Analysis of The Decoupling Elasticity of Carbon Emissions in Shenzhen Residents' Daily Consumption Based on Tapio Decoupling Model

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Abstract. The research period of this article is from 2014 to 2021. Starting from the perspective of residents' living consumption in Shenzhen, a decoupling index model is constructed to study the emission reduction capacity of Shenzhen, and to explore the decoupling relationship between carbon emissions from residents' living consumption and their living standards and economic development. The results show that during the research period, the total carbon emissions generated by residents in Shenzhen in the field of daily consumption have been increasing year by year, showing a fluctuating ideal decoupling relationship with residents' disposable income, and a fluctuating imperfect decoupling relationship with economic growth.

Keywords: Tapio Decoupling Model; Carbon emissions from daily consumption; Decoupling Elasticity

1. Introduction

Since the first industrial revolution in the 1860s, human emissions of greenhouse gases such as carbon dioxide have been increasing year by year, and atmospheric temperature has been continuously rising. Through the unremitting exploration and research of many scientists, it has been confirmed that emissions of greenhouse gases such as carbon dioxide are one of the main factors that exacerbate the greenhouse effect and promote global warming. According to research by Western scholars, in developed countries such as the United States and the United Kingdom, the carbon emissions generated by residents' daily consumption account for 3/5 of the total national carbon emissions[1,2]. This indicates that the carbon emissions generated by residents' daily consumption now exceed that of traditional industrial fields, and are a key part that cannot be ignored in studying the carbon dioxide emissions situation in a certain area[3].With the continuous development of the national economy and the continuous improvement of the social security system, the living standards of Chinese residents have been further improved, and the quality of life has been further optimized, which has also brought about more resource consumption and greenhouse gas emissions such as carbon dioxide. In recent years, the carbon emissions generated by Chinese residents in the field of daily consumption have been increasing year by year, accounting for nearly half of the total emissions in the country. The higher the level of regional economic development, the greater the proportion. Shenzhen, as the first special economic zone in China and an important bridge for opening up to the outside world, is the central city of China's economy, This article studies

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the decoupling relationship between the carbon emissions of residents' living consumption and their living standards and economic development level in Shenzhen, which is conducive to providing theoretical basis for research on carbon emissions of residents' living, enriching China's research on carbon emissions in the consumption field, and providing reference and reference for helping green and low-carbon consumption in Shenzhen. At the same time, in order to reduce the carbon emissions of residents in Shenzhen during their daily consumption, and to build a low-carbon city, it is of great significance to study the potential for reducing carbon emissions in Shenzhen residents' daily consumption.

2. Literature Review

More and more scholars have begun to conduct research on carbon emissions in various countries around the world, with a wide range of research fields and content. Research has shown that the investment effect and economic structure effect mainly play a facilitating role, while the energy intensity effect is the opposite. Therefore, emission reduction and decoupling policies should emphasize improving energy efficiency, investment patterns, and labor quality [4,5].Some scholars have conducted index decomposition on the driving factors of carbon emissions, and subsequently further analyzed the weak decoupling phenomenon between carbon emissions and economic growth through a decoupling model, which indicates that the growth rate of carbon emissions is less than the growth rate of the economy[6,7].Some scholars have also found that Guangdong Province has achieved a relatively ideal low-carbon consumption model, which can achieve carbon dioxide emission reduction without affecting the growth of disposable income of residents. As long as the entry point is identified, sustainable economic, social, and environmental development can be achieved.[8,9](Wang and Li,2017; Binbin and Yulong ,2020)

In conclusion, In the research on the relationship between carbon emissions and economic indicators, the main methods currently adopted at home and abroad are the environmental Kuznets curve hypothesis and decoupling indicators. Although there are differences in the data acquisition and calculation processes between the two, their results can intuitively reflect the interrelationships between the research objects.

3. Construction of Numerical Models

3.1 Direct carbon emission model

The direct carbon emission intensity is based on the carbon emission coefficient method, which converts the consumption of various types of energy into carbon dioxide emissions through coefficients. Finally, the total carbon dioxide emissions are obtained by adding up the carbon dioxide emissions obtained from all energy conversion.

$$C_{Direct} = \sum_{a=1}^{7} C_{Direct(a)} = \sum_{a=1}^{7} E_a \times \mu_a \times \lambda_a \quad (1)$$

In the formula, a=1,2…7 represents the selected 7 types of energy; $C_{Direct\ (a)}$ represents the direct carbon emissions generated after the consumption of Class a energy; Ea represents the consumption quantity of Class a energy; μ_a represents the standard coal conversion coefficient of Class a energy; λ_a represents the carbon emission coefficient of category a energy.

3.2 Indirect carbon emission model

The calculation of indirect carbon dioxide emissions is based on the principle of the environmental input-output method. 18 industry sectors related to daily household consumption expenditure are selected to match, and the carbon emission intensity of consumption expenditure content and indirect carbon emissions of residents' lives are constructed

$$CI_b = \frac{\sum_b^n C_{b,n}}{\sum_b^n I_{b,n}} \tag{2}$$

$$C_{Indirect} = \sum_b (CI_b \times X_b) \times P \tag{3}$$

N represents the number of industries in the production sector that match the content of consumer expenditure; C_b, n represents the carbon emissions of the nth production sector corresponding to the content of consumption expenditure in category b; I_b, n represents the output value of the nth production department corresponding to the content of consumption expenditure in category b; CI_b represents the carbon emission intensity of consumption expenditure content; X_b represents the per capita expenditure of Shenzhen residents in category b of consumption expenditure content; P represents the number of residents in Shenzhen.

3.3 Tapio Decoupling model

Tapio decoupling is based on the original decoupling model, which subdivides the decoupling states from the original 6 to 8[10,11]. The decoupling level is shown in Table 1

$$e = \frac{\frac{\Delta CO_2}{CO_2}}{\frac{\Delta GDP}{GDP}} \tag{4}$$

In the equation, e is the Tapio decoupling index, represented by the ratio of carbon emission change rate to GDP change rate, reflecting the relationship between the two; ΔCO_2 represents the change in carbon dioxide emissions, $\Delta CO_2/CO_2$ represents the rate of change in carbon dioxide emissions; ΔGDP represents the amount of change in GDP, and $\Delta GDP/GDP$ represents the rate of change in GDP.

Table 1 Description of decoupling status and decoupling flexibility

States		Environmental pressure growth rate	Economic growth rate	Decoupling elasticity(e)
Coupling	Growth coupling	>0	>0	0.8≤e≤1.2
	Recession coupling	<0	<0	0.8≤e≤1.2
Decoupling	Strong decoupling	<0	>0	e<0
	Recession decoupling	<0	<0	e>1.2

Negative decoupling	Expansion negative decoupling	>0	>0	e>1.2
	Strong negative decoupling	>0	<0	e<0
	Weak Negative decoupling	<0	<0	0≤e<0.8
	Weak decoupling	>0	>0	0≤e<0.8

Based on the Tapio decoupling model, this article constructs formulas (5) and (6) to explore whether Shenzhen can achieve zero or negative carbon dioxide emissions while maintaining economic growth and stabilizing residents' disposable income, with disposable income representing the consumption capacity of Shenzhen residents and GDP representing the level of economic development.

$$e_{di} = \frac{\Delta CO_2/CO_2}{\Delta DI/DI} \tag{5}$$

$$e_y = \frac{\Delta CO_2/CO_2}{\Delta Y/Y} \tag{6}$$

In the equation, e_{di}, e_y is the decoupling index, ΔY, ΔCO_2. ΔDI represents the changes in Shenzhen's GDP, total carbon emissions produced by residents in the field of daily consumption, and disposable income, respectively; $\Delta Y/Y$, $\Delta CO_2/CO_2$. $\Delta DI/DI$ respectively represent the GDP of Shenzhen, the total amount of carbon emissions produced by residents in the field of daily consumption, and the rate of change in disposable income; e_{di} represents the relationship between the carbon emissions produced by Shenzhen residents in the field of daily consumption and their income level; e_y represents the relationship between the carbon emissions produced by Shenzhen residents in the field of daily consumption and the level of economic growth.

4. Empirical Analysis

4.1 Data source

The data of carbon emissions generated by Shenzhen residents in the area of domestic consumption are obtaining from the above measurement results. Shenzhen's gross regional product is collating from the Shenzhen Statistical Yearbook. The disposable income of Shenzhen residents is calculating from the Shenzhen Statistical Yearbook of per capita disposable income of residents and the population size of Shenzhen residents.

4.2 Data results

4.2.1 Calculation and analysis of direct carbon emissions

Based on the measurement formula (1) constructed in the previous section, the calculation results are showing in Table 2.

Table 2 direct carbon emissions from Shenzhen residents' domestic consumption during the observation period (million tons)

Year	Domestic energy consumption (million tons/standard coal)	Direct carbon emissions from residential consumption (million tons)	Population (10,000 people)	Direct carbon emissions from domestic consumption per capita (tons/person)
2014	582.42	1614.24	1318	1.22
2015	615.43	1705.73	1408	1.21
2016	685.63	1900.29	1495	1.27
2017	744.09	2062.32	1587	1.30
2018	765.37	2121.30	1666	1.27
2019	823.57	2282.61	1710	1.33
2020	845.27	2342.75	1763	1.33
2021	904.78	2507.69	1768	1.42

Source: Based on measurement results

As can be seen from Table 2, the total direct carbon emissions from residential consumption and per capita carbon emissions in Shenzhen from 2014 to 2021 show a general growth trend, with fluctuations in some years, but the total direct carbon emissions from residential consumption grows from 5,824,200 tons in 2014 to 9,047,800 tons in 2021, an increase of 55.3%. In addition, the per capita direct carbon emissions from domestic consumption grows from 1.22 tons/person in 2014 to 1.42 tons/person in 2021, an increase of 16.4%. Although much higher than the national average, Shenzhen, as an innovative city, has continuous research and development of clean production methods and technologies along with economic growth, coupled with the increase in environmental awareness of residents. Therefore, from 2014-2021, Shenzhen shows a trend of increasing and then decreasing energy consumption growth rate, from 3.3% growth in 2014 to -2.7% growth in 2020. In addition, in 2021, due to the effectiveness of Shenzhen in Internet transformation and 5G promotion, Shenzhen's electricity consumption reaches 110.34 billion kWh, a record high, with energy consumption growth of 7.8%. According to the relevant data, Shenzhen's high-end manufacturing and green low-carbon industries account for the proportion of energy consumption is continuing to grow, demonstrating the high-quality development of Shenzhen's economy.

4.2.2 Calculation and analysis of indirect carbon emissions

Based on the measurement equations (2) (3) constructed in the previous section, the measurement results are showing in Table 3.

Table 3 Indirect carbon emissions from Shenzhen residents' domestic consumption during the observation period (million tons)

Year	Indirect carbon emissions from residential consumption (million tons)	Population (10,000 people)	Indirect carbon emissions from domestic consumption per capita (tons/person)
2014	877.11	1318	0.67
2015	1022.43	1408	0.73

2016	1173.31	1495	0.78
2017	3565.41	1587	2.25
2018	2205.48	1666	1.32
2019	3408.89	1710	1.99
2020	3120.14	1763	1.77
2021	3631.96	1768	2.05

Collation source: based on the measurement results

From Table 3, it can be seeing that the overall indirect carbon emission of domestic consumption of Shenzhen residents from 2014 to 2021 shows a fluctuating upward trend. From 8,771,100 tons in 2014 to 36,319,600 tons in 2021, an increase of 314%. The indirect carbon emission of per capita domestic consumption increases from 0.67 tons/person in 2014 to 2.05 tons/person in 2021, an increase of 206%. In addition, the changes in indirect carbon emissions from per capita domestic consumption of Shenzhen residents during 2014-2021 are nearly synchronizing with the changes in total indirect carbon emissions. It shows that with the continuous development of the economy, the energy consumption of residents in daily life consumption is gradually increasing and at a high level in order to meet the demand for increasing living standards. It can be seeing that the demand of residents' consumption is still one of the important driving forces for the increase of carbon emissions in Shenzhen.

4.2.3 Total carbon dioxide emissions

Based on the above measurement of direct and indirect CO_2 emissions, the data of total CO_2 emissions in Shenzhen is showed by Table 4.

Table 4 Total carbon emissions of Shenzhen residents' domestic consumption during the observation period (million tons)

Year	Direct carbon emissions from residential consumption (million tons)	Indirect carbon emissions from residential consumption (million tons)	Total carbon emissions from residential consumption (million tons)	Carbon emissions from domestic consumption per capita (tons/person)
2014	1614.24	877.11	2491.35	1.89
2015	1705.73	1022.43	2728.16	1.94
2016	1900.29	1173.31	3073.61	2.06
2017	2062.32	3565.41	5627.73	3.55
2018	2121.30	2205.48	4326.77	2.60
2019	2282.61	3408.89	5691.49	3.33
2020	2342.75	3120.14	5462.89	3.10
2021	2507.69	3631.96	6139.65	3.47

Collation source: According to the Shenzhen Statistical Yearbook

From Table 4, it can be seeing that the total carbon emissions generated by residents in Shenzhen in the field of domestic consumption show a fluctuating increase year by year during 2014-2021. The total carbon emissions generated by residents in the field of domestic consumption is 24,913,500 tons in 2014, and rises to 61,936,500 tons in 2021, an increase of 36,483,000 tons or 146%. By observing the trend of image change, it can be seeing that the curve of the change in the magnitude of the growth of indirect carbon emissions generated by residents in the field of domestic consumption and total carbon emissions is similar to the future trend.

From the above analysis, it can be seeing that the trend of changes in carbon emissions generated by residents in domestic consumption in Shenzhen from 2014 to 2021 is likely to continue to show a growth trend in carbon emissions from residents' domestic consumption in the future. Therefore, it is crucial to further study the emission reduction potential of Shenzhen.

4.2.4 The decoupling elasticity

The decoupling elasticity between carbon emissions generated by Shenzhen residents in the area of domestic consumption and disposable income and regional GDP during the observation period are measured according to equations (5) (6) above, and the results are shown in Tables 5 and 6.

Table 5 Decoupling Elasticity of Carbon Emissions from Household Consumption and Disposable Income of Shenzhen Residents in the Observation Period

Year	$\Delta CO_2/CO_2$	$\Delta DI/DI$	e_{di}	Decoupling Status
2014-2015	0.095	0.165	0.578	Weak decoupling
2015-2016	0.127	0.159	0.798	Weak decoupling
2016-2017	0.831	0.154	5.396	Expansion negative decoupling
2017-2018	-0.231	0.141	-1.640	Strong decoupling
2018-2019	0.315	0.115	2.733	Expansion negative decoupling
2019-2020	-0.040	0.070	-0.575	Strong decoupling
2020-2021	0.124	0.095	1.304	Expansion negative decoupling

Source: Based on decoupling model calculations

From the measured results in Table 5, it can be seeing that the decoupling relationship between carbon emissions produced by Shenzhen residents in the domestic consumption sector and disposable income during 2014-2021 shows a fluctuating ideal type of decoupling. The overall decoupling state is predominant. 2014-2015 and 2015-2016 show a weak decoupling phenomenon. In contrast, the periods 2017-2018 and 2019-2020 show a strong decoupling. This indicates that the disposable income of Shenzhen residents and carbon emissions are inversely relating during this period. However, the decoupling effect between individual years is not satisfactory. For example, the periods 2016-2017, 2018-2019 and 2020-2021 show a negative decoupling of expansion. According to the meaning of the state, it is clear that the carbon emissions of residential consumption in this period are rising faster than the disposable income of residents. For the individual cases where the decoupling state is not ideal, the possible reason for it is that the disposable income of residents will be influencing by the real and nominal income of residents. In addition, real income and nominal income will be affecting not only by the domestic economic environment, but also by the international economic environment. When the domestic and international economic environment is good, it provides residents with a stable employment environment and wage base, which is conducive to the increase of residents' disposable income. On the contrary, when the domestic and international economic environment is bad, it may lead to a decrease in the growth rate of residents' disposable income, or even a decrease in residents' disposable income.2016 saw complex and profound changes in the international landscape, with frequent "black swan" events in the chaotic international arena. This led to a tense international situation and increased risks and challenges. As Shenzhen is one of the most important international cities in China, changes in the international situation will certainly have a significant impact on regional economic development and people's income. In addition, the recurring outbreaks of the Sino-US trade war and the new crown pneumonia epidemic in 2019 have had a significant impact on the economy across China and are one of the reasons for the unsatisfactory decoupling status in the same period.

Table 6 Decoupling elasticity of carbon emissions from residential consumption and regional GDP in Shenzhen during the observation period

Year	$\Delta CO_2/CO_2$	$\Delta Y/Y$	e_y	Decoupling Status
2014-2015	0.095	0.098	0.973	Growth coupling
2015-2016	0.127	0.122	1.038	Growth coupling
2016-2017	0.831	0.125	6.625	Expansion negative decoupling
2017-2018	-0.231	0.085	-2.710	Strong decoupling
2018-2019	0.315	0.068	4.617	Expansion negative decoupling
2019-2020	-0.040	0.028	-1.414	Strong decoupling
2020-2021	0.124	0.105	1.183	Growth coupling

Source: Based on decoupling model calculations

Similarly, as can be seen from Table 6, the overall decoupling state presented between carbon emissions produced by Shenzhen residents in the domestic consumption sector and Shenzhen's regional economic growth is predominantly less desirable. Among them, the carbon dioxide emissions produced by residents in the area of domestic consumption and the regional GDP show a growth coupling between 2014-2015, 2015-2016 and 2020-2021. In addition, the decoupling relationship between carbon emissions produced by residents in the area of domestic consumption and the level of economic growth during 2016-2017 and 2018-2019 is nearly identical to the decoupling relationship between carbon emissions produced by residents in the area of domestic consumption and the level of disposable income during 2016-2017 and 2018-2019. It can be judging that it may be causing by the same reason, i.e. the domestic and foreign economic situation affecting the level of regional economic development. On the contrary, the periods 2017-2018 and 2019-2020 show a strong decoupling. It indicates that while the economic development is stabilizing, the carbon emissions of residents in the area of domestic consumption are effectively controlled. However, this decoupling state does not continue effectively, indicating that the implementation of Shenzhen's CO_2 emission reduction policies and measures still needs to find the key point to reduce the increase of carbon emissions from residents' daily consumption while achieving the improvement of residents' living standards and economic development. In this way, the sustainable development of economy and environment can be achieving.

5. Conclusions

This article analyzes the emission reduction capacity of Shenzhen city by constructing the Tapio decoupling index model. It is found that the carbon emissions generated by Shenzhen residents in the field of daily consumption and disposable income are mostly in a decoupling state, while the decoupling relationship with Shenzhen's economic growth is opposite, and the overall performance is mainly not ideal. Some years have shown that while stabilizing economic development and residents' quality of life, they have effectively controlled the carbon dioxide emissions generated in the field of daily consumption. However, this state has not been effectively continued, indicating that Shenzhen still needs to identify the entry point for emission reduction, use reasonable emission reduction methods, and simultaneously reduce the carbon emissions produced due to daily consumption while improving residents' living standards and economic development levels, To achieve sustainable economic and environmental development.

6. Recommendations

Therefore, recommendations are making based on the results of decoupling analysis. The government should strengthen policy guidance to reduce carbon emissions from both the producer and consumer sides of the energy structure and energy consumption. It should also formulate urban population development strategy to promote the harmonious development of population, economy and environment to reduce the carbon dioxide emissions from residential consumption due to the population scale effect. Enterprises are the producers themselves should develop low-carbon technology and green energy to reduce carbon dioxide emissions from energy structure. Individual residents should establish the concept of low-carbon consumption, reduce extravagance and wastefulness, save energy and protect the environment, reduce the carbon emissions caused by the effect of residents' living standards, and build a green and environmentally friendly living environment.

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