in a country or region. X_{it} stands for control variables, including energy consumption structure, measured by the logarithm of the consumption of raw coal; industrial structure, defined as the ratio of the secondary industry to GDP; foreign capital usage, measured by the logarithm of the actual use of foreign capital denominated in CNY; and R&D expenditures, measured by internal expenditures of R&D expenditures. α_0, β_1, β_2, and β_3 are all parameters to be estimated. μ_{it} represents the urban fixed effect, and ε_{it} is the random error term.

After controlling the above-mentioned influencing factors to establish the EKC, the relationship of the EKC of Zhejiang Province is determined by the symbols of β_1, β_2, and β_3 in Formula (4). The specific relationship is shown in Table 3. On the basis of the different curve relationships, the corresponding inflection point is calculated, and further study is conducted to determine whether quantity decoupling occurs between CO_2 emissions and economic growth in Zhejiang Province.

Data Sources and Processing

The energy consumption data and economic data of Zhejiang Province and its prefecture-level cities

Table 3. The EKC relationship between CO2 emissions and economic growth.

Type	β_1	β_2	β_3	EKC relationship
1	>0	=0	=0	Positive correlation linear
	<0	=0	=0	Negative correlation linear
2	>0	<0	=0	Invert "U" Shape
	<0	>0	=0	"U" Shape
3	<0	>0	<0	Invert "N" Shape
	>0	<0	>0	"N" Shape

are from historical statistical yearbooks. Given certain factors, such as inflation and constant price changes in economic development, the economic indicators in this article all use 2007 as the base period for comparable price calculations. The actual use of foreign capital is converted into CNY at the exchange rate, and the exchange rate data come from the 2020 China Statistical Yearbook. The conversion coefficient to standard coal comes from the China Energy Statistical Yearbook 2019. Meanwhile, the 2007-2011 energy consumption data of Lishui City are missing. Hence, the analysis uses the average growth rate method for 2012-2019 to make up for the unavailable information.

Results and Discussion

Descriptive Analysis

Fig. 1 shows the change trend of CO_2 emissions and GDP in Zhejiang Province from 2007 to 2019. Fig. 1 demonstrates that the CO_2 emissions of Zhejiang Province from 2007 to 2019 show a continuous upward trend, which can be divided into two stages: a rapid rise period and a slow rise period. The rapid rise period was in 2007-2011, when CO_2 emissions increased from 362.96 Mt to 445.50 Mt, which was an average annual increase of 4.18%. Meanwhile, 2012-2019 was a slow rise period, with an average annual growth rate of 2.71%. In addition, the highest CO_2 emissions in 2019 reached 559.60 Mt. In Fig. 1, the actual GDP of Zhejiang Province also shows a continuous upward trend, rising from 1,875 billion yuan in 2007 to 4,758 billion yuan in 2019, with an average annual growth rate of 7.42%. In summary, the economic growth rate is significantly higher than the growth rate of CO_2 emissions.

Decoupling Analysis

Table 4 shows the decoupling states in Zhejiang Province and its 11 prefecture-level cities from 2007 to 2019. During the sample period, the GDP of Zhejiang Province and its prefecture-level cities showed a rapid growth trend. The average annual real GDP growth rate of the 11 prefecture-level cities was 7.33%. Except for Huzhou City in 2013-2014 and Shaoxing City in 2018-2019, which had a slight decline, the actual GDP of each prefecture-level city increased each year. Hence, the calculation result of Formula (3) included five decoupling states, namely, strong decoupling, weak decoupling, expansion coupling, expansion negative decoupling, and strong negative decoupling.

Table 4 demonstrates that the overall speed decoupling relationship in Zhejiang Province was relatively good, which was consistent with the conclusions drawn by Hao et al. [33]. In addition, the decoupling state was mainly strong decoupling and weak decoupling. At the provincial level, the speed decoupling of Zhejiang Province was weak decoupling during the sample period, thus indicating that Zhejiang's carbon emissions and economy were growing. However, the economic growth rate was higher than the growth rate of carbon emissions, which was in a relatively good state.

From the perspective of prefecture-level cities, Hangzhou was only weakly decoupled for three years, and it was strongly decoupled for the remaining years. The strong decoupling state indicated that carbon emissions were declining. However, the economy was growing. This state was optimal, which indicated that Hangzhou's speed decoupling state was at a high level. Ningbo, Wenzhou, Jiaxing, Zhoushan, Taizhou, and Lishui showed expansion coupling or expansion negative decoupling in some years. However, weak decoupling was still the main state in these cities.
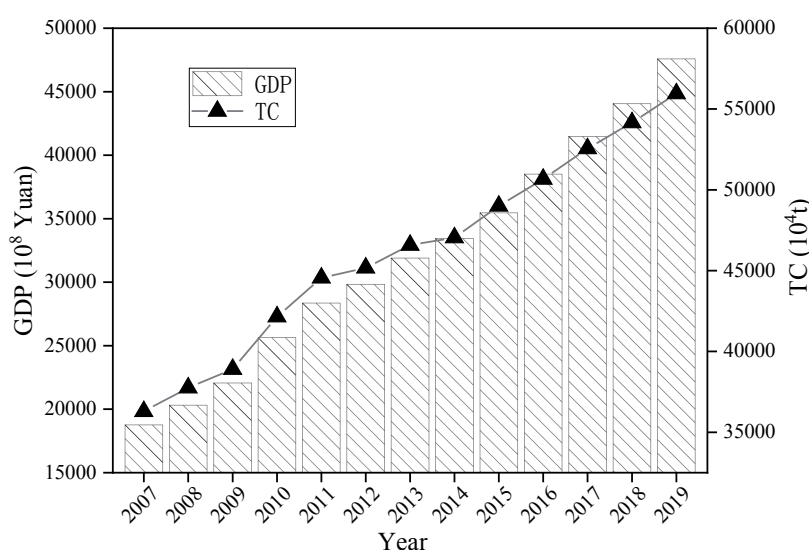

Fig. 1. The change trend of CO_2 emissions and GDP in Zhejiang Province from 2007 to 2019.

Table 4. Decoupling states of carbon emissions and GDP in Zhejiang Province.

Year	Zhe jiang	Hang zhou	Ning bo	Wen zhou	Jia xing	Hu zhou	Shao xing	Jin hua	Qu zhou	Zhou shan	Tai zhou	Li shui
2007-2008	WD	SD	WD	WD	WD	WD	SD	SD	WD	EC	WD	WD
2008-2009	WD	SD	WD	END	WD	SD	WD	SD	WD	END	WD	WD
2009-2010	WD	WD	WD	WD	WD	SD	WD	WD	WD	END	WD	WD
2010-2011	WD	SD	END	WD	WD	SD	WD	WD	WD	END	WD	WD
2011-2012	WD	SD	SD	SD	END	SD	SD	SD	EC	SD	WD	WD
2012-2013	WD	WD	WD	WD	WD	WD	EC	WD	WD	EC	EC	WD
2013-2014	WD	SD	SD	END	EC	SND	SD	SD	WD	END	WD	WD
2014-2015	WD	SD	SD	EC	SD	WD	END	SD	SD	END	WD	SD
2015-2016	WD	SD	SD	WD	WD	WD	WD	SD	SD	WD	END	END
2016-2017	WD	WD	WD	END	WD	EC	END	EC	WD	EC	WD	SD
2017-2018	WD	SD	WD	WD	WD	END	WD	EC	WD	SD	WD	EC
2018-2019	WD	SD	EC	WD	EC	WD	SND	WD	WD	END	SD	END

Note: SD, Strong decoupling; WD, Weak decoupling; RD, Recessive decoupling; EC, Expansive coupling; RC, Recessive coupling; END, Expansive negative decoupling; WND, Weak negative decoupling; SND, Strong negative decoupling.

Jinhua and Quzhou were also dominated by strong and weak decoupling, and a few years showed a state of expansion coupling. Meanwhile, Huzhou City in 2013-2014 and Shaoxing City in 2018-2019 showed strong negative decoupling. The economy was in recession, while carbon emissions were increasing, which was the most undesirable state.

Environmental Kuznets Curve in Zhejiang Province

This part is based on the static panel data of 11 prefecture-level cities in Zhejiang Province from 2007 to 2019. Stata 15 software is employed to test the EKC. In terms of specific model selection, the results of the Hausman test reveal that the random effects model is more efficient than the fixed effects model. Therefore, this research has selected the random effects model for benchmark regression. Furthermore, it has selected the comprehensive feasible generalized least square (FGLS) model for the robustness test because the comprehensive FGLS model also considers the three factors of heteroscedasticity between groups, contemporaneous correlation, and intra-group autocorrelation. The estimated results may be more efficient than the random effects model. In addition, to eliminate non-essential high collinearity among the PGDP terms in Equation (4) as much as possible, the mean centering method was used to process all variables, and then we perform econometric regression.

Columns (1) and (2) in Table 5 report the benchmark regression results. Column (2) adds control variables on the basis of column (1). According to the results,

the coefficient of the first order term of the PGDP is negative. The coefficient of the quadratic term is positive, and the coefficient of the cubic term is negative. Both are significant at a significance level of at least 5%, thus indicating that the quantity decoupling relationship between carbon emissions and economic growth in Zhejiang Province has an inverted "N" shape, which is inconsistent with the conclusions of an inverted U-shape inferred by Tenaw and other scholars [12, 13]. In addition, the return of the energy consumption structure and the use of foreign capital are both significantly positive, thus indicating that the increase in coal consumption and the increase in the actual use of foreign capital will significantly promote the increase of CO_2 emissions. The regression result of the industrial structure and R&D expenditure is positive but not significant.

The cubic curve estimation results of columns (3) and (4) in Table 5 using the comprehensive FFLS method also prove that the EKC relationship is an inverted "N" shape. Different from the benchmark regression, the regression coefficient of the industrial structure is significantly positive, thus indicating that the increase in the proportion of secondary industry in GDP will promote the increase of carbon emissions. In addition, the optimization and upgrading of the industrial structure will reduce carbon emissions.

According to the regression results in column (2) of Table 5, the fitting curve equation expressed by Equation (5) is:

$$lnTC_{it} = 0.554 - 52.918 * y_{it} + 5 * (y_{it})^2 - 0.156 * (y_{it})^3 \tag{5}$$

According to the characteristics of unary cubic function, the PGDP corresponding to the two inflection points is calculated as 15,543.15 yuan and 122,534.26 yuan, respectively. When the PGDP of Zhejiang Province is less than 15,543.15 yuan, the carbon emissions will decrease with the increase of the PGDP. When the PGDP is between 15,543.15 yuan and 122,534.26 yuan, the carbon emissions increase as the PGDP increases. Meanwhile, when the PGDP is greater than 122,534.26, the carbon emissions decrease as the PGDP increases. During the sample period, the PGDP of Zhejiang Province and its prefecture-level cities were between the two inflection points, that is, Zhejiang's carbon emissions and economic growth were still in the stage of increasing CO_2 emissions with economic growth. Moreover, the two were not yet quantitatively decoupled.

According to the regression results in column (4), the fitting curve equation expressed by Equation (6) is:

$$lnTC_{it} = 0.618 - 35.497 * y_{it} + 3.359 * (y_{it})^2 - 0.105 * (y_{it})^3 \qquad (6)$$

Similarly, the PGDP corresponding to the two inflection points is calculated as 15,567.81 yuan and 117,480.03 yuan, which are relatively close to the two inflection points of Equation (5). The above conclusions still apply. In addition, given that the Zhejiang Province's PGDP in 2019 was 82,126.14 yuan, which

is far below the second inflection point of the EKC, Zhejiang's CO_2 emissions is expected to continue to grow in the foreseeable future. Therefore, additional efforts must be made to meet the ambitious goal of having CO_2 emissions peak before 2030. Notably, Hangzhou's PGDP was 116,343.59 yuan in 2019, which is very close to the second turning point. It is expected to be the first city in Zhejiang to achieve the decoupling of carbon emissions and economic growth.

Discussion

The significance of the decoupling measurement not only lies on its ability to answer the question of whether to decouple but also to clarify whether the current CO_2 emissions and economic growth in Zhejiang Province are in a "dilemma" or a "win-win" situation [34]. The "dilemma" refers to the difficulty of taking into account economic development and environmental protection. When formulating environmental economic policies, the government weighs the trade-offs and usually adopts the appropriate loose or strict control. The "win-win" refers to the ability to take into account both economic development and environmental protection. The government usually implements environmental protection policies of strict management and control to meet a win-win situation for environmental protection and economic growth. The measurement of

Table 5. EKC relationship between per capita GDP and carbon emissions in Zhejiang Province from 2007 to 2019.

Variable	RE		FGLS	
	(1)	(2)	(3)	(4)
lnpgdp	-194.841*** (23.515)	-52.918** (27.349)	-141.050*** (13.072)	-35.497*** (10.259)
lnpgdp2	18.097*** (4.381)	5.000** (2.506)	13.124*** (1.206)	3.359*** (0.947)
lnpgdp3	-0.558*** (0.349)	-0.156** (0.077)	-0.405*** (0.037)	-0.105*** (0.029)
ln_ecs		0.579*** (0.064)		0.556*** (0.011)
ln_foreign		0.046*** (0.014)		0.024*** (0.005)
sec		0.005 (0.003)		0.005*** (0.001)
ln_rd		0.018 (0.009)		0.006 (0.004)
_cons	0.883*** (0.086)	0.554** (0.035)	0.874*** (0.047)	0.618*** (0.020)
city	YES	YES	YES	YES
R^2	0.9731	0.9958	/	/
Observations	143	143	143	143
Carve shape	Invert "N"	Invert "N"	Invert "N"	Invert "N"

Note: ***, **, and * represents significant at the level of 1%, 5% and 10%, respectively. Robust standard errors in parentheses.

the decoupling state determines when the critical point from the "dilemma" to the "win-win" situation will come. For speed decoupling, if the decoupling state is strong decoupling, then CO_2 emissions and economic growth will enter the win-win zone, while the rest are in the dilemma zone. For quantity decoupling, the critical point is the second inflection point of the EKC. If the PGDP is greater than the second inflection point, then it has entered the win-win zone. Otherwise, it is still in the dilemma zone.

Compared with the complicated derivation process proposed by Xia et al. [35], the derivation of the relationship between EKC model and decoupling analysis method in this paper is relatively simple, but there are clear conclusions too. From 2007 to 2019, the EKC model and the Tapio decoupling analysis method were used to reach the conclusion that Zhejiang Province's CO_2 emissions and economic growth were not yet in the win-win zone. First, from the analysis results of speed decoupling, the speed decoupling state at the Zhejiang level from 2007 to 2019 was weak decoupling, which did not yet reach the ideal strong decoupling state. At the level of prefecture-level cities, Hangzhou was in strong decoupling state from 2017 to 2019 and took the lead in entering the win-win zone. Therefore, Hangzhou could attempt to control the city's CO_2 emissions strictly to seek a win-win situation between CO_2 emissions and economic growth. However, other prefecture-level cities were dominated by weak decoupling, expansion coupling, and expansion negative decoupling. They did not reach a stable optimal strong decoupling state. Hence, they remained under dilemma and should implement appropriate environmental and economic policies.

Second, judging from the results of quantity decoupling, the EKC of Zhejiang Province was in an inverted "N" shape, and the economy was still between two inflection points. The per capita GDP did not exceed the second inflection point, that is, in the dilemma zone. From the perspective of prefecture-level cities, Hangzhou's PGDP in 2019 is very close to the PGDP corresponding to the second inflection point of the inverted "N" shape curve-which means that Hangzhou will be the first to enter the win-win zone. However, the PGDP of other cities is still far behind the turning point. They will continue to be in a dilemma zone. Therefore, quantity decoupling did not occur. Based on the above analysis results of speed decoupling and quantity decoupling, Zhejiang Province was still under dilemma between CO_2 emissions and economic growth.

Conclusions

On the basis of the data of Zhejiang Province and 11 prefecture-level cities from 2007 to 2019, the carbon emissions coefficient method is used to calculate carbon emissions of Zhejiang Province and prefecture-level cities. Moreover, this study divided decoupling into speed decoupling and quantity decoupling, and used the Tapio decoupling analysis method and the EKC analysis method to conduct further research on the relationship between economic growth and carbon emissions in Zhejiang Province. This study presents the following results:

From 2007 to 2019, Zhejiang Province's economic aggregate and carbon emissions continued to grow. The economic growth rate was significantly higher than the growth rate of carbon emissions. In terms of speed decoupling, the decoupling state of CO_2 emissions and economic growth in Zhejiang Province was in good condition, with weak decoupling at the provincial level and weak decoupling or strong decoupling at the city level. In a few years, some prefecture-level cities demonstrated expansion coupling or expansive negative decoupling. In terms of quantity decoupling, the EKC of Zhejiang Province had an inverted "N" shape. From 2007 to 2019, the per capita GDP of Zhejiang Province and its prefecture-level cities was between the two inflection points, and CO_2 emissions and economic growth had not yet achieved quantity decoupling.

Acknowledgments

Conflict of Interest

The authors declare no conflict of interest.

References

1. PANDOLFI J.M., CONNOLLY S.R., MARSHALL D.J., COHEN A.L. Projecting coral reef futures under global warming and ocean acidification. Science, **333**, 418, **2011**.

2. LI C., ZUO J., WANG Z., ZHANG X. Production-and consumption-based convergence analyses of global CO_2 emissions. Journal of Cleaner Production, **264**, 121723, **2020**.

3. ALVARADO R., DENG Q., TILLAGUANGO B., MÉNDEZ P., BRAVO D., CHAMBA J., LOPEZ M.A., AHMAD M. Do economic development and human capital

decrease non-renewable energy consumption? Evidence for OECD countries. Energy, **215**, 119147, **2021**.

4. LUO F., GUO Y., YAO M., CAI W., WANG M., WEI W. Carbon emissions and driving forces of China's power sector: Input-output model based on the disaggregated power sector. Journal of Cleaner Production, **268**, 121925, **2020**.

5. WEI W., ZHANG P., YAO M., XUE M., MIAO J., LIU B., WANG F. Multi-scope electricity-related carbon emissions accounting: A case study of Shanghai. Journal of Cleaner Production, **252**, 119789, **2020**.

6. ZHENG J., MI Z., COFFMAN D.M., MILCHEVA S., SHAN Y., GUAN D., WANG S. Regional development and carbon emissions in China. Energy Economics, **81**, 25, **2019**.

7. LI Y., DING L., YANG Y. Can the Introduction of an Environmental Target Assessment Policy Improve the TFP of Textile Enterprises? A Quasi-Natural Experiment Based on the Huai River Basin in China. Sustainability, **12**, 1696, **2020**.

8. XIA H., DING L., YANG S., WU A. Socioeconomic factors of industrial air pollutants in Zhejiang Province, China: Decoupling and Decomposition analysis. Environmental Science & Pollution Research, **27**, 28247, **2020**.

9. XIA C., LI Y., YE Y., SHI Z., LIU J. Decomposed driving factors of carbon emissions and scenario analyses of low-carbon transformation in 2020 and 2030 for Zhejiang Province. Energies, **10**, 1747, **2017**.

10. LU Y., HE Y., WANG B., YE S., HUA Y., DING L. Efficiency evaluation of atmospheric pollutants emission in Zhejiang Province China: a DEA-malmquist based approach. Sustainability, **11**, 4544, **2019**.

11. GROSSMAN G.M., KRUEGER A.B. Economic growth and the environment. The quarterly journal of economics, **110**, 353, **1995.**

12. TENAW D., BEYENE A.D. Environmental sustainability and economic development in sub-Saharan Africa: A modified EKC hypothesis. Renewable and Sustainable Energy Reviews, **143**, 110897, **2021**.

13. WANG Z., ZHAO N., WEI W., ZHANG Q. A differentiated energy Kuznets curve: Evidence from mainland China. Energy, **214**, 118942, **2021**.

14. SABOORI B., SULAIMAN J., MOHD S. Economic growth and CO_2 emissions in Malaysia: a cointegration analysis of the environmental Kuznets curve. Energy Policy, **51**, 184, **2012**.

15. MEHMOOD U., TARIQ S. Globalization and CO_2 emissions nexus: evidence from the EKC hypothesis in South Asian countries. Environmental Science and Pollution Research, **27**, 37044, **2020**.

16. WANG Y., HE X. Spatial economic dependency in the Environmental Kuznets Curve of carbon dioxide: The case of China. Journal of Cleaner Production, **218**, 498, **2019**.

17. IQBAL N., KHAN A., GILL A.S., ABBAS Q. Nexus between sustainable entrepreneurship and environmental pollution: evidence from developing economy. Environmental Science and Pollution Research, **27**, 36242, **2020**.

18. TAPIO P. Towards a theory of decoupling: degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. Transport policy, **12**, 137, **2005**.

19. WENBO G., YAN C. Assessing the efficiency of China's environmental regulation on carbon emissions based on Tapio decoupling models and GMM models. Energy Reports, **4**, 713, **2018**.

20. WU Y., ZHU Q., ZHU B. Decoupling analysis of world economic growth and CO_2 emissions: A study comparing developed and developing countries. Journal of Cleaner Production, **190**, 94, **2018**.

21. WU Y., CHAU K.W., LU W., SHEN L., SHUAI C., CHEN J. Decoupling relationship between economic output and carbon emission in the Chinese construction industry. Environmental Impact Assessment Review, **71**, 60, **2018**.

22. HAN H., ZHONG Z., GUO Y., XI F., LIU S. Coupling and decoupling effects of agricultural carbon emissions in China and their driving factors. Environmental Science and Pollution Research, **25**, 25280, **2018**.

23. HAN X., XU Y., KUMAR A., LU X. Decoupling analysis of transportation carbon emissions and economic growth in China. Environmental Progress & Sustainable Energy, **37**, 1696, **2018**.

24. WANG X., CHEN X., CHENG Y., ZHOU L., LI Y., YANG Y. Factorial Decomposition of the Energy Footprint of the Shaoxing Textile Industry. Energies, **13**, 1683, **2020**.

25. WANG Q., HAN X. Is decoupling embodied carbon emissions from economic output in Sino-US trade possible? Technological Forecasting and Social Change, **169**, 120805, **2021**.

26. WANG Q., SU M. Drivers of decoupling economic growth from carbon emission – an empirical analysis of 192 countries using decoupling model and decomposition method. Environmental Impact Assessment Review, **81**, 106356, **2020**.

27. TENAW D., LAMBAMO A. Carbon decoupling and economic growth in Africa: Evidence from production and consumption-based carbon emissions. Resources, Environment and Sustainability, 100040, **2021**.

28. MIKAYILOV J.I., HASANOV F.J., GALEOTTI M. Decoupling of CO_2 emissions and GDP: A time-varying cointegration approach[J]. Ecological indicators, **95**, 615, **2018**.

29. LI Y., WANG Y., HE Q., YANG Y. Calculation and evaluation of carbon footprint in mulberry production: A case of haining in China. International journal of environmental research and public health, **17**, 1339, **2020**.

30. ZHENG C., LIU S. Empirical Research of Carbon Emissions and Economic Growth in China Based on the Spatial Econometric Analysis. China population, resources and environment, **21**, 80, **2011** [In Chinese].

31. CAO S., XIE G. Tracking Analysis of Carbon Footprint Flow of China's Industrial Sectors. Resources Science, **32**, 2046, **2010** [In Chinese].

32. LV D., WANG R., ZHANG Y. Sustainability Assessment Based on Integrating EKC with Decoupling: Empirical Evidence from China. Sustainability, **13**, 655, **2021**.

33. HAO Y., HUANG Z., WU H. Do carbon emissions and economic growth decouple in China? An empirical analysis based on provincial panel data. Energies, 12, 2411, **2019**.

34. SHENG Y., OU M., LIU Q. Methods of Measuring Decoupling of Resource Environment: Speed Decoupling or Quantity Decoupling? China population, resources and environment, **25**, 99, **2015** [In Chinese].

35. XIA Y., ZHONG M.C. Relationship between EKC hypothesis and the decoupling of environmental pollution from economic development: Based on China prefecture-level cities' decoupling partition. China population, resources and environment, **26**, 8, **2016** [In Chinese].