

Decomposition and Decoupling Analysis of Industrial Solid Waste in the Yangtze River Economic Belt

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Abstract: In this paper, LMDI method is used to analyze the driving factors of industrial solid waste production in the Yangtze River Economic Belt from 2005 to 2018, and the decoupling state is analyzed by Tapio indicator. We found that: ① Industrial pollution intensity effect and industrial structure effect inhibited industrial solid waste production, while regional output effect and population size effect played a role in increasing the pollution; ② in different periods, the decoupling states of industrial solid waste in the Yangtze River Economic Belt were weak decoupling, weak decoupling and expansive negative decoupling. The decoupling indicator showed a trend of first decreasing and then increasing. It is suggested to guide investment to environment-friendly industries and strengthen the research on solid waste reduction technology.

1 Introduction

Industry is the most important material production sector, which plays an irreplaceable role in economic development. However, industrial production, especially low-end industrial production, will produce a large number of pollutants, including solid wastes. The industrial solid waste may pollute the atmosphere, soil and water, impairing environmental quality and long-term sustainable development^[1]. For an extended period of time, the characteristics of industry in China were high energy consumption and high emissions^[2]. China is confronted with the problem of large quantity of industrial solid waste^[3]. The Yangtze River Economic Belt, a major national strategic development area, has an important impact on China's economic development and ecological security. The industrial economy in the economic belt is active, with industrial added value accounting for more than 40% of China. From 2005-2018, the average annual growth rate of its industrial added value was 10.00%, while the average annual growth of industrial solid waste production was 7.42%. The solid pollution generated in the process of rapid industrial growth posed a serious threat to the environment in the Yangtze River Economic Belt. Identifying the driving factors of industrial solid waste production in the Yangtze River Economic Belt, studying the decoupling relationship between solid pollution and economic development, and putting forward industrial pollution reduction policies can promote the industrial green transformation of the Yangtze River Economic Belt, and provide reference for other regions' high-quality development.

2 Literature review

2.1 Decomposition method

Decomposition analysis can be divided into Structural Decomposition Analysis (SDA) and Index Decomposition Analysis (IDA). SDA is generally combined with the input-output table. However, China publishes the input-output table every five years, so the availability of relevant data is poor. IDA only needs sector-level aggregate data, so it is more flexible to use. LMDI method is an IDA method proposed by Ang et al^[4-5]. Because of advantages of no residual items and so on, it has been widely used in the fields of energy and environment. The study on application of LMDI method in industrial field is shown in Table 1. LMDI method is widely used in the field of water and carbon, but rarely used in the field of solid waste. Most scholars decomposes aggregate indicator based on factors in terms of intensity, structure change and output, and intensity is often defined as a technical factor.

Table 1 Literature on application of LMDI method in industrial field

Authors	Aggregate indicator	Influencing factors
Chen et al ^[6]	Industrial water use	Economic output, industrial structure, industrial water intensity
Shang et al ^[7]	Industrial water use	Industrial output value, technology, industrial structure
Quan et al ^[8]	Carbon emissions of logistics industry	Carbon emission coefficient, energy intensity, energy structure, economic level and

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Fatima et al ^[9]	Industrial CO2 emissions	population size Energy structure effect, income effect, energy intensity effect, carbon emission effect, and labor effect
Chen et al ^[10]	Industrial solid waste	Population, per capita GDP, industrial structure, investment intensity in treatment of ISW, investment efficiency of ISW recycle, and ISWD intensity

2.2 Decoupling analysis

Decoupling refers to breaking the link between economic growth and resource consumption or environmental pollution. There are two main decoupling indicators frequently used. One is the decoupling indicator introduced by OECD ^[11]. The second decoupling indicator is the elastic indicator proposed by Tapio^[12]. OECD indicator is sensitive to the choice of benchmark years, leading to the poor stability of the calculated results^[13]. Tapio indicator is not limited by the length of time and can present decoupling states in more refined details^[14]. Therefore, it is widely used. The study on the use of Tapio indicator is shown in Table 2. In the existing research literature, the decoupling analysis of industrial solid waste is rarely seen.

Table 2 Literature on application of Tapio indicator

Authors	Countries/Cities	Pollutants
Hu et al ^[15]	57 BRI countries	Carbon dioxide emissions
Xia et al ^[16]	Zhejiang, China	Industrial air pollutant emissions
Wang et al ^[17]	China	CO2 emissions in the iron and steel industry
Qian et al ^[18]	China	Industrial sulfur dioxide emissions
Wang et al ^[19]	China	CO2 emissions of China's metal industry

Decoupling analysis alone cannot evaluate the effects of environmental externalities and capture useful information^[20]. This paper jointly uses LMDI method and decoupling analysis. Firstly, the driving factors of industrial solid waste production are decomposed into industrial pollution intensity effect, industrial structure effect, regional output effect and population size effect. On this basis, the decoupling relationship between industrial solid waste and industrial added value is investigated.

3 Methods and data

3.1 LMDI decomposition model

LMDI method is used to decompose industrial solid waste production:

$$ISW = \frac{ISW}{IAV} \times \frac{IAV}{G} \times \frac{G}{P} \times P \quad (1)$$

Where, *ISW* refers to industrial solid waste production, *IAV* refers to industrial added value, *G* refers to GDP and *P* refers to the population. Rewrite equation (1) as:

$$ISW = IPI \times S \times RO \times P \quad (2)$$

Where, $IPI = \frac{ISW}{IAV}$ refers to the industrial pollution intensity, which is mainly related to technical factors such as clean production. $S = \frac{IAV}{G}$ refers to the industrial structure. $RO = \frac{G}{P}$ refers to the regional output level.

The change of industrial solid waste production can be decomposed into four driving factors:

$$\Delta ISW = \Delta ISW_{IPI} + \Delta ISW_S + \Delta ISW_{RO} + \Delta ISW_P \quad (3)$$

$$\Delta ISW_{IPI} = \frac{ISW^t - ISW^0}{\ln ISW^t - \ln ISW^0} \ln \left(\frac{IPI^t}{IPI^0} \right) \quad (4)$$

$$\Delta ISW_S = \frac{ISW^t - ISW^0}{\ln ISW^t - \ln ISW^0} \ln \left(\frac{S^t}{S^0} \right) \quad (5)$$

$$\Delta ISW_{RO} = \frac{ISW^t - ISW^0}{\ln ISW^t - \ln ISW^0} \ln \left(\frac{RO^t}{RO^0} \right) \quad (6)$$

$$\Delta ISW_P = \frac{ISW^t - ISW^0}{\ln ISW^t - \ln ISW^0} \ln \left(\frac{P^t}{P^0} \right) \quad (7)$$

Where, ΔISW_{IPI} , ΔISW_S , ΔISW_{RO} and ΔISW_P respectively represent the contribution of industrial pollution intensity effect, industrial structure effect, regional output effect and population size effect to the change of industrial solid waste production.

3.2 Tapio indicator

The Tapio indicator associated with industrial solid waste production and industrial added value is constructed, as shown in the formula (8):

$$\lambda = \frac{ISW^t - ISW^0}{ISW^0} / \frac{IAV^t - IAV^0}{IAV^0} \quad (8)$$

Where, λ refers to the Tapio indicator, ISW^t and IAV^t respectively refer to industrial solid waste production and industrial added value in phase T. ISW^0 and IAV^0 respectively refer to industrial solid waste production and industrial added value in the base period

Decoupling states can be classified into three categories and eight sub-categories, as shown in Table 3. Strong decoupling state is most ideal and strong negative decoupling state is most unfavorable.

Table 3 Decoupling judgments of the Tapio indicator

State		$\frac{ISW^t - ISW^0}{ISW^0}$	$\frac{IAV^t - IAV^0}{IAV^0}$	λ
Decoupling	Strong decoupling(SD)	<0	>0	(-∞,0)
	Weak decoupling(WD)	>0	>0	(0,0.8]
	Recessive decoupling(RD)	<0	<0	(1.2,+∞)
Coupling	Recessive coupling(RC)	<0	<0	(0.8,1.2]

	Expansive coupling(EC)	>0	>0	(0.8,1.2]
Negative decoupling	Expansive negative decoupling(END)	>0	>0	(1.2,+∞)
	Strong negative decoupling(SND)	>0	<0	(-∞,0)
	Weak negative decoupling(WND)	<0	<0	(0,0.8)

3.3 Data source and description

This study focuses on the time span during 2005-2018. The data are from *China Statistical Yearbook on Environment*, statistical yearbooks of various provinces, and official website of China Bureau of Statistics. To eliminate the influence of price factor, the raw data of output has been measured at 2005 constant price.

According to Figure 1, from 2005 to 2018, the industrial solid waste production in the Yangtze River Economic Belt showed a fluctuating upward trend, rising from 462.09 million tons to 1171.08 million tons, with an average annual change rate of 7.42%. The industrial added value showed a steady upward trend, rising from 3348.55 billion yuan in 2005 to 11562.44 billion yuan in 2018, with an average annual change rate of 10.00%.

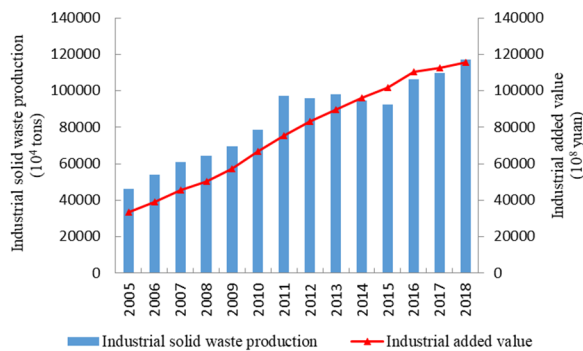


Fig.1. Trend of industrial solid waste production and industrial added value in the Yangtze River Economic Belt from 2005 to 2018

4 Results

4.1 Driving effect decomposition of industrial solid waste production

The cumulative effect value of each driving factor of industrial solid waste production in the Yangtze River Economic Belt from 2005 to 2018 was calculated, as shown in Table 4.

Table 4 Decomposition of changes in industrial solid waste production in the Yangtze River Economic Zone from 2005 to 2018 (10⁴ tons)

Region	ΔISW_{IP}	ΔISW_S	ΔISW_{RO}	ΔISW_P	ΔISW
Shanghai	-1864.49	-339.72	1565.64	466.95	-171.62
Jiangsu	-3721.65	-589.22	11049.29	527.21	7265.63
Zhejiang	-366.52	-981.24	4010.51	543.24	3206.00
Anhui	-2133.79	1445.13	11679.34	283.32	11274.00
Jiangxi	-7759.20	92.05	12086.83	702.60	5122.29
Hubei	-2945.34	1288.24	9248.02	245.07	7836.00
Hunan	-3292.95	-279.82	5933.63	399.71	2760.56
Chongqing	-2321.04	-182.55	3158.91	225.68	881.00

Sichuan	-4206.97	-371.67	14698.10	167.66	10287.13
Yunnan	1424.54	-371.82	13196.53	856.75	15106.00
Guizhou	-4808.61	545.64	11877.54	-282.57	7332.00
Economic Belt	-23582.56	-5066.01	94620.31	4927.25	70898.99

According to Table 4, for industrial solid waste in the Yangtze River Economic Belt from 2005 to 2018, the industrial pollution intensity effect was -235.83 million tons, reaching -33.26% of the total effect, which was the primary factor to reduce industrial solid waste production. The industrial structure effect was -50.66 million tons, reaching -7.15% of the total effect, which was the secondary factor to reduce industrial solid waste production. The regional output effect was 946.20 million tons, reaching 133.46% of the total effect. The population size effect was 49.27 million tons, reaching 6.95% of the total effect. Comparing the absolute value of each effect, we can find that regional output effect > industrial pollution intensity effect > industrial structure effect > population size effect. The absolute value of regional output effect was about 4.01 times of that of industrial pollution intensity effect.

Furthermore, from the provincial perspective, we can find that: ① Except Yunnan, the industrial pollution intensity effect was negative in all provinces, indicating that the industrial solid waste production per unit of industrial added value was reduced in most regions. This was mainly due to the improvement of pollution control technology. Among the provinces, the industrial pollution intensity effect in Jiangxi was the most significant; ② the industrial structure effect in Anhui, Jiangxi, Hubei and Guizhou was positive, which indicated that promoting industrialization would aggravate environmental pollution and increase solid waste. Among the provinces, the industrial structure effect in Anhui was the most significant, which indicated that Anhui greatly sacrificed the environment in the process of industrialization; ③ the regional output effect in all provinces was positive, indicating that economic growth intensified resource consumption and stimulated the increase of industrial solid waste; ④ except Guizhou, the population size effect in all provinces was positive. The increase of population brought about the increase in labor force and the expansion of consumption market, which would stimulate industrial production and lead to the increase in the industrial solid waste; ⑤ except Shanghai, the industrial solid waste production in all provinces showed an upward trend. Shanghai took the finance industry as the pillar industry, and actively developed the high-tech environmental industry, which alleviated the solid waste pollution. Among other provinces, Yunnan's production of industrial solid waste increased most significantly, reaching 151.06 million tons. The pillar industries of Yunnan included mining industry and electric power industry. Mining and the construction of water conservancy and hydropower projects could produce a large number of solid wastes, resulting in the aggravation of pollution.

4.2 Decoupling results

China regularly promulgates the five-year plan, which is the outline of national economic operation and social development. Therefore, this paper divides the time interval into 2005-2010, 2010-2015 and 2015-2018. On this basis, we investigate the relationship between industrial solid waste production and industrial economy. The result is shown in Table 5.

Table 5 Decoupling states of industrial solid waste in the Yangtze River Economic Belt from 2005 to 2018

Region	2005-2010		2010-2015		2015-2018	
	λ	state	λ	state	λ	state
Shanghai	0.40	WD	-1.49	SD	-0.13	SD
Jiangsu	0.69	WD	0.34	WD	0.98	EC
Zhejiang	0.99	EC	0.32	WD	1.73	END
Anhui	0.78	WD	0.54	WD	3.84	END
Jiangxi	0.28	WD	0.22	WD	1.62	END
Hubei	0.61	WD	0.20	WD	2.68	END
Hunan	0.53	WD	0.32	WD	1.60	END
Chongqing	0.39	WD	-0.03	SD	-0.79	SD
Sichuan	0.50	WD	0.19	WD	13.67	END
Yunnan	1.11	EC	0.85	EC	1.87	END
Guizhou	0.92	EC	-0.11	SD	4.13	END
Economic Belt	0.71	WD	0.33	WD	1.99	END

In different periods, the decoupling states of industrial solid waste in the Yangtze River Economic Belt were weak decoupling, weak decoupling and expansive negative decoupling. The decoupling indicator showed a trend of first decreasing and then increasing, which reflected the repeatability and difficulty of solid waste pollution treatment.

In the period of 2005-2010, ①72.73% of provinces were in weak decoupling state, and 27.27% of provinces were in expansive coupling state. The latter included Zhejiang, Yunnan and Guizhou; ②for Zhejiang, there were many industrial enterprises whose extensive production modes generated a large number of solid wastes. For Yunnan and Guizhou, they took the opportunity of the "Development of the Western Region in China" strategy and "West-East Electricity Transmission" project, and increased their investment and construction in power projects from 2005 to 2010. However, the production of hydropower and thermal power increased the industrial solid waste significantly.

In the period of 2010-2015, ①27.27% of provinces were in strong decoupling state, 63.64% of provinces were in weak decoupling state, and 9.09% of provinces were in expansive coupling state; ② Shanghai, Chongqing, Guizhou were in strong decoupling state. This showed that they had strengthened environmental control and improved clean transformation; ③Yunnan was in expansive coupling state. In order to build a moderately prosperous society in step with the whole country in the future, during the 12th Five-Year Plan period, Yunnan took promoting economic development as the main goal. The average annual economic growth rate of Yunnan, reaching 11.1%, was 3.3 percentage points higher than that of the whole country. However, due to the relatively extensive development mode and

low-end industrial division of labor, solid waste increased significantly in the process of industrial production.

In the period of 2015-2018, ①18.18% of provinces were in strong decoupling state, 72.73% of provinces were in expansive negative decoupling state, and 9.09% of provinces were in expansive coupling state; ② Shanghai and Chongqing were still in strong decoupling state, which reflected that they had made continuous progress in green transformation; ③the decoupling state of Jiangsu changed from weak decoupling to expansive coupling. Since there were many manufacturing enterprises in Jiangsu, the government had great pressure on the control of industrial solid waste pollution; ④other provinces were in expansive negative decoupling state. From 2015 to 2018, industrial economic growth slowed down, and $\frac{IAP^t - IAP^0}{IAP^0}$ was quite small in these provinces, especially in Sichuan. In addition, the industrial solid waste pollution was deteriorating, which might be due to the bottleneck of pollution control technology. Thus, the λ in these provinces was relatively big.

5 Conclusions and policy

In this paper, LMDI method is used to decompose industrial solid waste production in the Yangtze River Economic Belt from 2005 to 2018, and Tapio indicator is used to study the decoupling relationship between industrial solid waste and industrial economy. We find that:

(1) Industrial pollution intensity effect and industrial structure effect played a role in reducing industrial solid waste in the Yangtze River Economic Belt, and regional output effect and population size effect played a role in increasing the pollution. According to the absolute value of each effect, it can be found that regional output effect > industrial pollution intensity effect > industrial structure effect > population size effect.

(2) In different periods, the decoupling states of industrial solid waste in the Yangtze River Economic Belt were weak decoupling, weak decoupling and expansive negative decoupling. The decoupling indicator showed a trend of first decreasing and then increasing. It was urgent to strengthen the control of industrial solid waste.

Based on the above results, this paper proposes the following suggestions:

(1) Enhance the research on solid waste reduction technology. To obtain technological breakthroughs, enterprises can strengthen cooperation with universities and scientific institutions.

(2) Promote the adjustment of industrial structure. In order to curb solid pollution, it is suggested to guide investment from pollution-intensive industries to environment-friendly and high-tech industries.

(3) Uphold the concept of high quality development and build an environment-friendly economic growth pattern. It is necessary to eliminate backward production capacity to restrain the increase of industrial solid waste

(4) The population layout should be rationally

planned to prevent the industrial pollution surge caused by the excessive population concentration.

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