Simulation and influencing factors of carbon emission peak in Wenzhou's textile and clothing industry

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ABSTRACT – REZUMAT

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To reflect the huge pressure on the environment caused by carbon emissions (CEs) in the production process of the textile and clothing industry, this study uses the CE coefficient method to calculate the CEs of the textile and clothing industry in Wenzhou, China from 2004 to 2018. Moreover, this study analyses the decoupling relationship between Wenzhou's textile and clothing industry and economic growth by using the decoupling theory and using the Laspeyres decomposition method to analyse the impact of CE factors. Research results show as follows: the decoupling of the CE and economic growth in Wenzhou's textile and clothing industry from 2004 to 2018 was five years of non-decoupling (2005, 2006, 2007, 2012, 2016) and four years of relative decoupling (2008, 2010, 2013, 2015), five years of absolute decoupling (2009, 2011, 2014, 2017, 2018), the overall decoupling state is good; among the main factors affecting CE, the cumulative effect of industrial scale is the key factor that drives the growth of CE. The industry structure effect and technology level effect inhibit the increase in CE, and the technology level effect has a small impact on the CE of the textile and clothing industry. This paper fills in the gaps between the environmental regulation means and methods of pillar industrial clusters in specific regions and provides paths and measures for Wenzhou's textile industry and regional energy conservation and emission reduction.

Keywords: *textile industry, clothing, carbon emissions, decoupling, Laspeyres*

Factorii de simulare și influență ai vârfului de emisie de carbon în industria textilă și de îmbrăcăminte din Wenzhou

Pentru a reflecta presiunea uriașă asupra mediului cauzată de emisiile de carbon (CE) în procesul de producție al industriei textile și de îmbrăcăminte, acest studiu folosește metoda coeficientului CE pentru a calcula factorii CE ai industriei textile și îmbrăcămintei din Wenzhou, China, din 2004 până la 2018. Mai mult, acest studiu analizează relația de decuplare dintre industria textilă și de îmbrăcăminte din Wenzhou și creșterea economică prin utilizarea teoriei decuplării și folosind metoda de descompunere Laspeyres, cu scopul de a analiza impactul factorilor CE. Rezultatele cercetării arată după cum urmează: decuplarea CE și creșterea economică în industria textilă și de îmbrăcăminte din Wenzhou din 2004 până în 2018 a fost de cinci ani de nedecuplare (2005, 2006, 2007, 2012, 2016) și patru ani de decuplare relativă (2008, 2010, 2013, 2015), cinci ani de decuplare absolută (2009, 2011, 2014, 2017, 2018), starea generală de decuplare este corespunzătoare; printre principalii factori care afectează CE, efectul cumulativ la scară industrială este factorul cheie care conduce la creșterea CE. Structura industriei și nivelul tehnologic inhibă creșterea CE, iar nivelul tehnologic are un impact redus asupra CE din industria textilă și de îmbrăcăminte. Această lucrare completează golurile dintre mijloacele și metodele de reglementare a mediului clusterelor industriale pilon din regiuni specifice și oferă căi și măsuri pentru industria textilă din Wenzhou, precum și conservarea energiei regionale și reducerea emisiilor.

Cuvinte-cheie: *industria textilă, îmbrăcăminte, emisii de carbon, decuplare, Laspeyres*

INTRODUCTION

The massive emission of greenhouse gases and the resulting environmental problems are worsening, becoming a worldwide problem affecting human development [1]. Energy consumption, especially fossil energy consumption, is an important factor in the increase in the number of greenhouse gases in the atmosphere. And the more fossil fuel and non-green energy are used, the more negative impact on social and environmental sustainability [2], the usage of renewable energy not only enhances environmental sustainability but also spurs sustainable regional economic growth [3]. To accelerate the promotion of a resource-saving and environment-friendly society, the textile and clothing industry sector has to propose higher requirements for energy conservation, emission reduction and the elimination of backward production capacity in the textile industry, and the task of reducing non-renewable energy consumption further is imminent [4, 5].

China is the world's largest producer, consumer and exporter of textiles and garments. The textile and clothing industry of China is an important civilian production and international competitive advantage industry [6]. This industry has made great contributions to China's national economy, social development and employment. However, China's textile and clothing industry typically consumes and emits huge amounts of energy and pollution, respectively [7, 8]. According to calculations, the energy consumption of the entire process of China's textile industry is approximately 4.84 t of standard coal/1 t of fibre which is equivalent to 10.99 t of carbon dioxide/1 t of fibre, and its total energy consumption accounts for 4.3% of China's industrial energy consumption [9]. The energy consumption of the printing and dyeing sub-industry accounts for approximately 58.7% of the entire industry. The water, electricity and steam energy consumptions of printing and dyeing plants account for 40–60% of the total cost of printing and dyeing fabrics which is the focus of energy conservation in the textile industry [9]. China's textile and clothing industry has been receiving great pressure to save energy and reduce emissions for a long time.

The textile and clothing industry is one of the four pillar industries in Wenzhou. Wenzhou, an economically developed coastal city in the southeast of Zhejiang Province in China, is an important textile production base and distribution centre in China, with obvious advantages in agglomeration, market and information. The main textiles include clothing and clothing accessories; textile yarns, fabrics and products; and upper shoe textiles. Wenzhou's textile and garment enterprises are booming. In 2018, there were more than 1,000 enterprises above the designated size in Wenzhou's textile and clothing industry, with an output value of more than USD 4 billion, accounting for approximately 4.7% of China's domestic textile and garment output [10]. Wenzhou's textile and garment industry occupies a pivotal position in the territory of China's textile industry. Wenzhou is known as 'China's Textile and Clothing Brand Central City' and 'China's Clothing Fashion Customisation Demonstration Industry Base'. In the international market, Wenzhou's textile and clothing exports are also highly reputable. Wenzhou textiles and garments are sold to more than 130 countries and regions, mainly in the European Union, Japan, Hong Kong, Macao and Taiwan regions and North America. From 2009 to 2017, Wenzhou's textile exports increased from USD 4.049 billion to USD 5.442 billion, an increase of 34.40%. Wenzhou's textile exports accounted for 5.8% of the annual average proportion of Zhejiang Province, China [11,12]. As the second batch of low-carbon city pilots in China, the 'Wenzhou City's 13th Five-Year Implementation Plan for Controlling Greenhouse Gas Emissions') targets the carbon emission (CE) intensity reduction of 18% and the carbon intensity per unit of industrial added value decrease of 20% in 2020 compared to those in 2005 and the effective control of CEs [13].

Decoupling analysis is widely used in the study of the relationship between the environment and economic development. In the field of resource-environmental economy, decoupling refers to the breakdown of the coupling relationship between economic growth, resource consumption and environmental emissions. Scholars at home and abroad have conducted extensive research on the relationship between economic growth, energy consumption and CE using the decoupling theory. Li et al. used decoupling theory to quantitatively analyse the decoupling relationship between China's environmental regulations, technological progress and water consumption from 2002 to 2015 [14] and studied and analysed the decoupling relationship between water resource consumption, water footprint and economic growth [15–16]. Lu et al. analysed the decoupling effect between economic growth, transportation energy demand and carbon dioxide emissions and concluded that rapid economic growth and motor vehicle ownership are the most important factors of CO_2 emissions increase [17]. Meanwhile, Kovanda and Hak analysed and compared the decoupling situations of resource consumption and the gross industrial output value of major EU countries from 1990 to 2002 [18]. Zhang et al. analysed the decoupling elasticity between carbon dioxide, the gross domestic product and energy consumption in China and the ASEAN countries over the period 1990–2014. Their research shows that the economic effect of per capita GDP is the dominant driving force for the increase in CO_2 emissions and suggests that energy policies in China and the ASEAN countries need to expand the proportion of renewable energy and increase the efficiency of energy use[19]. Scholars had carried out relevant research at the national and regional levels. At the national level, the research includes the decoupling analysis of energy consumption [20], carbon dioxide emissions [21–23], water resources consumption [24], wastewater discharge [25], farmland occupation [26] and economic growth, whilst that at the regional level includes the decoupling relationship between economic growth and farmland occupation [27], environmental pressure [28], CEs [29] and energy consumption [30, 31].

The factor decomposition methods commonly used in research mainly include two types, i.e. index decomposition analysis (IDA) [32–35] and structural decomposition analysis [36–40]. Among them, the IDA based on the Laspeyres index method was proposed by the German mathematician E. Laspeyres in 1864. This idea was gradually applied to the field of energy decomposition from the late 1970s to the early 1980s [41, 42]. Based on the CE and economic growth data of Wenzhou's textile and clothing industry from 2004 to 2018, this study uses the IPAT/IGT decoupling method to analyse the decoupling relationship between Wenzhou's textile and clothing industry's CE and economic growth and the Laspeyres decomposition method to determine the main factors affecting this decoupling relationship. This study provides paths and measures for Wenzhou's textile industry and regional energy conservation and emission reduction and offers relevant suggestions for sustainable development.

MATERIAL AND METHODS

CE Coefficient Method

According to the IPCC '2006 Greenhouse Gas Emissions Inventory Guidelines' guidance method [43], the CE coefficient method is used to calculate the CE of the textile and clothing industry as follows:

$$CE = \sum CE_{ij} = \sum E_{ij} \times f_j \times c_j \quad (1)$$

In equation 1, CE represents the CE of the textile and clothing industry; $i = 1, 2, 3$ respectively represent the three sub-sectors that constitute the textile and clothing industry, i.e. textile manufacturer, textile wearing clothing manufacturer and footwear and caps and manufacturer of chemical fibres; $j = 1, ..., 11$ respectively represent 11 energy types, such as raw coal, coke and clean coal; CE_{ij} represents the CE generated by sub-industry i that consumes type j energy; E_{ij} represents the amount of type j energy consumed by sub-industry i; f_j represents the conversion coefficient of type j energy into standard coal; and c_j represents the CE coefficient of type j energy. The CE and standard coal conversion coefficients of various energy sources are shown in table 1.

Table 1

CE AND STANDARD COAL CONVERSION COEFFICIENTS OF DIFFERENT ENERGY TYPES

Energy	Carbon emission factor (kg/kg SCE)	Standard coal coefficient (kg SCE/kg)
Raw coal	0.7559	0.7143
Coke	0.8550	0.9714
Wash clean coal	0.7559	0.9000
Heat	0	0.03412
Electricity	0	0.1229
Petrol	0.5538	1.4714
Coal oil	0.5714	1.4714
Diesel oil	0.5921	1.4571
Fuel oil	0.6185	1.4286
Natural gas	0.4483	1.3300
Liquefied petroleum gas	0.5042	1.7143

The conversion coefficients of various energy sources are from the 'China Energy Statistical Yearbook 2014', and the CE coefficients are derived from the data provided in the 2006 'IPCC Guidelines for National Greenhouse Gas Emission Inventories'. The coefficient of conversion to standard coal for heat is kg/MJ, the coefficient of conversion to standard coal for electricity is kg/kW·h, and the other energy units are in kg standard coal/kg.

IPAT/IGT Decoupling Indicator

Based on the IPAT equation, Professor Lu proposed the decoupling indicator for resource use (D_r) [44] based on the IGT equation between resource consumption and economic growth [45–47] as follows:

$$D_r = \frac{t}{g} \times (1 + g) \quad (2)$$

In equation 2, D_r represents the resource decoupling indicator, g is the increase rate of total industrial output value (TIOV) within a certain period ($g > 0$ during the economic growth; $g < 0$ during the economic recession), and t is the average annual decrease rate in resource consumption per unit TIOV during the same period (when falling, $t > 0$; when rising, $t < 0$). Among them, according to the size D_r, the decoupling state of resource consumption and TIOV is classified into three types: absolute decoupling, relative decoupling and non-decoupling. The classification method is shown in table 2.

Table 2

CORRESPONDENCE BETWEEN THE D_r VALUE AND DIFFERENT TYPES OF DECOUPLING

Decoupling State	Economy Increase	Economy Decrease
Absolute decoupling	$D_r \geq 1$	$D_r \leq 0$
Relative decoupling	$0 < D_r < 1$	$0 < D_r < 1$
Non-decoupling	$D_r \leq 0$	$D_r \geq 1$

Laspeyres factor decomposition method

The Laspeyres factor decomposition method was first proposed by Howarth et al. [48] and Park [49] for the comparative analysis of similar research objects. Sun [50, 51] modified the method to effectively solve the residual problem in the traditional algorithm by using the principles of co-creation and equal distribution. This study uses the Laspeyres factor decomposition method to intensively analyse the factors influencing CEs in the textile and clothing industry in terms of industrial scale, industry structure, and technology level, and the CEs accounting formula can be transformed into:

$$CE = \sum_i CE_i = \sum_i TIOV \times \frac{TIOV_i}{TIOV} \times \frac{CE_i}{TIOV_i} = \sum_i TIOV \times I_i \times T_i \quad (3)$$

CE denotes the CE of the textile and clothing industry (tons); $i = 1, 2, 3$ respectively represent the manufacturers of textiles (MT), textile wearing clothing, footwear and caps (MTC) and chemical fibres (MCF); CE_i represents the CE of the sub-industry i; $TIOV$ represents the TIOV of the textile and clothing industry (million \$); $TIOV_i$ represents the TIOV of sub-industry i; I_i represents the proportion of the TIOV of sub-industry i to the TIOV of the textile and clothing industry (%); and T_i represents the CE intensity of sub-industry i (tons/million).

Let I_i^{t-1} be the share of textile and clothing sub-industry i in the TIOV of the textile and clothing industry in year t–1, and T_i^{t-1} be the CE intensity of sub-industry i

in year t–1. According to Sun's complete decomposition model [50], the following equations can be obtained.

$$\Delta CE_{TIOV} = \sum_i \Delta TIOV \times I_i^{t-1} \times T_i^{t-1} + \frac{1}{2}\sum_i \Delta TIOV \,(I_i^{t-1} \times \Delta T_i + T_i^{t-1} \times \Delta I_i) + \frac{1}{3}\sum_i \Delta TIOV \times \Delta I_i \times \Delta T_i \quad (4)$$

$$\Delta CE_{I} = \sum_i TIOV^{t-1} \times \Delta I_i \times T_i^{t-1} + \frac{1}{2}\sum_i \Delta I_i (TIOV^{t-1} \times \Delta T_i + T_i^{t-1} \times \Delta TIOV) + \frac{1}{3}\sum_i \Delta TIOV \times \Delta I_i \times \Delta T_i \quad (5)$$

$$\Delta CE_{T} = \sum_i TIOV^{t-1} \times I_i^{t-1} \times \Delta T_i + \frac{1}{2}\sum_i \Delta T_i (TIOV^{t-1} \times \Delta I_i + I_i^{t-1} \times \Delta TIOV) + \frac{1}{3}\sum_i \Delta TIOV \times \Delta I_i \times \Delta T_i \quad (6)$$

In equations 4–6, ΔCE_{TIOV} is the contribution of industrial scale, ΔCE_I is the contribution of the industry structure factor, and ΔCE_T is the contribution of the technology level factor. If CE^{t-1} is the total CE of the textile and clothing industry in year t–1, and CE^t is the total CE of the textile and clothing industry in year t, then we can obtain the following equation by adding the three terms.

$$\Delta CE_{TIOV} + \Delta CE_I + \Delta CE_T = CE^t - CE^{t-1} = \Delta CE \quad (7)$$

ΔCE represents a change in the CE from the textile and clothing industry from year t–1 to year t. By combining ΔCE and equation 4, the following equation is obtained.

$$\Delta CE_{TIOV} = \Delta CE_{TIOV_1} + \Delta CE_{TIOV_2} + \ldots + \Delta CE_{TIOV_n} \quad (8)$$

Thus, the formula for calculating the contribution of each factor to the CE of subsector i in year t can be derived as follows.

$$\Delta CE_{TIOV_i} = \Delta TIOV \times I_i^{t-1} \times T_i^{t-1} + \frac{1}{2}\Delta TIOV \,(I_i^{t-1} \times \Delta T_i + T_i^{t-1} \times \Delta I_i) + \frac{1}{3}\Delta TIOV \times \Delta I_i \times \Delta T_i \quad (9)$$

$$\Delta CE_{I_i} = TIOV^{t-1} \times \Delta I_i \times T_i^{t-1} + \frac{1}{2}\Delta I_i \,(TIOV^{t-1} \times \Delta T_i + T_i^{t-1} \times \Delta TIOV) + \frac{1}{3}\Delta TIOV \times \Delta I_i \times \Delta T_i \quad (10)$$

$$\Delta CE_{T_i} = TIOV^{t-1} \times I_i^{t-1} \times \Delta T_i + \frac{1}{2}\Delta T_i \,(TIOV^{t-1} \times \Delta I_i + I_i^{t-1} \times \Delta TIOV) + \frac{1}{3}\Delta TIOV \times \Delta I_i \times \Delta T_i \quad (11)$$

ΔCE_{TIOV_i} represents the change in TIOV of the textile and clothing industry from year t–1 to year t, ΔCE_{I_i} represents the change in the share of the TIOV of sub-industry i in the TIOV of the textile and clothing industry from year t–1 to year t, and ΔCE_{T_i} is expressed as the intensity of CE in sub-industry i from year t–1 to year t.

Data Sources

According to China's national economic industry classification method, China's textile and clothing industry classification includes three sub-sectors: MT, MTC and MCF. The TIOV and energy consumption data of enterprises above the designated size in Wenzhou's textile and clothing industry and sub-industries were obtained from the 2005–2019 Wenzhou Statistical Yearbook. Given the inflation and other factors that influence the constantly changing prices, the gross production value of Wenzhou's textile industry was compared with its energy consumption which was calculated by the TIOV comparable price using 2004 as the base period. The nomenclature comparison is presented in table 3.

Table 3

NOMENCLATURE COMPARISON

Abbreviation	Detailed Name
CE	Carbon emission
TIOV	Total industrial output value
MT	Manufacturer of textiles
MTC	Manufacturer of textile wearing clothing, footwear and caps
MCF	Manufacturer of chemical fibers

RESULTS AND DISCUSSION

Descriptive analysis

The change trends of Wenzhou's textile and clothing industry's TIOV from 2004 to 2018 are shown in figure 1. The TIOV of Wenzhou's textile and clothing industry demonstrates an overall trend of rapid increase, smooth fluctuations and slow decline. The TIOV from 2004 to 2010 shows a rapidly increasing trend from 183.4 thousand dollars in 2004 to 667.5 thousand dollars in 2010, with an average annual increase of 24.02%, and the TIOV reached its peak in 2010. The TIOV fluctuated gently from 669.0 thousand dollars in 2011 to 470.2 thousand dollars in 2014 and exhibits a slow downward trend from 715.4 thousand dollars in 2015 to 583.9 thousand dollars in 2018, indicating an average annual decrease of 6.55%. In 2017, the TIOV was the smallest at 502.9 thousand dollars.

The CEs increased first and then decreased. The CE from 2004 to 2006 shows an upward trend, i.e., from 100.56 Kt in 2004 to 136.58 Kt in 2006, indicating an average annual growth of 16.5%, and CE reached the peak in 2006. The CE from 2007 to 2018 shows a downward trend, i.e., from 136.80 Kt in 2007 to 68.06

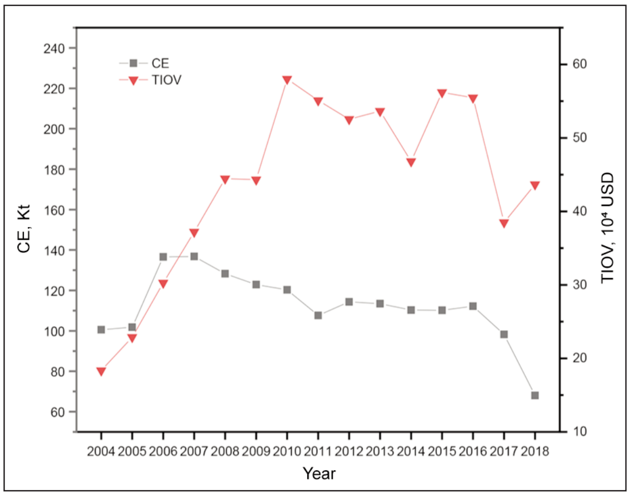

Fig. 1. TIOV and CE of Wenzhou's textile and clothing industry from 2004 to 2018

Kt in 2018, indicating an average annual decline of 6.15%. In 2018, the lowest CE was 68.06 Kt.

Decoupling analysis

The decoupling relationship between the CE and economic growth of Wenzhou's textile and clothing industry is shown in table 4. Table 4 shows that the decoupling state is generally good. From 2005 to 2018, 9 years displayed decoupling (5 years of absolute decoupling, and 4 years of relative decoupling), and 5 years exhibited no decoupling. The most recent five years, i.e., four of the five years from 2014 to 2018, displayed decoupling.

The year 2005 to the year 2007 showed no decoupling, 2008–2011 alternately presented a shock wave decoupling state of 'relative decoupling–absolute decoupling', and 2012 and 2016 were non-decoupling.

The relative decoupling states were observed for 2008, 2010, 2013 and 2015, and the absolute decoupling states were noted for 2009, 2011, 2014, 2017 and 2018.

From 2005 to 2007, Wenzhou's textile and clothing industry developed rapidly. Driven by international and domestic demands, China's entry into the World Trade Organisation (2001) and other factors, Wenzhou's textile and clothing industry's production capacity rapidly increased at an annual rate of more than 20%. Wenzhou, as an important textile and clothing production and export trade city in China, experienced long-term extensive economic growth and had a carbon-based energy consumption structure that led to its high CE. Therefore, the decoupling state at this period was not decoupled. Thus, the coupling relationship between CEs and economic growth was not completely broken.

From 2008 to 2018, 9 years were decoupling, and 2 years were non-decoupling (2012 and 2016). During this period, Wenzhou's textile and clothing industry's economic growth and CE were in a state of decoupling. Firstly, it was in the '11th Five-Year Plan' of China's textile industry (2005–2010), that China's textile and clothing industry's requirements for energy conservation, emission reduction and environmental protection were strengthened. Wenzhou City also actively responded to the call of the state. For example, 'Guiding Opinions of the People's Government of Zhejiang Province on Deepening the Remediation and Promotion of the Heavy Pollution and energy-consuming Industries in the 12th Five-Year Period' [52] and 'Wenzhou the Notice on Comprehensive Implementation Plan for Comprehensive Work on Energy Conservation and Emission Reduction' [53] were proposed for energy-saving technological transformation, with approximately 10 key energy-saving projects, such as textiles, printing and dyeing, and to promote the energy-saving actions of key energy-using enterprises; 'Opinions on Strengthening the Elimination of Backward Production Capacity' [54]

Table 4

DECOUPLING STATE BETWEEN THE CE AND THE ECONOMIC GROWTH OF WENZHOU'S TEXTILE AND CLOTHING INDUSTRY FROM 2004 TO 2018

Year	*t*	*g*	D_r	Decoupling state
2005	–0.0123	0.2477	–0.0621	non-decoupling
2006	–0.3416	0.3227	–1.4002	non-decoupling
2007	–0.0016	0.2289	–0.0085	non-decoupling
2008	0.0625	0.1951	0.3827	relative decoupling
2009	0.0417	–0.0032	–12.8962	absolute decoupling
2010	0.0211	0.3092	0.0895	relative decoupling
2011	0.1056	–0.0505	–1.9843	absolute decoupling
2012	–0.0626	–0.0461	1.2947	non-decoupling
2013	0.0080	0.0209	0.3928	relative decoupling
2014	0.0276	–0.1277	–0.1887	absolute decoupling
2015	0.0012	0.2009	0.0070	relative decoupling
2016	–0.0186	–0.0131	1.4007	non-decoupling
2017	0.1247	–0.3058	–0.2832	absolute decoupling
2018	0.3071	0.1339	2.6001	absolute decoupling

required the textile and clothing industry to eliminate printing and dyeing production lines with an annual processing capacity of fewer than 30 million meters and backward chemical fibre production capacity. Secondly, owing to the strict environmental access standards, Wenzhou strictly implemented the system of linking construction project environmental assessment and approval to regional environmental quality and pollution emission reduction performance and the total balance policy and substitute reduction standards of 'bringing the old with the new', 'increasing production and reducing pollution' and 'regional reduction and substitution'. Thirdly, the environmental supervision of the pollution sources of the gas-related textile and clothing industry was strengthened. Enterprises that emit air pollutants should set up air pollutant discharge outlets by laws, and relevant regulations and adopt effective waste gas treatment measures to reduce CEs and increase industry energy utilisation. Enterprises that could not stably meet the energy utilisation rate of the industry should take measures, such as clean production transformation, intensive pollution control and remediation and transformation within a time limit. Many factors cause CE and economic growth to be decoupled at this stage. Environmental pressures and CEs decreased as the TIOV increased.

The years 2012 and 2016 were not decoupled state. In 2012, the world economy slowed, the economic situation was bad and complicated, and international trade faced great pressure. Wenzhou's textile and clothing industry faced pressure from the continuous growth of domestic textile demand and the tight textile capital, and the CE increased significantly due to the long-term extensive economic growth model. In 2016, the growth rate of China's textile and clothing industry tended to be flat, and the profit margins were compressed. Wenzhou's textile and clothing industry is also affected by many unfavourable factors, such as sluggish domestic and foreign market demands, intensified industry competition, increased resource and environmental constraints, rising production costs and the emergence of new Internet-based business competition models. These and long-term high-speed and unbalanced development have led to problems, such as high low-end production capacity, irrational supply and demand structure and insufficient technological innovation, especially the relative increase in CE caused by companies in the industry with poor product quality, high chemical consumption, high energy consumption and weak production capacity. The CE of Wenzhou's textile and clothing industry increased in 2016 by 1.86% compared to that 2015. Therefore, the states of decoupling during these two years did not seem ideal, that is, they were both in the non-decoupling state.

Laspeyres factor decomposition

The CE of Wenzhou's textile and clothing industry from 2004 to 2018 was decomposed by the Laspeyres factor decomposition method. The three main factors included the industrial scale effect (ΔCE_{TIOV}), the industrial structure effect (ΔCE_I) and the technology level effect (ΔCE_T). The calculation results are shown in table 5 below in which the total effect of the CE of Wenzhou's textile and clothing industry from 2004 to 2018 pulls first and then suppresses, and overall pulling and suppressing trends can be observed from 2004 to 2010 and from 2010 to 2018, respectively. Figure 2 shows that the cumulative effect of industry size is positive for 2004–2018, and the cumulative effect of industry structure and technology level is negative for 2010–2018.

Table 5

CE FACTORS DECOMPOSITION OF WENZHOU'S TEXTILE AND CLOTHING INDUSTRY DURING 2004–2018

Year	ΔCE_{TIOV}	ΔCE_I	ΔCE_T	ΔCE
2005	2.45	–0.21	–0.65	1.59
2006	3.41	–0.04	0.21	3.57
2007	3.35	0.08	–2.05	1.38
2008	3.07	–0.07	–1.52	1.48
2009	–0.16	0.03	–0.46	–0.60
2010	3.85	0.06	–1.81	2.10
2011	0.02	–0.04	–0.47	–0.49
2012	–0.52	–0.02	0.02	–0.52
2013	0.62	0.07	–0.21	0.47
2014	–1.39	–0.04	0.26	–1.16
2015	2.00	–0.22	–0.28	1.50
2016	–0.08	0.05	–0.23	–0.25
2017	–3.67	–0.05	0.08	–3.64
2018	1.26	0.02	–1.76	–0.47
sum	14.22	–0.38	–8.88	4.96

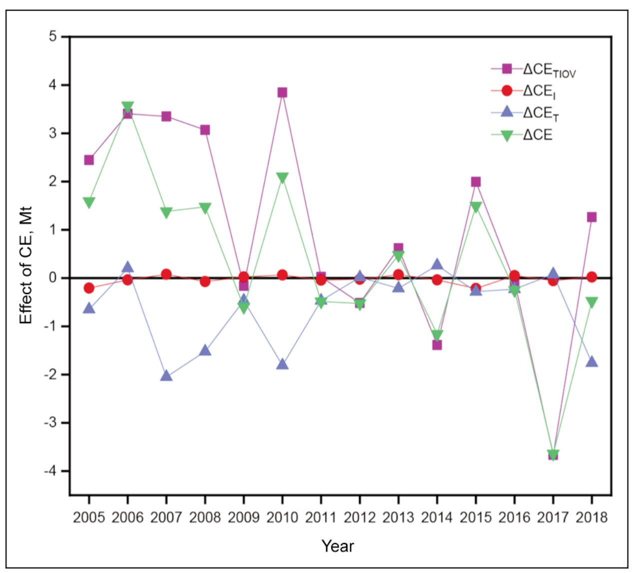

Fig. 2. CE effect decomposition of Wenzhou's textile and clothing industry during 2004–2018

Overall, the industrial-scale effect is positively correlated with the impact of CE in the textile and clothing industry. The CE contributed by the industrial-scale effect in the textile and clothing industry from 2004 to 2018 was 14.22 Mt, and the increase in CE during the eight years was more than the total increase in CE in the same year (figure 2). From 2006 to 2009, the economic development of Wenzhou's textile and clothing industry declined because of two reasons. Firstly, in 2008, China's textile and clothing industry was affected by the financial crisis, the industry-wide economic growth was slow, the MT output growth was slow, and the MTC and MCF output regressed. Correspondingly, the cumulative industrial-scale effect of the three reduced the CE of the textile and clothing industry. Secondly, during the 11th Five-Year Plan period (2006–2010), China had strengthened energy conservation, emission reduction and pollution control, and the Wenzhou Municipal Government issued the '2007 Wenzhou City Rectification of Illegal Sewage Enterprises to Protect the Health of the Masses Environmental Protection Special Action Work Plan' [55], which conducted comprehensive inspections and clean-ups of printing and dyeing enterprises, specifically, enterprises with imperfect pollution control facilities, inability to achieve stable discharge standards and causing serious environmental pollution should all stop production for rectification. From 2010–2018, the cumulative industrial-scale effect was negative, because during the 12th Five-Year Plan period (2010–2015), 'Implementation Plan for Deepening the Regulation and Promotion of Heavy Pollution and High Energy Consumption Industries in Wenzhou During the 12th Five-Year Plan Period' [56] emphasised the resolute closure of small-scale, high-energy consuming, heavy-pollution emitting enterprises and production lines annually. Several companies with a relatively backward production capacity that does not have the advantage of environmental protection, have high pollutant emission intensity and low value-added products were being eliminated. The shutdown of enterprises partly led to the decline in the TIOV of the textile and clothing industry. Meanwhile, in 2011 the developed economies recovered slowly, the decline of textile exports in the international market, coupled with rising labour and energy costs, resulted in a slow economic development trend of the textile and clothing industry from 2011 to 2013. In 2016, the Wenzhou government issued the 'Wenzhou Heavy Pollution Industry Remediation and Enhancement of the Three-Year Action Plan (2016–2018)' [57] according to the 'shut down and eliminate a batch, gather a batch into a park and upgrade a batch' requirements to strengthen pollution prevention and control and ensure strict law enforcement supervision. Consequently, the 2016–2017 industrial-scale effect reduced the contribution value of CE to the textile and clothing industry.

The industrial structure effect on the CE of the textile and clothing industry is small. The cumulative effect of industry structure reduced the CE of the textile and clothing industry by 0.38 Mt from 2004–2018. The industry structure effect led to the largest reduction of CE in the textile and clothing industry in 2015, i.e., 0.22 Mt, and the largest increase of CE in 2007, i.e., 0.08 Mt. The industrial structure of the textile and clothing industry in Wenzhou from 2004–2018 is shown in figure 3. The trend of the economic share of the MT is decreasing, the trend of the economic share of the MTC is relatively flat, and the trend of the MCF is increasing. These trends can be attributed to the following reasons: it is difficult to treat the MT because of its long process chain, a large amount of input chemicals, a large amount of discharge of industrial wastewater and great variation of water quality; the MTC consumes less energy and accounts for a smaller proportion of the CEs; the TIOV of MCF accounts for less of the TIOV of the textile and clothing industry, and its CE is correspondingly smaller. The Wenzhou government has made the following efforts to reduce pollution in the textile and clothing industry. 'The Opinions of Wenzhou People's Government on Strengthening the Work of Eliminating Backward Production Capacity' [58] emphasised the elimination of backward production capacity in the textile and clothing industry, such as the elimination of printing and dyeing production lines whose annual processing capacity is less than 30 million meters; 'Notice of Wenzhou People's Government on the Three-Year Action Plan (2013–2015) for the Elimination of Backward Production Capacity of Wenzhou City' [59] (Notice of Wenzhou People's Government on the Three-Year Action Plan (2013–2015) for the Elimination of Backward Production Capacity of Wenzhou City) (Notice of Wenzhou People's Government on the Three-Year Action Plan (2013–2015) for the Elimination of Backward Production Capacity of Wenzhou City) strengthened the elimination of the printing and dyeing industry, and planned to eliminate 21.5 million meters of backward production capacity in the printing and dyeing industry by 2015; 'Three-Year Action Plan for Upgrading and Developing Wenzhou's Garment Industry (2014–2016)' [60] proposed the

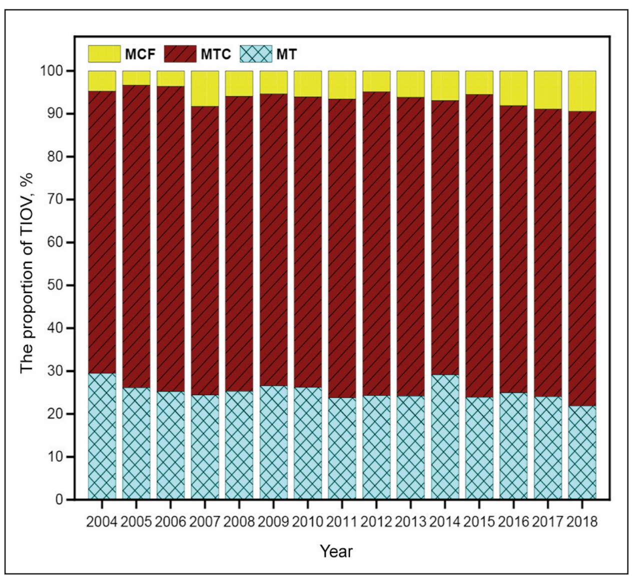

Fig. 3. The industrial structure of Wenzhou's textile and clothing industry from 2004 to 2018

vigorous promotion of the construction of industry-supported fashion blocks and the innovation in marketing models, moving towards fashion and branding to promote the transformation and improvement of the clothing industry. Overall, optimising and adjusting the structure of the industry, promoting brand marketing and strengthening brand building promote the industry structure effect on the suppression of CE in the textile and clothing industry.

The contribution of the cumulative technology level effect on CE is smaller with 8.88 Mt than that of the industrial structure effect. Specifically, the cumulative technology level effect is obvious from 2004 to 2010, and the suppression effect is moderate from 2010 to 2018. The cumulative technology level effect had the best suppression effect on CE in 2007, with 2.05 Mt, followed by those on CE in 2010 and 2018, with 1.81 and 1.76 Mt, respectively. Since the 11th Five-Year Plan (2006–2010), the technical transformation of Wenzhou printing and dyeing enterprises has been increasing, low-energy consumption and high-efficiency equipment have been utilised in the production process of the textile and clothing industry, and the strict control of production emissions has reduced the CE of the textile and clothing industry to a certain extent. Accordingly, the Wenzhou government issued the 'Notice of 11th Five-Year Plan Industrial Upgrading Plan' [61], proposing that the MTC should adopt international advanced technology and process equipment. During the 12th Five-Year Plan period (2011–2015), Zhejiang Province focused on strengthening key common technology research and improving the creative design to increase the added value of products. Technological progress has been used to upgrade the backward production capacity of the textile and clothing industry to reduce energy consumption, protect the environment and ensure quality. Wenzhou City advocates prioritising the development of low-toxicity, low-pollution and low-energy alternative and clean production processes and encourages the use of advanced, environmentally friendly production processes and equipment [56]. This advocacy has kept the cumulative effect of technology level contribution to the CE value of the textile and clothing industry flat. In the 13th Five-Year (2015–2020) period, given the few shortcomings of the Wenzhou textile and clothing industry technology assembly, the Wenzhou government directed the 'Wenzhou Garment Industry Promotion and Development Plan (2014–2020)' [62] and proposed the garment technology development priorities mission to improve product quality, promote the integration of garment production supply chain information, support enterprise technology transformation, improve the level of innovative design, and support the establishment of an enterprise design research and development centre [58]. Given the intensive and difficult protection of intellectual property rights in industries, such as shoes and garments, the garment chamber of commerce was established in Wenzhou City to support the new clothing brand enterprise and cultivate the development of designers. Therefore, the suppression effect of the technology level effect on CE from 2015 to 2017 was robust, and the suppression effect of development in 2018 reached the maximum.

Figure 4 shows the energy structure of Wenzhou's textile and clothing industry from 2004 to 2018. Among the six energy sources, raw coal, electricity and diesel oil are the main contributors to the energy consumption of the textile and clothing industry in Wenzhou, with raw coal and electricity as the main contributors. During the sample period, the proportion of electricity consumption increased, the proportion of raw coal and diesel consumption declined, and the proportion of other energy sources did not change significantly. Among the various energy sources, the CE coefficient of raw coal was second only to coke; the long-term thermal power structure in China placed the CE coefficient of electricity third only to coal [63]. In other words, the electricity and coal-dominated energy sources in Wenzhou's textile and clothing industry contribute a large amount of CE. The Wenzhou government has made many efforts to save energy and reduce emissions. The following is an example from three periods. During the 11th Five-Year Plan period (2005–2010), the office of the Wenzhou municipal people's government issued the 'Notice on Implementation Plan for the Comprehensive Work of Promoting Energy Conservation and Emission Reduction in Wenzhou' [64] that proposed to promote the adjustment and optimisation of the energy structure. Specific measures include promoting the clean and efficient use of coal, continuously optimising the electrical structure, and accelerating the research on strategies for the use of renewable energy, including wind power, solar power, waste incineration and straw power. During the 12th Five-Year Plan period (2010–2015), 'Wenzhou's Energy Development 12th Five-Year Plan' proposed the following development goals: enhance the energy supply capacity, build the province's important electric energy production base,

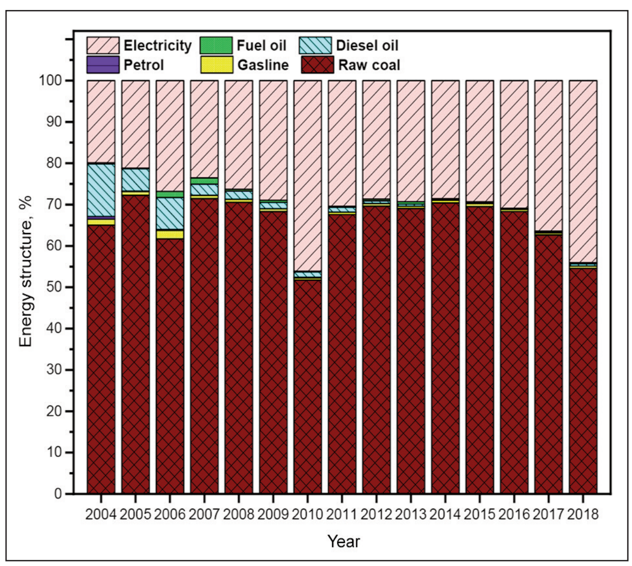

Fig. 4. Energy structure of Wenzhou's textile and clothing industry

build the province's new energy development and utilisation demonstration zone, and build the province's important energy equipment industry base. During the 13th Five-Year Plan period (2015–2020), the office of the Wenzhou municipal people's government issued the 'Notice of the 13th Five-Year Plan for Energy Development in Wenzhou' [65] that focused on promoting wind power, a new generation of biofuels and other technological innovation, vigorously developing non-fossil energy, effectively strengthening the clean utilisation of coal, and promoting the implementation of electric power substitution.

CONCLUSIONS

CE is an important factor in measuring the sustainable development of the region. This study accounts for and analyses the relationship between the CE and economic growth of the textile and clothing industry in Wenzhou and the three factors that affect the CE of the textile and clothing industry, providing a reference for the formulation of energy policies and sustainable development in Wenzhou. The conclusions of this study are as follows.

- Wenzhou's TIOV generally shows a fluctuating trend. The TIOV from 2004 to 2008 shows a continuous upward trend, with an average annual growth of 24.78%. The TIOV from 2008 to 2018 show downward and then upward trends, with the largest TIOV in 2015 at 715.4 thousand dollars and the highest and lowest gross values of output from the textile and garment industry in 2010 at 580.2 thousand dollars and in 2004 at 183.44 thousand dollars, respectively.
- The decoupling status of CE and economic growth in Wenzhou's textile and clothing industry from 2005–2018 is generally good, with 9 years out of 14 years of decoupling (5 years of absolute decoupling and 4 years of relative decoupling) and 5 years of non-decoupling. This condition is mainly attributed to the implementation of national energy conservation and emission reduction policies and the strengthening of environmental protection. Owing to the demand from both international and domestic markets, Wenzhou's a textile and clothing industry has flourished, with a growth trend in the gross industrial product, but it also leads to an increase in the CE. Wenzhou attaches great importance to energy-saving emission reduction and transformation and the upgrade of textile and clothing enterprises and helps enterprises transform and upgrade through technical subsidies, financial subsidies, intelligent manufacturing transformation and other measures. However, technical problems and insufficient capital have put pressure on several small and medium-sized enterprises, which have reduced the TIOV of the textile and clothing industry to a certain extent. Therefore, Wenzhou City should not only implement an energy-saving emission reduction policy but also should address the transformation of small and medium-sized enterprises according to the local conditions.
- The cumulative industrial-scale effect drives the increase of CEs, the industrial structure and technology level effects inhibit the increase of CE, and the technology level effect has a small influence on the CE of the textile and clothing industry. To reduce energy consumption, the textile and clothing industry must modify the industry structure and improve the technology level. Thus, new textile materials and green manufacturing technology should be the focus of research, eco-friendly chemicals must be developed to reduce the generation of pollutants from the source, and the use of natural gas, liquefied petroleum gas and other clean energy in the production process must be promoted. The influence of industrial-scale effect on CEs is the driving effect which means that the implementation of energy policy has not solved the problem of producing large amount of pollution caused by the production. Thus, Wenzhou's textile and clothing industry should expedite the adjustment of the industrial structure and focus on promoting independent innovation capacity.

With the transformation of the global economic situation, the development of Wenzhou's textile and clothing industry is facing many opportunities and challenges. With the current industrial structure of China's textile and clothing industry, economic development inevitably brings environmental degradation and CE increase. Therefore, optimising the industrial structure remains the most important reform for Wenzhou's textile and clothing industry. Meanwhile, enterprises should enhance the concept of environmental protection and accelerate the development of a circular economy in the textile and clothing industry to achieve the reuse of waste from the production of textile products. Technology level effect is the core of CE suppression. Therefore, promoting the innovation of products and production technology; vigorously developing new materials, processes and technology; and enhancing the network of product production, intelligence and automation are necessary endeavours. The government should enhance the formulation of policies and standards, strictly supervise textile enterprises, strictly prohibit the input and output of serious polluting substances and reduce CEs from the source. Furthermore, the process of Wenzhou's clothing industry's branding and fashion must be accelerated, and international brands must be actively created for a good fashion atmosphere.

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