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Article

Decoupling Water Consumption and Environmental Impact on Textile Industry by Using Water Footprint Method: A Case Study in China

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Abstract: The rapid development of China's textile industry leads to consumption and pollution of large volumes of water. Therefore, the textile industry has been the focus of water conservation and waste reduction in China's 13th Five-Year Plan (2016–2020). The premise of sustainable development is to achieve decoupling of economic growth from water consumption and wastewater discharge. In this work, changes in blue water (water consumption), grey water (water pollutants), and water footprints of the textile industry from 2001 to 2014 were calculated. The relationship between water footprint and economic growth was then examined using the Tapio decoupling model. Furthermore, factors influencing water footprint were determined through logarithmic mean Divisia index (LMDI) method. Results show that the water footprint of China's textile industry has strongly decoupled for five years (2002, 2006, 2008, 2011, and 2013) and weakly decoupled for four years (2002, 2007, 2009, and 2010). A decoupling trend occurred during 2001–2014, but a steady stage of decoupling has not been achieved yet. Based on the decomposition analysis, the total water footprint is mainly increased by production scale and inhibited by the technology. In addition, the effect of industrial structure adjustment is relatively weak.

Keywords: textile industry; water footprint; economic growth; decoupling; decomposition

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1. Introduction

The concept of decoupling, which originated from physics field, indicates the reduction or elimination of the mutual relationship between two or more physical quantities. Decoupling analysis is widely applied and has received great attention in studies of economic growth in relation to resource consumption and environmental pressure. Decoupling refers to breaking the link between economic wealth growth and environmental hazards. Achieving decoupling between economy and environment is the key step for implementing green economic development, which is the basic goal of human development that proposed by the Organization for Economic Cooperation and Development [1]. Decoupling can be achieved by forcing people to rethink the nexus among resource utilization, environmental quality, and economic growth [2].

Decoupling has been increasingly used to measure the relationship between resource consumption (environmental damage) and economic development [3–9]. In studies of industrial

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water consumption (environmental damage), decoupling refers to the dependence between economic growth and water consumption (environmental damage) fades out to unrelated. Previous studies focused on the decoupling relationship between industrial water consumption and economic growth [10–12] or between wastewater discharge and economic growth [13–16]. Only one of the water resources or environmental effect is considered in former studying the decoupling relationship. However, improvement of integrated water management in the industrial sector requires simultaneous reduction in water consumption and wastewater discharge. Over stringent resource control policies and unduly lenient environmental constraints do not efficiently promote the sustainable and healthy development of the industry. Hence, the overall industrial growth in the "resources and environment" system should be considered. Water resource management cannot be comprehensively evaluated nor effectively promoted without introducing the environment as an important factor in resource-economic dual system research or the resource in the environmental-economic binary system research. Scholars have attempted to establish a comprehensive decoupling system by combining resources and environment with empirical or expert consultation methods. Li et al. [17] evaluated the decoupling status among resources, environmental pressure, and economic development in Chongqing metropolitan area in China. Ge et al. [18] cited the aforementioned method in the study of China's Yangtze River delta region. Expert consultation method, which has strong subjectivity, and empirical method, which causes deviation in calculation results, cannot appropriately reflect the real condition. By contrast, water footprint method provides an objective way to scientifically integrate water resource and water environmental science as one factor; this technique can be used to accurately perform decoupling analysis.

Wang [19] defined and calculated the blue and gray water footprints of China's textile industry and analyzed the decoupling relationship between these footprints and economic growth. The results showed that the blue and grey water footprints were both in a decoupling trend, indicating the improvement in water saving and wastewater discharge reduction in the textile industry. Zhang et al. [20] performed a case study in Heilongjiang Province of China by integrating water footprint method into the decoupling relationship analysis of agricultural output with water consumption and environmental impact of crop production. Strong decoupling frequently occurred in the analysis of agricultural water consumption of crop production. Gilmont [21] calculated the food industry water footprints of Middle East and North Africa countries in 1961–2009 and analyzed the decoupling of the water footprint of the food industry from social development. Increasing the proportion of imported foods in food consumption will reduce the domestic or even global blue water footprint. Pan et al. [22] used water footprint to represent water resource utilization in Hubei Province of China and investigated the decoupling relationship between the footprint and economic growth. The decline in decoupling water footprint and GDP growth weakened. These studies show that water footprint method is feasible in decoupling studies. However, this technique does not consider water resources and water environment as an organic system. As such, the present study aims to integrate water resources and water environment into water footprint method and analyze the decoupling relationship between water footprint and economic growth. The textile industry is selected as an example because it consumes the great amount of water and mainly causes water pollution in China. We also determine factors influencing decoupling and propose corresponding countermeasures and suggestions.

2. Study Object

Textile is related to people's daily lives. China's textile industry has a long history, and Chinese silk mainly affects world civilization communication dating from 2000 years ago. The textile industry is China's traditional pillar industry and belongs to the first batch of the China's industrial sector. The textile industry has a core position because the products are related to the livelihood of the people and the industry greatly contributes to China's national economy. In 2014, the total output value of China's textile industry reached 1,684.18 billion Yuan (constant price in 2014), with an average annual increase of 34.37% compared with that in 2001 [23–24]. The textile industry employs more than 10 million people, which reached 8.74% of China's industrial employment in 2014 [25]. The textile

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industry utilizes raw materials derived from agriculture and is related to the livelihood of 100 million Chinese farmers [26]. China has become the largest textile exporter worldwide and possesses the largest production scale, thereby providing affordable and superior-quality textile products. In 2014, the total of amount of textiles imported from China reached US $ 111.662 billion, accounting for 35.56% of the total global textile export market; the amount increased from 24.15% in 2001 [27]. In terms of earning foreign exchange through exports, the accumulated trade volume of China's textile and apparel industry in 2014 was US $ 334.333 billion, with a cumulative surplus of US $ 279.583 billion; hence, this industry plays an important role in ensuring China's foreign exchange reserves and maintaining balance in international payments [28].

Economic growth of textile industry is costly in terms of water resources and environment. China's textile industry consumes a total of 864.7 Mt water and ranked No. 7 in 41 chief industrial sectors, accounting for 6.3% of the total water consumption. In addition, the water repetition rate and water productivity are 63.66% and 51.34 million tons/10^4 Yuan, respectively, which are lower than the average values (89.46% and 0.9412 million tons/10^4 Yuan). As such, the textile industry should take adequate responsibility for water pollution in China. The wastewater emissions of this industry reached 1960 Mt in 2014, which ranks third in 41 industrial sectors and constitutes 10.5% of the China's total industrial wastewater discharge [24]. In the eastern coastal areas in China where the textile industry is concentrated, villages with poor water quality, limited water supply and high incidence of cancer; in these areas, the textile industry places great pressure on resources and environment and poses a threat to public health [29]. Hence, water efficiency and sewage discharge reduction must be improved.

In 2016, the Chinese government aimed to reduce the water consumption of unit industries by 23% and the total discharge of major pollutants by 10% until 2020 [30]. However, whether the textile industry can successfully reduce its water consumption and discharge remains unclear. Moreover, strategies for developing the economy while reducing the pressure on water resources and environment remain to be established. This study addresses these concerns through decoupling analysis of the water footprint and economy in the textile industry water.

3. Methodology and Data

3.1. Water Footprint

Water footprint is used as supplementary indicator of traditional water consumption statistics [31]; water footprint is defined as the total amount of water resources required by a country, a region, or a person for all products and services consumed within a given period of time [32]. Water footprint is derived from a particular process in the production chain, from the final product, or from the consumer, product, or economic sector. We also use geographic perspectives to analyze water footprint across different spatial scales, such as watersheds, prefectures, provinces, countries, and even worldwide [33]. Thus, water footprint approach can use water footprints of a process [34–35], product and consumer (group) [36–37], nation or region [38–39], industry [40], and corporation [41, 42]. In the industrial sector, water footprint refers to the total amount of fresh water directly or indirectly consumed by the product and includes the consumption and pollution of all process water in the production chain [43]. Water footprint is a comprehensive indicator; on the one hand, the footprint accounts for the total amount of water consumption that reflects the production process; on the other hand, the footprint accommodates the total amount of pollutants in the water that reflects the environmental impact of the production process [44].

Water footprint can be categorized into blue, green, and gray water footprints [32]. In the textile industry, the blue water footprint refers to the consumption of surface water or groundwater resources in the production chain of the textile industry. The green water footprint is the amount of rainwater consumed in the production and the total amount of water in soil air; this footprint is negligible in the study because of minimal consumption. The gray water footprint indicates water resources required to enclose contaminants during the production. The blue water footprint can be directly calculated using the water consumption of the textile industry. The gray water footprint can

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be determined using the total amount of fresh water required to assimilate the pollutant load before the wastewater treatment of the textile industry, with the natural background concentration and the existing water quality environment as benchmarks [19].

Calculation methods are as follows:

$$WF = WF_b + WF_{gy} \quad (1)$$

$$WF_b = W_u \quad (2)$$

$$WF_{gy} = max\left[\frac{L[k]}{C_s[k] - C_n[k]}\right] \quad (3)$$

where WF is the water footprint (Mt/a); WF_b is the blue water footprint (Mt/a); WF_{gy} is the gray water footprint (Mt/a); W_u is the textile industry water (Mt/a); $L[k]$ is the amount of pollutant *k* in the textile industry (Mt/a); $C_s[k]$ is the concentration limit of contaminant *k* (Mt/a), as specified in the pollutant discharge standard; and $C_n[k]$ is the concentration of pollutants *k* in natural water (Mt/a), assumed as 0 Mt/a in this study.

3.2. Decoupling Method

Decoupling elasticity method, proposed by Tapio [45], is commonly used to characterize the direction and degree of decoupling. In the decoupling study of resource consumption (environmental damage) and industrial economic growth, the decoupling elasticity coefficient is defined as the ratio of the change rate of the base and current resource consumption or environmental pressure to the rate of change in economic conditions over a certain period of time. The calculation method is as follows:

$$D = \frac{\%\Delta VOL}{\%\Delta G} = \frac{(VOL_t - VOL_{t-1}) / VOL_{t-1}}{(G_t - G_{t-1}) / G_{t-1}} \quad (4)$$

In the formula (4), D is the elastic coefficient; VOL_t, VOL_{t-1} represent the environmental stress in year *t* and year *t-1*, respectively; and the corresponding G_t, G_{t-1} represent the GDP in year *t* and year *t-1*, respectively. $\%\Delta VOL$ (Growth rate of resource consumption or environmental pressure) and $\%\Delta G$ (growth rate of economy) are obtained by calculating the corresponding data at two time points. The decoupled state is defined by the range of elastic values, and the eight levels of decoupling and range of elastic values are shown in Table 1 [45].

Table 1. Criteria of decoupling status.

	Status	Elastic Values
Negative decoupling	Expansive negative decoupling	$\Delta VOL>0, \Delta G>0, D \in (1.2,+\infty)$
	Strong negative decoupling	$\Delta VOL>0, \Delta G<0, D \in (-\infty,0)$
	Weak negative decoupling	$\Delta VOL<0, \Delta G<0, D \in [0,0.8]$
Decoupling	Weak decoupling	$\Delta VOL>0, \Delta G>0, D \in [0,0.8]$
	Strong decoupling	$\Delta VOL<0, \Delta G>0, D \in (-\infty,0)$
	Recessive decoupling	$\Delta VOL<0, \Delta G<0, D \in (1.2,+\infty)$
Coupling	Expansive coupling	$\Delta VOL>0, \Delta G>0, D \in [0,0.8]$
	Recessive coupling	$\Delta VOL<0, \Delta G<0, D \in [0.8,1.2]$

According to the magnitude of elasticity class, the decoupling state is categorized into negative decoupling, decoupling, and coupling, which are further classified as expansive negative decoupling, strong negative decoupling, weak negative decoupling, weak decoupling, strong decoupling, recessive decoupling, expansive coupling, and recessive coupling. Strong decoupling is the ideal

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decoupling state because of the decline in resource consumption or environmental pressure with economic growth. Strong negative decoupling is the worst case because of the simultaneous recession and increased consumption of resources or environmental pressure.

3.2. Water Footprint Decoupling Model

According to Formulas (2) – (4), we establish models for decoupling of economic growth with water consumption and water pollution:

$$D_{G-WF_b} = \frac{\%\Delta WF_b}{\%\Delta G} = \frac{\%(WF_{b}{}^{t} - WF_{b}{}^{t-1})\,G_{t-1}}{\%(G_t - G_{t-1})\,WF_{b}{}^{t-1}} \tag{5}$$

$$D_{G-WF_{gy}} = \frac{\%\Delta WF_{gy}}{\%\Delta G} = \frac{\%(WF_{gy}{}^{t} - WF_{gy}{}^{t-1})\,G_{t-1}}{\%(G_t - G_{t-1})\,WF_{gy}{}^{t-1}} \tag{6}$$

where D_{G-WF_b} is the decoupling index of the blue water footprint, and $\%\Delta WF_b$ is the annual change rate of the blue water footprint. In Equation (6), $D_{G-WF_{gy}}$ represents the decoupling index of the gray water footprint, and $\%\Delta WF_{gy}$ refers to the annual change rate of the water environmental impact. Substituting *WF* into Equation (4), we obtain the decoupling model of water footprint and economic growth:

$$D_{G-WF} = \frac{\%\Delta(WF_b + WF_{gy})}{\%\Delta G} = \frac{\%\Delta WF}{\%\Delta G} = \frac{\%(WF_t - WF_{t-1})\,G_{t-1}}{\%(G_t - G_{t-1})\,WF_{t-1}} \tag{7}$$

where D_{G-WF} is the decoupling elasticity index between the water footprint and the gross output value of the textile industry. We can judge the decoupling states by calculating the elasticity index. WF_t, WF_{t-1} represent the textile industry water collection in year *t* and year *t-1*, respectively. G_t, G_{t-1} indicate the output value of the textile industry in year *t* and year *t-1*, respectively. $\%\Delta WF$ (change rate of water footprint of textile industry) and $\%\Delta G$ (rate of change of total output value of textile industry) can be obtained by calculating the corresponding data at two time points.

3.4. LMDI Method

Decomposition method mainly aims to decompose changes in a target variable into several influencing factors to discern the influence degree of each factor (contribution rate); this method can be used to objectively determine actors with high contribution. LMDI method is a commonly used decomposition method [46–48] and can be divided into multiplication [49] and addition modes [50]. LMDI decomposition method in both multiplication and addition modes can obtain reasonable decomposition results with specific relationships; hence, the results are converted through the corresponding mathematical formula [46]. The decomposition margin in the addition mode of LMDI decomposition is zero; the decomposition result is not affected by the zero value present in the data [50]. In this regard, the current study employs LMDI addition mode to decompose water footprint. Factors affecting water footprint in the textile industry are divided into three aspects: industry size, industry structure, and technology. Water footprint can be calculated as:

$$WF = \sum WF_i = \sum G \times \frac{G_i}{G} \times \frac{WF_i}{G_i} = \sum G \times S_i \times WFI_i \tag{8}$$

where WF_i is the industrial water footprint of the textile sub-industry *i*; G_i is the total industrial output value of *i* (in million); G_i/G is the proportion of the total industrial output value of *i* to the total industrial output value of the textile industry, representing the structural factor of the industry (S_i); and WF_i/G_i is the water footprint consumed per unit of production value and also called the water footprint intensity, which represents the technical level factor (WFI). $WF(t)$ is defined as

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the water footprint of the textile industry in year *t*, and $WF(t-1)$ is defined as the water product of the textile industry in year *t-1*. The decomposition of annual water footprint change ΔWF can be expressed by the following formula:

$$\begin{aligned}\Delta WF &= WF(t) - WF(t-1)\\ &= \sum G(t)\times S(t)\times WFI(t-1) - \sum G(t-1)\times S(t-1)\times WFI(t-1)\\ &= \Delta WF_G + \Delta WF_{S_i} + \Delta WF_{WFI_i}\end{aligned} \quad (9)$$

where ΔWF_G is the contribution of industrial structure to the annual change in the water footprint of the textile industry (Mt/a); ΔWF_{S_i} is the contribution of industrial structure to the annual change in the water footprint of the textile industry (Mt/a); and ΔWF_{WFI_i} is the contribution of technical level to annual changes in the water footprint of the textile industry (Mt/a). The contribution of each factor can be calculated by the following formula:

$$\Delta WF_G = \sum \frac{WF(t) - WF(t-1)}{\ln WF(t) - \ln WF(t-1)} \times \ln \frac{G(t)}{G(t-1)} \quad (10)$$

$$\Delta WF_{S_i} = \sum \frac{WF(t) - WF(t-1)}{\ln WF(t) - \ln WF(t-1)} \times \ln \frac{S(t)}{S(t-1)} \quad (11)$$

$$\Delta WF_{WFI_i} = \sum \frac{WF(t) - WF(t-1)}{\ln WF(t) - \ln WF(t-1)} \times \ln \frac{EFI(t)}{WFI(t-1)} \quad (12)$$

3.5. Data

Sub-sectors of the textile industry can be classified based on the characteristics of the industry in the Statistical Yearbook (Table 2) based on the China's National Economic Industry Classification Standard (GB/T 4754) [51]. The data of the textile industry are aggregated from the data of three sub-sectors.

Table 2. China's textile industry names and classifications.

	Sub-Sectors	The Name in the China's Statistical Yearbook
Textile Industry	Textile industry	Textile industry
	Garment Industry	Clothing and other fiber products manufacturing; Textile and garment, shoes, hats manufacturing; textile and garment, apparel industry
	Chemical fiber industry	Chemical fiber industry

This study is based on annual data covering the period of 2001 to 2014. The value of textile industrial output (converted to 2014 constant prices), total consumption of textile industrial water, and wastewater contaminants are collected from the China Environment Yearbook (2002–2006) and China Environmental Statistics Annual Report (2006–2014) [23–24]. The recorded total industrial water from chemical fiber manufacturing industry was 2055 Mt in 2012, which significantly deviated from the values with year temporally adjoining. Therefore, the calculated result could be considered as invalid. In this regard, we adopt the value of 4055 Mt according to the trend in the recent years.

In Formula (3), *CS[k]* adopts the relevant provisions of the concentration limit standard in the water pollutant discharge standard (GB13458-2013) issued by the Ministry of Environmental Protection of China on February 25, 2013 [52] (Table 3).

Table 3. Emission limits for waste water pollutants in the textile industry.

Unit: mg / L

Limits of pollutant species	Limits
PH	6-9
COD_{Cr}	100
BOD_5	25
Suspended matter	60
Chroma	70
Aniline	1.0
Total nitrogen	20
Total phosphorus	1.0
Chlorine Dioxide	0.5
Adsorbable organic halogen	15
Sulfide	1.0
Ammonia nitrogen	12
Hexavalent chromium	0.5

According to Formula (3), pollutant content in waste water, and data shown in Table 3, the present study calculated the gray water footprint of the textile industry. Based on the actual situation of wastewater discharge in the China's textile industry with COD as the main measurement standard, the total amount of fresh water needed to absorb the assimilated COD was used as reference for determining the gray water footprint.

4. Results and Discussion

4.1. Water Footprint of Textile Industry

Figure 1 shows the output value and water footprint of China's textile industry in 2001–2014. The overall output values of the industry exhibited a rapid upward trend, from 308.03 billion Yuan in 2001 to 1684.18 billion Yuan in 2014. Industrial output presented a substantially increasing trend, except for a slight decline in 2012. The overall tendency is divided into two phases. The first phase (2001–2011) is a rising stage, where the gross industrial output value rapidly increases and the development momentum is satisfactory. The second stage (2012–2014) is the fluctuation phase, where the growth rate of industrial output value evidently declines.

During the sampling period, the water footprint of China's textile industry increased with the growth of the total output value of the textile industry in seven years (2002, 2004, 2005, 2007, 2009, 2010, and 2014). The water footprint decreases with the decline in textile industry output value in one year (2012) and with the increase in the textile industry output in five years (2003, 2006, 2008, 2011, and 2013). The overall trend of the water footprint is an inverted "U" type, which can be divided into two stages. A fluctuating upward trend was detected in 2001–2007. The water footprint increased from 10325.78 Mt/a in 2001 to 14044.83 Mt/a in 2007 at this stage. The water footprint of the second stage (2008–2014) decreased. The water footprint from 2007 to 2010 was maintained at a high value of 13816.18 Mt/a. In 2011, the water footprint sharply dropped to 12507.11 Mt/a. In 2014, the water footprint slightly increased to 12623.19 Mt/a, which is mainly related to the regain in the blue water footprint. In general, during the sampling period, the China's textile industry has controlled the amount of wastewater discharge and achieved significant effects on wastewater management. However, water consumption is not stable; several issues on water-saving aspects of management remain unresolved.

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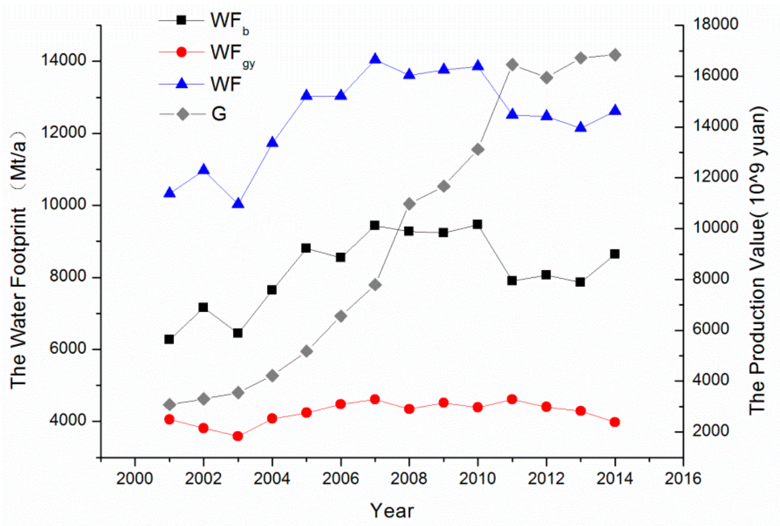

Figure 1. Changes in total output and water footprint of China's textile industry (2001–2014).

4.2. Analysis of Decoupling Models

Table 1 shows the results of decoupling elastic calculation between water footprint and economic growth from 2002–2014. The water footprint exhibited the following statutes: strong decoupling with the industrial output value for five years (2003, 2006, 2008, 2011, and 2013), weak decoupling for four years (2005, 2007, 2009, and 2010), expansive coupling in 2004, weak negative decoupling in 2012, and expansive negative decoupling in 2014.

Table 4. Decoupling of water footprint and economic growth in China's textile industry (2002–2014).

Year	%△G	%△WF	$D_{G\text{-}WF}$	Degrees of decoupling/coupling
2002	7.15%	6.29%	0.88	Expansive coupling
2003	7.66%	-8.61%	-1.12	Strong decoupling
2004	18.67%	16.93%	0.91	Expansive coupling
2005	22.86%	11.18%	0.49	Weak decoupling
2006	26.64%	-0.08%	-0.003	Strong decoupling
2007	18.85%	7.79%	0.41	Weak decoupling
2008	40.73%	-3.09%	-0.08	Strong decoupling
2009	6.38%	1.09%	0.17	Weak decoupling
2010	12.40%	0.68%	0.05	Weak decoupling
2011	25.39%	-9.71%	-0.38	Strong decoupling
2012	-3.09%	-0.35%	0.11	Weak negative decoupling
2013	4.84%	-2.58%	-0.53	Strong decoupling
2014	0.75%	3.96%	5.27	Expansive negative decoupling

The decoupling between water footprint and economic growth is generally considered satisfactory. Factors affecting the tendencies observed were analyzed by splitting the study period into three intervals.

From 2002 to 2004, the decoupling situation of the water footprint from economic growth was unstable, alternating between expansive coupling and strong decoupling. This phenomenon could be due to China's accession to WTO in 2001, thereby stimulating the investment and demand of the textile industry. Thus, the industry was regarded to be in a florescent growth period. In this context, the textile enterprises are significant to the pace of economic development. These enterprises exploited the environment in exchange for economic growth. The differences between the economy and environment of the textile industry have intensified because of the lack of total water control coupled with backward production technology and equipment. China began to implement the new Water Law of the People's Republic of China in 2002 to encourage companies to use advanced technology, processes, and equipment; this law aims to increase the number of cycles of water and the water recycling rate. The law clearly declares that the main actors of illegal water pollution shall bear legal responsibility [53]. The textile industry actively adjusted the structure, reduced the water consumption, and strengthened the pollution control to initially improve the state of decoupling in 2003.

From 2005 to 2011, the decoupling of water footprint and economic growth was positive. Although the development of China's textile industry remain independent on the water footprint, the negative effect of economic development on the water environment was attenuated compared with the previous stage. First, the technology of China's textile industry was developed in the "Eleventh Five-Year" period (2006–2010). Technology and equipment was rapidly updated, and backward production capacity was gradually removed from the market. The entire industry technology, equipment level, and production efficiency steadily increased, resulting in effective reduction of the water consumption and sewage discharge. Second, the Chinese government has promulgated a series of policy documents related to its industry access, technological innovation, and improvement; these policies include the Law of the People's Republic of China on Prevention and Control of Water Pollution initiated from 2008 [54]; and the issued opinions on Further Strengthening Industrial Water Saving Work of the Ministry of Industry and Information Technology (MIIT) (MIIT [2010] No. 218) [55]. The law forces enterprises to increase their investment in water pollution control, upgrade the production equipment and processes, and improve the water environment. However, from the views of decoupling elastic values, the water footprint of the textile industry and economic growth is not a stable decoupling. In the year of strong decoupling, the absolute value of the elasticity coefficient is less than 0.1 for two years. Specifically, the elastic coefficient in 2006 is -0.003, which is close to the critical value of strong decoupling. In the year of weak decoupling, only the decoupling index (0.05) of 2010 is close to the critical value of the decoupling strength. Thus, the water saving and emission reduction work of the textile industry must be further improved.

In 2012–2014, strong decoupling and negative decoupling alternately occurred between water footprint and economy because China's textile industry underwent structural adjustment and transformation. The backward production was repeatedly constructed in central and western regions. In 2014, the number of textile enterprises in the central region was 36301, an increase of 1364 compared with that in 2012 [24]. In the process of industrial relocation, reduced environmental protection requirements is one of the favorable conditions for industrial transfer and investment promotion in some central and western regions. This condition affects and destroys the relatively fragile water environment in central and western regions, resulting in terrible decoupling results. Particularly in 2012, the cost of the textile industry continuously increased, thereby weakening the international comparative advantage. Since then, the economy exhibits negative growth, leading to the current state of weak negative decoupling. By contrast, state environmental standards continue to improve. For example, the State Council issued the State Council on the Implementation of the Most Stringent Water Management System View (Guo Fa [2012] No. 3) [56]. In the same year, China's Ministry of Environmental Protection introduced a new Standard for Discharge of Water Pollutants for Textile Dyeing and Finishing Industry (GB 4287-2012) [57]. The law further constricts the standards for wastewater discharge, forcing companies to increase their investment in environmental protection funds, improve the production processes, reduce the waste water discharge, and increase the wastewater treatment capacity to improve the decoupling status. The increase in the water footprint of the textile industry has exceeded the industrial output value in 2014, and the elastic coefficient is 5.27, showing a negative expansion in passive decoupling state. This phenomenon, combined with changes in water footprint, could be due to rapid increase in water consumption of the textile industry in 2014. Economic development and water consumption re-combined. The relation of the enterprise and the government will prevail for a long time.

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4.3 Decomposition Analysis

Table 5 and Fig. 2 show the results of the decomposition of the water footprint of China's textile industry from 2002 to 2014. Industrial scale factor showed the major positive contribution to the textile water footprint, except for 2012. From 2002 to 2014, the average contribution of industrial scale factors to water footprint growth was 1674.55 Mt/a, which is higher than the industrial structure factor (-3.06 Mt/a) and the technical level factor (-1494.78 Mt/a). The industrial scale significantly influenced the water footprint in 2002–2011, with contribution of 4724.20 Mt/a in 2008, reaching the maximum value in the sample period. As a labor-intensive industry, the textile industry expands the industrial scale through China's labor-rich and low-cost advantages.

The effect of internal structure on water footprint is not evident. From 2002 to 2014, the contribution of industry structural factor to the water footprint remained positive for six years and negative for seven years. Industry structural factor contributed lower absolute value compared with the other two factors; particularly, the maximum value of the contribution in 2007 is 1158.26 Mt/a, and only within 100 Mt/a in four years (2004, 2005, 2011, and 2013). The structure of the industry has limited effect on the water footprint. Hence, the structure of China's textile industry was not significantly changed; China is still in the international division of labor in the low-end links. The industrial structure of the water footprint of the inhibitory effect is more apparent with the adjustment and upgrading of the structure.

Technical factor is important to reduce the water footprint of China's textile industry. In addition to 2013 and 2014, the contribution of technical factors to the water footprint is negative, reaching a maximum of -4323.21 Mt/a in 2011. Although the inhibition of the water footprint growth fluctuates, technology remains the largest contributor. Textile Industry Development Plan (2016-2020) [30] showed that the valid invention patents of large and medium textile enterprises reached 5381 Mt/a in 2014, which was 2.3 times higher than that in 2010. During the "Twelfth Five-Year Plan", a large number of new energy-saving and emission reduction technology is widely used; the printing and dyeing of cloth using 100 m of fresh water is performed to reduce water consumption from 2.5 ton down to 1.8 tons, and increase water reuse rate of 15% to over 30%. The textile industry has completed a comprehensive increase in value-added energy consumption reduction, water abatement, pollutant emission reduction, and other binding targets. Reuse of fiber accounting for the proportion of total fiber processing increased from 9.6% in 2010 to 11.3% in 2015. In the future, the technology level will remain the most important factor to inhibit the growth of water footprint; as the technology advances and matures, the inhibition of water footprint will increase and become stable.

Table 5. Decomposition analysis of water footprint factors for China's textile industry, 2002-2014.

Year	$\triangle WF_G$(Mt /a)	$\triangle WF_{Si}$(Mt /a)	$\triangle WFI_i$(Mt /a)
2002	734.88	351.72	-437.15
2003	773.93	-485.78	-1233.45
2004	1856.60	-67.75	-90.99
2005	2546.43	5.16	-1239.96
2006	3077.94	-419.49	-2668.28
2007	2336.59	1158.26	-2479.61
2008	4724.20	-1076.68	-4081.96
2009	845.91	-657.46	-40.77
2010	1613.06	1053.40	-2573.08
2011	2976.76	2.10	-4323.21
2012	-391.61	-126.59	475.01
2013	581.83	-50.48	-852.59
2014	92.63	273.81	113.95

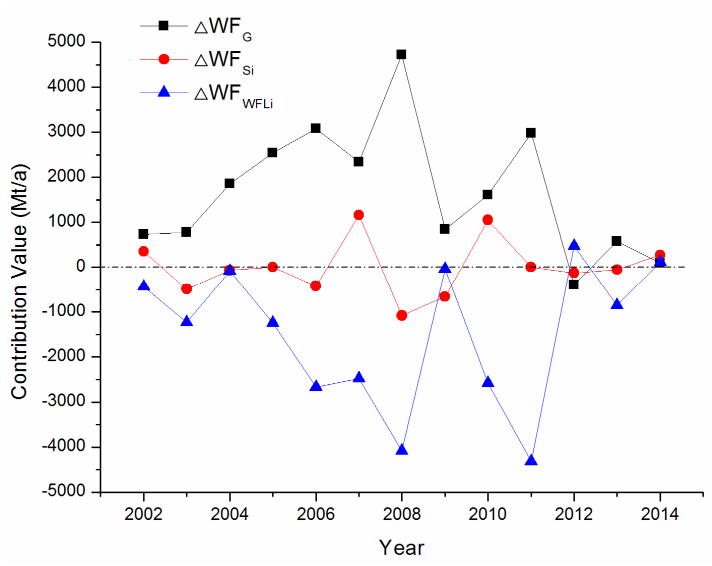

Figure 2. Decomposition analysis of water footprint factors for China’s textile industry, 2002-2014.

5 Conclusions

The water footprint of the textile industry in China was calculated based on the panel data of water consumption, wastewater discharge, and gross industrial output value from 2001 to 2014. The decoupling relationship between water footprint and economic growth of China textile industry was analyzed by using the improved decoupling model. The main conclusions are as follows:

(1) From 2001 to 2014, the water footprint of China's textile industry generally followed an inverted "U" trend and rebounded in 2014. The trend can be divided into two stages: the rising (2001–2007) and decline phases (2008–2014).

(2) In 2002–2014, China's textile industry overall water footprint showed good decoupling between economic growth, with five years strong decoupling (2003, 2006, 2008, 2011, and 2013) and four years of weak decoupling (2005, 2007, 2009, and 2010). The decoupling trend as a whole is good, but the development of the textile industry is not completely independent of the water footprint. Governments and enterprises should raise the awareness of water-saving emission reduction and technical level to prevent reversal of the trend of decoupling development.

(3) The main factors affecting the decoupling of water footprint and economic growth in China's textile industry are industry scale and technology level; the influence of industry structure is not evident. Industry scale factor is the primary factor that causes water footprint growth; technical level is the biggest contributor in the suppression of water footprint growth.

Establishing a resource-saving and environment-friendly textile production system is an essential goal of the development of China's textile industry, and also a prerequisite for China to achieve green modernization. These findings will help Chinese textile enterprises and government decision-makers adopt appropriate decisions to improve the water management level and ultimately achieve sustainable development of the textile industry.

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