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Empirical Analysis on Relationship between Water Footprint of China's Textile Industry and Eco-environment

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Abstract

Water footprint is a composite indicator of measuring the occupation of human social and economic activities on water resources, and also a focus point in research of water resources. The textile industry is a high water consuming one, but researches on the water footprint of the textile industry are relatively small. Therefore, the systematical study on the relationship between the water footprint of China's textile industry and economic development has great potential and importance in targeted controlling and optimizing the use of water resources and sustainable economic development. Based on the water footprint theory, this paper makes analyses on the water footprint of China's textile industry from 2001 to 2012. Then it empirically analyzes the relationship between the water footprint of China's textile industry and the economic development from the variation trend of long term and short period by using the Environmental Kuznets Curve (EKC) and decoupling model. In the last part, the author proposes targeted conclusions for water saving and emission reduction of the industry.

Keywords: water footprint, textile industry, economic development, Environmental Kuznets Curve

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INTRODUCTION

Since the Cultural Revolution, China's textile industry has kept rapid growth and achieved unprecedentedly developing scale and speed while also being confronted with severe consumption of water and pollution. In 2016, the beginning year of the thirteenth "five-year plan", China's textile industry as well as the national economy will run into the "new normal". In this context, the state proposes higher standards and stricter requirements of water saving and emission reduction for textile industry on the basis of the twelfth "five-year plan". The industry must transform the economic development mode for sustainable development by increasing the intensity of water saving and emission reduction and promoting cleaner production.

Water footprint is a composite indicator of measuring the occupation of human social and economic activities on water resources and also a focus point in research of water resources (Chouchane et al. 2015, Hoekstra and Chapagain 2007, Koki et al. 2017, Oel et al. 2009, Roson and Sartori 2015). It has been widely used in the industrial sector (Chen et al. 2015, Liang et al. 2015, Wang et al. 2011). In recent years, China's scholars began to apply water footprint theory in the textile industry (Chen et al. 2015, Wang et al. 2013). For example, Wang Laili etc. (2012) analyzed the water footprint of seven cotton knit fabrics (Grzadziela et al. 2015, Wang et al. 2012, Wu et al. 2018). These researches have greatly expanded the scope and content of water resources research and evaluation, and provided new ideas and methods for efficient management, supervision of water resources and policy formulation of textile industry. Based on the above, this paper accounts the water footprint of China's textile industry with relevant theories, then empirically analyzes the relationship between the water footprint of the industry and economic development, and accordingly proposes targeted conclusion and recommendations.

MATERIAL AND METHODS

There is no uniform definition of the water footprint of China's textile industry, but only Wang Laili gives one in the research and demonstration of the

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Table 1. The definition of the water footprint of China's textile industry

Definition	Connotations
The water footprint of China's textile industry	As a part of the process water footprint, it means the total amount of used water resources in the entire industrial production stage of textile industry. It can be divided into the blue water footprint, the original grey water footprint and the residual grey water footprint.
The blue water footprint of China's textile industry	It refers to the consumption of surface water and groundwater resources in textile industrial production.
The original grey water footprint of China's textile industry	It means, with reference to current environmental water quality standards, the amount of freshwater resources consumed when the pollutants are diluted into allowed emission concentration, before the waste water is discharged.
The residual grey water footprint of China's textile industry	It means, with reference to natural background levels, the amount of freshwater resources consumed when the pollutants are diluted into natural background levels, after the waste water is discharged.

Table 2. The limits of textile industrial waste water pollutant discharge concentration

Unit: mgL (except for PH and Chromaticity)

Number	Pollutant	Limit	Number	Pollutant	Limit
1	PH	6-9	8	TP	0.5
2	COD	80	9	ClO_2	0.5
3	BOD	20	10	AOX	12
4	Suspension	50	11	Sulfide	0.5
5	Chromaticity	50	12	Aniline	0
6	Ammonia nitrogen	10	13	Hexavalent chromium	0
7	TN	15	/	/	/

carbon footprint and water footprint of textile and garment (Meyer et al. 2017, Wang et al. 2012). He divided the water footprint into three categories: the blue water footprint, the original grey water footprint and the residual grey water footprint. The original grey water footprint and the residual grey water footprint are explained, but the blue water footprint isn't in his paper. Therefore, based on the water footprint theory and the particularity of China's textile industry, this paper will define the water footprint of textile industry from the industrial level (see **Table 1**).

RESULTS

The Accounting of the Water Footprint of China's Textile Industry

The accounting methods

According to the definition of the water footprint of China's textile industry, the accounting methods can be as follows:

(1) The accounting methods of the blue water footprint of China's textile industry

It can be directly accounted with the total amount of the industrial water:

$$WF_{blue} = W_{total} \tag{1}$$

In the formula, WF_{blue} means the blue water footprint of China's textile industry; W_{total} means the total amount of textile industrial water, and its unit is ten thousand tons/year.

(2) The accounting methods of the original grey water footprint of China's textile industry

$$WF_{ori-grey} = max\left(\frac{L_{ori}(k)}{C_{sta}(k) - C_{nat}(k)}\right) \tag{2}$$

In the formula, $WF_{ori-grey}$ means the original grey water footprint of China's textile industry, whose unit is ten thousand tons/year; $L_{ori}(k)$ means the removal amount of the pollutant k in the waste water new generated, and the unit is tons/year; $C_{sta}(k)$ means the limited concentration of pollutant k specified in the relevant emission standards, and the unit is mg/L; $C_{nat}(k)$ means the natural background concentration of pollutant k in the storing water, and the unit is mg/L.

(3) The accounting methods of the residual grey water footprint of China's textile industry

$$WF_{res-grey} = max\left(\frac{L_{res}(k)}{C_{sta}(k) - C_{nat}(k)}\right) \tag{3}$$

In the formula, $WF_{res-grey}$ means the residual grey water footprint of China's textile industry, whose unit is ten thousand tons/year; $L_{res}(k)$ means the residual amount of the pollutant k in the waste water after treatment, and the unit is tons/year.

Data sources

Data used in this section comes from *China Environment Yearbook* of 2002-2004 and *China Environment Statistical Yearbook* of 2005-2013 (China Statistical Bureau). The pollutants discharge standards of textile industry waste water refer to water pollutants discharge standards of textile industry GB 4287-2012, which are shown in **Table 2**.

Table 3. The water footprint of China's textile industry of 2001-2012.
(Unit: ten thousand tons/year)

Year	The blue water footprint of China's textile industry	The original grey water footprint of China's textile industry	The residual grey water footprint of China's textile industry
2001	627174	1496872.13	506755.38
2002	716397	1316992.88	476408.50
2003	644004	1397482.88	448736.88
2004	765040	1367641.63	509674.01
2005	879845	1533063.51	530121.44
2006	855303	1550520.13	559569.30
2007	943233	1886289.13	576562.63
2008	927025	2224385.51	542517.37
2009	923860.2	2251267.02	564934.79
2010	946301.1	2244110.01	548555.88
2011	789348.3	3416298.06	576702.88
2012	606082.6	2720335.50	550386.63

Table 4. The ADF test results of variables

Variables	Test form (C,T,N)	ADF Statistical values	P value	ADF Threshold (1%, 5%, 10%)	Conclusion
GDP_t	(C,T,1)	-3.65	0.08	-5.30, -4.01, -3.46	Steady
GDP_t^2	(C,T,1)	-3.63	0.08	-5.30, -4.01, -3.46	Steady
GDP_t^3	(C,T,1)	-3.63	0.08	-5.30, -4.01, -3.46	Steady
$WF_{blue,t}$	(0,0,3)	-2.51	0.02	-2.89, -2.00, -1.60	Steady
$WF_{ori\text{-}grey,t}$	(C,T,0)	-3.53	0.09	-5.12, -3.93, -3.42	Steady
$WF_{res\text{-}grey,t}$	(C,T,3)	-2.53	0.32	-5.84, -4.25, -3.59	Unsteady
$dWF_{res\text{-}grey,t}$	(0,0,0)	-3.52	0.003	-2.82, -1.98, -1.60	Steady

Accounting results

The accounting results of the water footprint of China's textile industry during 2001-2012 are shown in **Table 3**.

The EKC Empirical Analysis on the Water Footprint of China's Textile Industry

Model construction and index selection

This paper will choose EKC ternary polynomial model (Dinda 2004, Richmond 2014) (the liner type and the quadratic type can be dealt with as the special cases of the ternary type) to study the long-term variation trends of the relationship between the water footprint of China's textile industry and economic growth. According to the research, the paper will choose the water footprint of China's textile industry (the blue water footprint, the original grey water footprint, and the residual grey water footprint) as the environmental pressure index and industrial output value of the industry (supposing price of 2001 is constant) as indicators of economic growth. Taking delay factors into account, the EKC model is as follows:

$$WF_t = \gamma_0 + \gamma_1 GDP_{t-m} + \gamma_2 GDP_{t-m}{}^2 + \gamma_3 GDP_{t-m}{}^3 + \mu_t \quad (4)$$

wherein, WF_t represents the water footprint of China's textile industry in the *tth* year, and GDP_{t-m} represents the output value of China's textile industry in the *(t-m)th* year. m can be 0 and 1; when m=0, it indicates the impact of the *tth* GDP on WF of that period; when m=1,it indicates the impact of the *(t-1)th* GDP on the *tth* WF due to some factors of time delay because of policies and decisions. Γ_i and (i=0,1,2,3) are parameters to be estimated, and μ is a random error term.

Empirical analysis

In this section, the relationships between the blue water footprint, the original grey water footprint, the residual grey water footprint of China's textile industry, and the economic growth will be examined in EKC model, and the relationships as well as the specific form of the relationships will be studied to see if they meet the EKC hypothesis or not.

A stationary test will be done before the analysis of the time series to avoid "spurious regression" phenomenon. In this paper, ADF method will be used to test the unit root of variable, and test results of all the variables are shown in **Table 4**.

In **Table 4**, (C, T, N) stands for the test type: C for constant, T for time trend item, N for hysteresis value. $WF_{blue,t}$ stands for the blue water footprint of China's textile industry, $WF_{ori\text{-}grey,t}$ for the original grey water footprint, $WF_{res\text{-}grey,t}$ for the residual grey water footprint, and $dWF_{res\text{-}grey,t}$ stands for the difference of $WF_{res\text{-}grey,t}$. **Table 4** shows that only the original sequence of $WF_{res\text{-}grey,t}$ is unsteady with unit root, while the others are steady, and difference order of $WF_{res\text{-}grey,t}$ is also steady without unit root.

Table 5. The regression results of WFblue,t and GDPt, WFblue,t and GDPt2

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GDP	4773.531	1998.302	2.388794	0.0406
GDP2	-0.500503	0.211176	-2.370074	0.0419
C	-10490078	4700392.	-2.231745	0.0525
R-squared	0.394109	Mean dependent var		801967.8
Adjusted R-squared	0.259467	S.D. dependent var		128952.5
S.E. of regression	110969.1	Akaike info criterion		26.28421
Sum squared resid	1.11E+11	Schwarz criterion		26.40544
Log likelihood	-154.7053	Hannan-Quinn criter.		26.23933
F-statistic	2.927082	Durbin-Watson stat		1.689039
Prob (F-statistic)	0.104900			

Table 6. The regression results of WFblue,t and GDPt-1, WFblue,t and GDPt-12

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GDP(-1)	6054.723	1092.910	5.539999	0.0005
GDP2(-1)	-0.646459	0.115409	-5.601481	0.0005
C	-13262896	2573247.	-5.154148	0.0009
R-squared	0.803431	Mean dependent var		817858.1
Adjusted R-squared	0.754289	S.D. dependent var		122305.3
S.E. of regression	60625.85	Akaike info criterion		25.08983
Sum squared resid	2.94E+10	Schwarz criterion		25.19835
Log likelihood	-134.9941	Hannan-Quinn criter.		25.02143
F-statistic	16.34908	Durbin-Watson stat		2.109539
Prob(F-statistic)	0.001493			

Table 7. ADF test of residuals

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.171516	0.0120
Test critical values:	1% level	-4.297073	
	5% level	-3.212696	
	10% level	-2.747676	

According to Formula (4), models of the *tth* GDP and the *tth* $WF_{blue,t}$ will be built. This paper constructs quadratic regression equation models of $WF_{blue,t}$ and GDP_t, and $WF_{blue,t}$ and GDP_t^2. The regression results are shown in **Table 5**.

Table 5 indicates that all the variable coefficients pass the T test, but R^2 is small with a poor fit degree. So the relationships between variables are not explained well. Then quadratic regression equation between $WF_{blue,t}$ and GDP_t, $WF_{blue,t}$ and GDP_t^2 are built and the results are shown in **Table 6**.

Analysis on **Table 5** and **Table 6** demonstrates that the regression results of $WF_{blue,t}$ and GDP_{t-1}, $WF_{blue,t}$ and GDP_{t-1}^2 are more preferable. All the variable coefficients of regression equation passed the T test. Among which, F is bigger and regression equation is of overall significance; R^2 is bigger with a good fit degree; the value of DW is about 2, which shows that there is no autocorrelation in model residuals; and the whole equation is a reasonable explanation of relationship between variables. So the relationship between the blue water footprint of China's textile industry and the output value of the industry is as the following Formula (5).

$$WF_{blue,t} = 6054.723GDP_{t-1} - 0.6465GDP_{t-1}{}^2 - 13262896 + \mu_t \quad (5)$$
$$(t1 = 5.54\ t2 = -5.60)\ (R2 = 0.80\ F = 16.35\ DW = 2.11)$$

Because the ADF test can determine whether there is long-term co-integration relationship between the variables by testing the residual sequence of the regression equation (Jiang et al. 2017, Marsily and Abarca-Del-Rio 2015), this paper will test the residuals unit root, to determine the co-integration relationship between the variables.

Formula (5) indicates that $\hat{\mu}_t$ the result of testing

$$\hat{\mu}_t = WF_{blue,t} - 6054.723GDP_{t-1} + 0.6465GDP_{t-1^2} + 13262896$$

is shown in **Table 7**.

The test result shows that the ADF statistics is -4.17. On the significance level of 5%, residual sequence is steady, and ～I(0), there is co-integration relationship between the variables. In the model structure, GDP_{t-1} coefficient is positive but GDP_{t-1}^2 coefficient is negative, which indicates that the relationship between blue water footprint of China's textile industry and economic development are in with the inverted U-curve, and the "Kuznets curve" of blue water footprint of China's textile industry surely exists. When the

Table 8. The regression results of WFori-grey,t and GDPt-1, GDPt-12 and GDPt-13

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GDP(-1)	-408748.2	87752.03	-4.657991	0.0023
GDP2(-1)	88.96853	18.75943	4.742604	0.0021
GDP3(-1)	-0.006393	0.001330	-4.807351	0.0019
C	6.22E+08	1.36E+08	4.569934	0.0026
R-squared	0.937080	Mean dependent var		1991671.
Adjusted R-squared	0.910114	S.D. dependent var		660264.3
S.E. of regression	197954.1	Akaike info criterion		27.50475
Sum squared resid	2.74E+11	Schwarz criterion		27.64944
Log likelihood	-147.2761	Hannan-Quinn criter.		27.41354
F-statistic	34.75054	Durbin-Watson stat		2.122233
Prob (F-statistic)	0.000142			

Table 9. ADF test of residuals

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.222235	0.0046
Test critical values:	1% level	-2.816740	
	5% level	-1.982344	
	10% level	-1.601144	

output value of the textile industry is low, the increasing speed of blue water footprint of China's textile industry is higher than that of the output value. With the growth of the output value, the increasing speed of blue water footprint slows down, and when it comes to an inflection point, the blue water footprint will turn into decrease with the increasing of output value. Of note is the fact that the changing of blue water footprint is one year later than that of the output value. In other words, the changing of t output value in the *(t-1) th* year of will have an impact on the blue water footprint in the *tth* year.

According to Formula (4), the model of GDP and $WF_{ori\text{-}grey,t}$ of the *tth* period will be built. After several attempts, the variable coefficients of the regression equation can't pass the T test, so a regression equation of $WF_{ori\text{-}grey,t}$ and GDP_{t-1}, GDP_{t-1}^2 and GDP_{t-1}^3 is needed. A ternary regression equation of them is built in the paper, which results are shown in **Table 8**.

In **Table 8**, the regression results of $WF_{ori\text{-}grey,t}$ and GDP_{t-1}, GDP_{t-1}^2 and GDP_{t-1}^3 are preferable, and all the variable coefficients of equation passed the T test. F is bigger and the equation is remarkable; R^2 is bigger with favorable fit degree; the value of DW is about 2, which shows that there is no autocorrelation in model residuals; and the equation is a reasonable explanation of relationship between variables. So the relationship between the grey water footprint and the output value is as Formula (6).

$$\begin{gathered} WF_{ori-grey,t} = -408748.2GDP_{t-1} + 88.9685GDP_{t-1}{}^2 \\ -0.0064GDP_{t-1}{}^3 + 6.22\times10^8 + \mu_t \\ (t1 = -4.66\ t2 = 4.74\ t3 = -4.81); \\ (R2 = 0.94\ F = 34.75\ DW = 2.12) \end{gathered} \quad (6)$$

The residual sequence will be tested by unit root test to confirm whether there is long-term co-integration relationship between the variables.

The test result shows that

$$\begin{aligned} \widehat{\mu_t} = WF_{ori-grey,t} &+ 408748.2GDP_{t-1} \\ &- 88.9685GDP_{t-1^2} \\ &+ 0.0064\,GDP_{t-1^3} - 6.22 * 10^8 \end{aligned}$$

the result of testing $\widehat{\mu_t}$ is shown in **Table 9**.

The test result shows that the ADF statistics is -3.22. On the significance level of 1%, the residual sequence is steady, and -I(0), so there is a co-integration relationship between the variables.

It can be concluded from the model structure that the relationship between original grey water footprint and the economic development meets the inverted N-curve, and the "Kuznets curve" of the original grey water footprint indeed exists. When the output value is low, the original grey water footprint decreases with the increasing of the output value. When the first inflection point comes, the original grey water footprint increases with the growth of the output value, but the increasing speed of grey water footprint is lower; while the second inflection point comes, it will decrease with the increasing of the output value.

According to Formula 4, the regression model of GDP and $WF_{res\text{-}grey,t}$ of the *tth* period. A ternary regression equation of $WF_{res\text{-}grey,t}$ and GDP_t, GDP_t^2 and GDP_t^3 is constructed, which results are shown in **Table 10**.

Table 10. The regression results of WFres-grey,tand GDPt, GDPt2 and GDPt3

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GDP	28140.30	8623.472	3.263222	0.0138
GDP2	-5.985314	1.841916	-3.249504	0.0141
GDP3	0.000422	0.000131	3.234639	0.0144
C	-43890430	13400820	-3.275205	0.0136
R-squared	0.609945	Mean dependent var		3966.477
Adjusted R-squared	0.442779	S.D. dependent var		31961.94
S.E. of regression	23858.71	Akaike info criterion		23.27297
Sum squared resid	3.98E+09	Schwarz criterion		23.41766
Log likelihood	-124.0014	Hannan-Quinn criter.		23.18177
F-statistic	3.648730	Durbin-Watson stat		2.616724
Prob (F-statistic)	0.071936			

Table 11. ADF test of residuals

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.195639	0.0008
Test critical values:	1% level	-2.816740	
	5% level	-1.982344	
	10% level	-1.601144	

Table 10 demonstrates that the regression results of $WF_{res\text{-}grey,t}$ and GDP_{t-1}, GDP_{t-1}^2 and$GDP_{t-1}^3$are preferable, and all the variable coefficients of the equation passed the T test. F is bigger and the equation is of overall significance; R^2 is bigger with a good fit degree; the value of DW is about 2, which shows that there is no autocorrelation in model residuals. The whole equation can reasonably explain the relationship of the variables. So the relationship between the residual grey water footprint and the output value is as Formula 7.

$$\begin{gathered} WF_{res-grey,t} = 28140.3GDP_t - 5.9853GDP_t^{\,2} \\ +0.0004GDP_t^{\,3} - 43890430 + \mu_t \\ (t1 = 3.26\ t2 = -3.25\ t3 = 3.23); \\ (R2 = 0.61\ F = 3.65\ DW = 2.62) \end{gathered} \tag{7}$$

The unit root test will be done to the residual sequence of the regression equation for judging the long-term co-integration relationship among the variables.

The test result shows that =, the result is shown in **Table 11**.

The test result manifests that the ADF statistics are -4.20. On the significance level of 1%, the residual sequence is steady, and -I(0), so there is a co-integration relationship between the variables.

It can be derived from the model structure that the relationship between the residual grey water footprint and its output value accords with the N-curve and the "Kuznets curve" of the residual grey water footprint does exist. When the output value is low, residual grey water footprint will increase with the growth of its output value and the speed will be gradually lower than the latter. When it comes to the first inflection point, the residual grey water footprint will decrease with the increasing of output value, while when it comes to the second inflection point, it will increase with the increasing of output value.

DISCUSSION

The Decoupling Analysis on the Water Footprint of China's Textile Industry and the Economic Development

Model construction and index selection

This paper chooses Tapio elastic analysis model to analyze the relationship of the water footprint of China's textile industry and the economic development and the model is as follows:

$$M = \frac{environmental\ pressure\ change\ (\%)}{economic\ driving\ change\ (\%)} = \frac{\frac{EP_t - EP_{t-1}}{EP_{t-1}}}{\frac{DF_t - DF_{t-1}}{DF_{t-1}}} \tag{8}$$

M is decoupling elasticity coefficient; EP_t and EP_{t-1} respectively stand for environmental pressure of the *tth* and *(t-1)th* year; DF_t and DF_{t-1} respectively refers to economic driving forces of the *tth* and *(t-1)th* year.

According to the elastic analysis model and the relationship among the variables, blue water footprint, grey water footprint and residual grey water footprint of China's textile industry are chosen as indexes to measure the environmental pressure and the output value of the industry as the index to evaluate the economic driving forces (supposing price of 2001 is constant).

The decoupling analysis on the blue water footprint of China's textile industry and the economic development

The decoupling relationship between the blue water footprint of China's textile industry and the economic

Table 12. Decoupling type of the blue water footprint of China's textile industry and the economic development of 2002-2012

year	Changing of blue water footprint of China's textile industry (%)	Changing of textile industrial output value (%)	decoupling elastic value	Decoupling type
2002	0.142261956	-0.049537385	-2.87180997	Strong & negative
2003	-0.101051512	0.022803918	-4.43132228	strong
2004	0.187942932	0.049447787	3.800836045	Expansive & negative
2005	0.150064049	0.014756017	10.16968498	Expansive & negative
2006	-0.027893549	0.017940221	-1.55480521	strong
2007	0.102805672	0.014179789	7.250155422	Expansive & negative
2008	-0.017183453	0.010048989	-1.70996829	strong
2009	-0.003413932	-0.035474214	0.096236994	weak & negative
2010	0.024290363	0.093497825	0.259796026	weak
2011	-0.16585926	0.108735006	-1.52535293	strong
2012	-0.232173427	-0.051920125	4.471742447	decline

Table 13. Decoupling type of the original grey water footprint of China's textile industry and the economic development of 2002-2012

year	Changing of original grey water footprint of China's textile (%)	Changing of textile industrial output value (%)	decoupling elastic value	Decoupling type
2002	-0.120169865	-0.049537385	2.42584192	decline
2003	0.061116465	0.022803918	2.68008609	Expansive & negative
2004	-0.02135355	0.049447787	-0.4318404	strong
2005	0.120954113	0.014756017	8.1969348	Expansive & negative
2006	0.011386756	0.017940221	0.63470544	weak
2007	0.216552493	0.014179789	15.2719125	Expansive & negative
2008	0.179238895	0.010048989	17.8365097	Expansive & negative
2009	0.012084915	-0.035474214	-0.3406676	Strong & negative
2010	-0.003179103	0.093497825	-0.0340019	strong
2011	0.522339834	0.108735006	4.80378725	Expansive & negative
2012	-0.203718337	-0.051920125	3.92368733	decline

development of 2002--2012 can be derived from Formula 8, and the results are shown in **Table 12**.

Table 12 indicates that, the decoupling type is strong in 2003, 2006, 2008 and 2011, which is the ideal state of industrial development. With the increasing of industrial output value, blue water footprint (the volume of water consumption) decreases. In 2010, the decoupling type is weak, and both the blue water footprint and the industrial output value increase, but the increasing speed of the output value is higher. In 2012, both the blue water footprint and the output value decrease in the declining decoupling type, but the decreasing speed of the blue water footprint is higher. In 2004, 2005 and 2007, both the blue water footprint and the output value increase in the expansive and negative decoupling type, while the increasing speed of blue water footprint is higher. In 2009, the decoupling type is weak and negative, and both the blue water footprint and the output value decrease, but the decreasing speed of the output value is higher. In 2002, the decoupling type is strong & negative, which is the worst state of industrial development. With the decreasing of the industrial output value, the blue water footprint of China's textile increases.

Overall, the relationship between the blue water footprint of China's textile industry and the economic development can be divided in two stages. There is no decoupling from 2002 to 2010, during which it is negative and coupling type. The increasing speed of the blue water footprint is higher than that of the economic development, or they are of the same speed, which is not favorable to sustainable development. In contrast, a three-year-decoupling comes out from 2010 to 2012, during which the increasing speed of the blue water footprint is lower than that of the economic development and it is the ideal state of sustainable development.

The decoupling analysis of the grey water footprint of China's textile industry and the economic development

It can be derived from Formula 8 that the decoupling relationship between the original grey water footprint of China's textile industry and the economic development of 2002--2012, which is shown in **Table 13**.

Table 13 indicates that the decoupling type is strong and negative in 2009, which is the worst state of industrial development. With the decreasing of the

Table 14. Decoupling type of the residual grey water footprint of China's textile industry and the economic development of 2002-2012

year	Changing of residual grey water footprint of China's textile industry (%)	Changing of textile industrial output value (%)	decoupling elastic value	Decoupling type
2002	-0.059884645	-0.049537385	1.208877793	decline
2003	-0.058083925	0.022803918	-2.547102797	strong
2004	0.135796967	0.049447787	2.746269846	Expansive & negative
2005	0.040118644	0.014756017	2.718798879	Expansive & negative
2006	0.055549272	0.017940221	3.096353791	Expansive & negative
2007	0.030368589	0.014179789	2.141681329	Expansive & negative
2008	-0.059048676	0.010048989	-5.87608109	strong
2009	0.04132111	-0.035474214	-1.164821034	Strong & negative
2010	-0.028992567	0.093497825	-0.310088148	strong
2011	0.05131109	0.108735006	0.471891176	weak
2012	-0.04563225	-0.051920125	0.878893299	decline coupling

output value, the original grey water footprint of China's textile industry increases. In 2003, 2005, 2007, 2008 and 2011, the decoupling type is expansive and negative, in which both the original grey water footprint and the output value increase but the increasing speed of the former is higher. In 2002 and 2012, the decoupling type sees a decline in which both of them decrease but the decreasing speed of the original grey water footprint is higher. The decoupling type is weak in 2006, and both of them increase, but the increasing speed of the output value is higher. In 2004 and 2010, the decoupling type is strong. With the growth of the output value, the original grey water footprint decreases.

Overall, the decoupling between the original grey water footprint and the output value can only be found in five years from 2002 to 2012, while the other six years are not decoupling. This state is quite bad for sustainable economic development. The relationship between them is better in the "twelfth five-year" than that in "tenth five-year" and "eleventh five-year".

The decoupling analysis on the residual grey water footprint of China's textile industry and the economic development

The decoupling relationship between the residual grey water footprint of China's textile industry and the economic development of 2002-2012 can be deduced from Formula 8, and the results are shown in **Table 14**.

Table 14 shows that the decoupling type is strong and negative in 2009 which is the worst state of industrial development. The residual grey water footprint increases when output value decreases. From 2004 to 2007, the decoupling type is expansive and negative, and both of them increase but the increasing speed of the residual grey water footprint is higher. The decoupling type is decline coupling in 2012, when both the residual grey water footprint and the output value decrease and the value of decoupling is between 0.8 and 1.2. In 2002 the decoupling type sees decline, and both of them decrease, but the decreasing speed of the residual grey water footprint is higher. The decoupling type is weak in 2011, and both of them increase but the increasing speed of the output value is higher. In 2003, 2008 and 2010, the decoupling type is strong. With the increasing of the output value, the residual grey water footprint gradually decreases.

There is no Decoupling among the Blue Water Footprint, the Original Grey Water Footprint, the Residual Grey Water Footprint and the Economic Development

Overall, there is no decoupling from 2002 to 2012 and its weak decoupling in five years. Especially during 2004 to 2007, the pressure from the increasing residual grey water footprint is much bigger than the driving forces of the economic development, while in the other years, the relationship between the residual grey water footprint and the economic development turns better. It's mostly negative decoupling, which is quite bad for the sustainable economic development.

CONCLUSION

(1) The unreasonable structure of the economy causes the high consuming and low output of the textile industry. The readjustment of economic structure is key in realizing a circular economy. At present, the following three steps could be taken. Firstly, set up the scientific and environmental protection chain, in which production craft is adjusted and new technological achievements in production under the guidance of environmental protection production technology are applied. Secondly, promote rational distribution and regionally coordinated development through exerting comparative advantages. For instance, setting up industrial parks, providing political support, good

intermediary service and support system of finance, land, public devices and environmental governance. Thirdly, prevent overproduction and eliminate outdated capacity.

(2) Provide support to these new environmental protection enterprises, which have new technology, to promote less pollution and good profit; while at the same time, eliminate the enterprises which have overproduction, more pollution, high resources consuming and unreasonable layout and advance economy structure optimization to realize the best economic and environmental benefits with the limited resources.

(3) Compared with developed countries, weak public environmental awareness is a big letdown of environmental protection in China. The most realistic and closest way is to awaken public environmental awareness through governmental environmental education and propaganda. In addition, the government needs to encourage the public to participate in the protection of the environment through environmental regulations and systems.

(4) Established environmental protection organizations can also be guided to play positive role in water saving and pollutants emission and fulfill the quiet zone in conjunction with governmental management through society and consensus supervision.

(5) Revise and complete policy for a complete index system. On one side, take the economy method as the primary one and the policy method as its assistant to develop the basic function of market mechanism in water allocation. Set up all kinds of environmental standards system, especially water quota, limited pollution, clean production and others and complete the distribution and management system of water. On the other side, policy making must conform to regional conditions in different times to avoid universal application. The energy saving and emission reduction standards of China's textile industry are still imperfect, so it's requisite to offer support to it.

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REFERENCES

Chen LZ, Ding XM, Wu XY (2015) Water Management Tool of Industrial Products: A case study of screen printing fabric and digital printing fabric. Ecological Indicators, 58: 86-94.

China Statistical Bureau (20XX) China statistical yearbook on environment.

Chouchane H, Hoekstra AY, Krol MS, Mekonnen MM (2015) The water footprint of Tunisia from an economic perspective. Ecological Indicators, 52: 311-319.

Dinda S (2004) Environmental Kuznets Curve Hypothesis: A Survey. Ecological Economics 49: 431-455.

Ghanbari M, Abbasi MA, Ravanshadnia M (2017) Environmental Life Cycle Assessment and Cost Analysis of Aggregate Production Industries Compared with Hybrid Scenario. Applied Ecology and Environmental Research, 15(3): 1577-1593.

Grzadziela A, Musial J, Muslewski L, Pajak M (2015) A method for identification of non-coaxiality in engine shaft lines of a selected type of naval ships. Polish Maritime Research, 22(1): 65-71.

Hoekstra AY, Chapagain AK (2007) Water footprints of nations: Water use by people as a function of their consumption pattern Springer Netherlands.

Jiang L, Schneider R, Andersen OB, Bauer-Gottwein P (2017) CryoSat-2 Altimetry Applications over Rivers and Lakes. Water, 9(3): 211.

Koki IB, Low KH, Juahir H, Azid A, Zain SM (2017) Assessment of water quality of man-made lakes in Klang Valley (Malaysia) using chemometrics: the impact of mining. Desalination and Water Treatment, 74: 125-136.

Liang X, Hua XJ, Su LF, Li W, Zhang JD (2015) Energy Conservation Control Strategy of Autonomous Underwater Vehicle for Ocean Search. Journal of Coastal Research, 73: 589-593.

Marsily GD, Abarca-Del-Rio R (2015) Water and Food in the Twenty-First Century. Surveys in Geophysics, 37: 1-25.

Meyer S, Genesio L, Vogel I, Schmidt H, Soja G, Someus E, Shackley S, Verheijen FGA, Glaser B (2017) Biochar Standardization and Legislation Harmonization. Journal of Environmental Engineering and Landscape Management, 25(2SI): 175-191.

Oel PRV, Mekonnen MM, Hoekstra AY (2009) The external water footprint of the Netherlands: Geographically-explicit quantification and impact assessment. Ecological Economics, 69: 82-92.
Richmond A (2014) Environmental Kuznets Curve. Language.
Roson R, Sartori M (2015) A Decomposition and Comparison Analysis of International Water Footprint Time Series. Sustainability, 7: 5304-5320.
Wang D, Rong LI, Song Y, Wang JQ, Yan KL (2011) Water footprint and textile wet processing. Dyeing & Finishing.
Wang L, Ding X, Wu X (2013) Blue and grey water footprint of textile industry in China. Water Science & Technology A Journal of the International Association on Water Pollution Research, 68: 2485-2491.
Wang LL, Xiong-Ying WU, Ding XM, Wang LH, Jian-Ming YU (2012) Case study on industrial carbon footprint and industrial water footprint of cotton knits. Dyeing & Finishing.
Wu L, Liu G, Zhou C, Liu R, Xi S, Da C, Liu F (2018) Spatial distributions, fractionation characteristics, and ecological risk assessment of trace elements in sediments of Chaohu Lake, a large eutrophic freshwater lake in eastern China. Environmental Science and Pollution Research, 25(1): 588-600.