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Study on the Decoupling of Forestry Economic Growth Based on Material Flow Accounting

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Abstract: Forestry is endowed with an important role in the construction of ecological civilization, forestry production is the first to rush to realize material input reduction and low emission production. Based on the EW-MFA compilation guide published by the European statistics bureau, the material flow scale of the input-output forestry economic system is calculated. On this basis, the decoupling coefficient of forestry economic growth is studied according to the decoupling theory. The results show that the EKC curve of DMI and the per capita forestry GDP has crossed the inflection point and entered the decline channel; in the input and output side of forestry economic system, forestry economic growth show strong decoupling simultaneously in the year of 1996, 1998 and 2016. If the trend of reduction of material input in forestry production can be maintained, it is estimated that forestry economic growth will enter sustainable development model.

Keywords: Forestry Economic Production, Material Flow Accounting, EKC Curve, Decoupling Analysis

1. Introduction

Facing the increasingly severe environmental problems, human beings have to reexamine the relationship of the material transformation between economic activities and the natural environment, and gradually realize that the existing material acquisition scale and consumption pattern are unsustainable [5, 13]. In 2007, Chinese government put forward the construction of ecological civilization, introduced a series of strategic decisions, and put forward to accelerate the reform of the ecological civilization system in 2017, and strived to reverse the deterioration of the ecological environment from the source. Forestry is entrusted with the basic position in tackling climate change and is endowed with an important role in the construction of ecological civilization. Therefore, forestry development takes both economic production and ecological benefits into account. In order to achieve this dual goal, the input and output of forestry production process and the sustainability of forestry production must be paid attention to.

The operation of an economic system must take advantage of the resources and other inputs provided by the natural environment, while the waste material produced through the metabolic process of the system is required to be discharged to the environment [2]. The former will cause environmental disturbance and the latter impact the environment [1]. The natural input of the economic system and the scale of waste material released to the environment are usually measured by the physical unit, and the material flow accounting (EW-MFA) guide issued by the European statistics bureau provides the basic framework and standard method for the accounting of the material transformation between the economic system and the environment [2-3]. In recent years, according to the "EW-MFA Accounting Guide" compiled by the European Union, the researches on material flow in the regional level of the country and provinces are rich, and the material flow accounting and analysis from of specific systems is still relatively small, such as the study of the material flow of the agricultural sector [7] and the material flow characteristics of the highway transportation system [12], but less research on the material flow of forestry economic system. Based on the material flow accounting, this paper observes the resources material input in the forestry development process and the scale of waste discharged from the production process, and analyzes the coupling relationship between the environmental impact index of these input and output and the economic growth of forestry. The purpose is to provide a reference view for evaluating the sustainability of forestry development.

2. Methods and Data Sources

2.1. Material Flow Accounting of Forestry Economic System

The SEEA2012 central framework proposes a proposal for the accounting of the material flow of the economic system, and recommends the "EW-MFA method guide" published by the European Statistics Bureau [2]. The calculation of the natural inputs and emissions from the economic system will help to describe to what extent the economy increases or reduces the efficiency of resource input or residual output, that is, the degree of decoupling between economic growth and environmental pressure [13].

As shown in Figure 1, the forestry production process is also the forestry economic system [15]. According to the EW-MFA method guide, the resources and energy into the forestry economic system from the domestic environment are divided into biological material, energy material, metal and non-metallic minerals, and dissipative material, water and air. Among them, the biological substances specifically refer to the logging and non-wood forest products. As the forest has both natural and economic attributes, on the one hand, the harvested forest products are regarded as the biological material flow obtained from the environment. On the other hand, the forest management and forestry production activities are regarded as the economic process of obtaining natural input. The substances obtained from domestic natural environment are called *Domestic Extraction Used* (DEU), such as biological substances, energy substances, minerals and dissipative substances. The waste material discharged into the environment through forestry production process, such as waste water, exhaust gas and dust, is called *Domestic Processed Output* (DPO). In addition, there are still a large number of forest products import and export between forestry economic system and foreign economies. Obviously, the material input to the forestry economic system includes domestic DEU, and the import of forest products from foreign markets, the sum of which is called *Direct Material Input* (DMI).

The development of forestry economy in our country has been accompanied by a large amount of natural input and waste of pollution, which also produces a large scale of hidden flow [4]. The environmental impact of the material flow of these inputs and outputs is also increasing with the increase of the scale of the material [6, 7].

To explore the material scale of consumption and metabolism in forestry production for a long time, Data for 28 years in 1985 and 1990-2016 years were collected. The basic data were from the official statistical yearbook, such as China Statistical Yearbook, China forestry statistical yearbook, China Energy Statistics Yearbook, China Iron and steel statistical yearbook, FAO statistical yearbook, and so on. Some of the parameters were derived from the material flow analysis, and a few lacks of data were missing. The inference was carried out by the over linear interpolation method, which ensured the reliability of data and data. Some parameters were derived from the literature, and a few missing data could be infused by linear interpolation, which in general could guarantee the reliability of data and data.

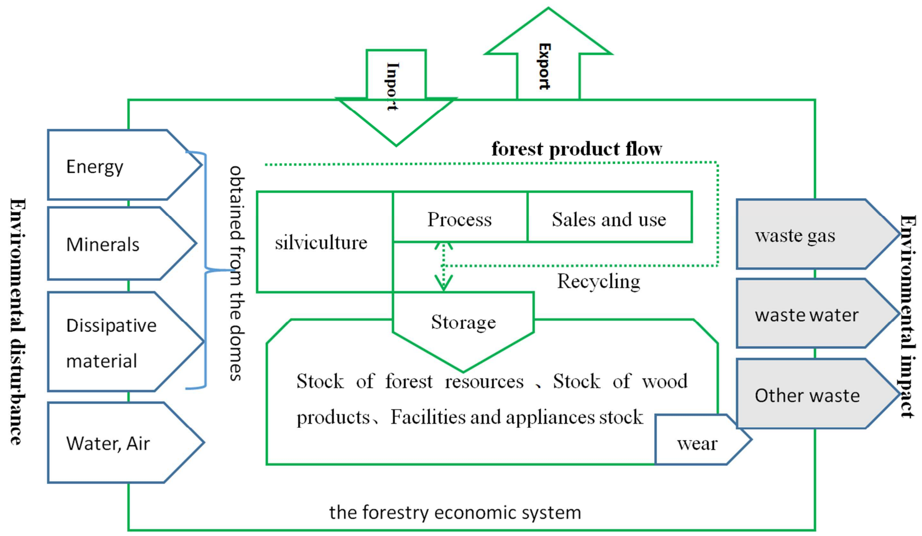

Figure 1. *Material flow accounting framework for forestry economic system.*

2.2. EKC Analysis Method

In 1955, when the environmental economist Kuznetz studied the relationship between the income of residents and the economic growth of the country, the famous “Environmental Kuznets Curve” (EKC) was proposed [14]. EKC curve analysis can be applied flexibly to investigate the relationship between environmental pressure and economic development [8]. It can help us to study the nonlinear relationship between the changes of natural environment and the level of economic growth [14]. The EKC curve explains the development process of "pollution first and post governance" in some countries, and the economic growth is raised to a certain extent, the country will manage and improve the polluted natural environment through the investment of back feeding to prevent the ecological degradation. The EKC curve can be expressed as:

$$y = b_0 + b_1 x + b_2 x^2 \quad (1)$$

In formula: x is an independent variable, representing the per capita forestry GDP; y is a dependent variable that represents the environmental pressure indicator.

2.3. Decoupling Analysis Method

In 2002, OECD, in the report on sustainable development, proposed an indicator of decoupling between economic growth and environmental pressure [10]. The aim was to improve consumption and production patterns in general, to encourage more efficient utilization of resources, and to eventually decouple the environmental load from economic growth [10]. Because of the decoupling index itself has some defects, such as affected by the changes of the base tends to be unstable [13], In 2005, Japanese scholar Tapio improved the OECD decoupling model [11], which is called the Tapio decoupling model. Its expression is:

$$t = \frac{\%\Delta CO_2}{\%\Delta GDP} = \frac{\Delta CO_2/CO_2}{\Delta GDP/GDP} \quad (2)$$

In formula 1, $\%\Delta CO_2$, $\Delta CO_2/CO_2$, both indicate the annual average growth rate of carbon dioxide; $\%\Delta GDP, \Delta GDP/GDP$ both indicate the annual average growth rate of gross domestic product.

According to the principle of Tapio elastic coefficient expression, the elastic coefficient between forestry economic growth and DMI, and DPO is constructed respectively:

$$EC_{DMI} = {}^{V_{DMI}}/_{V_{GDP}} \quad (3)$$

$$EC_{DPO} = {}^{V_{DPO}}/_{V_{GDP}} \quad (4)$$

In formula: EC indicates the elasticity index of environmental pressure and forestry GDP. V_{DMI}, V_{DPO}, V_{GDP} represent separately annual growth rate of direct material input indicators DMI, of forestry production process emissions index DPO, and of forestry GDP. The criteria of judgment are: 1, environmental pressure and forestry economic growth rate are both more than 0, when 0<EC<1 indicates that forestry development is in a relative "decoupling" state; when EC>1 indicates that the growth rate of environmental pressure is greater than the growth rate of forestry economy, which indicates that forestry development is in a relative "coupling" state. 2, forestry economic growth rate is greater than 0, and environmental pressure is less than 0. EC<0 indicates that forestry development is in a strong decoupling state. It can be regarded as absolute decoupling. 3, the growth rate of forestry is less than 0, which rarely occurs.

3. Results and Analysis

3.1. Analysis of Accounting Results

3.1.1. Dynamic Analysis of DMI

DMI includes two parts: DEU and imported forest products. As shown in Figure 2, DMI expanded from 3,500,000,000 t to 1,000,000,000 billion t in 2015, but it suddenly dropped in 2016. The biological materials in DMI, including the domestic forest products and the imported forest products, occupied an absolute proportion in the DMI, and showed a declining trend during the whole period of observation, the proportion of which fell from 91% to 61%. In the 90s of last century, the biomass kept steady, the annual average was 323,331,500 t. This century, the input of biological material increased continuously, 2000-2015 years, the annual input amount was 423,912,800 t, but in 2016, the input volume decreased by 18.54%, compared with 2015, the decrease was 98,898,100 t. To a certain extent, the large reduction of input volume in 2016 resulted from the sharp reduction of forest harvesting in that year. On the contrary, the proportion of forest products imported was relatively small, but it kept rising. In 1985, the import of forest products was 12,243,000 t, then, the annual average 7.77% growth rate and the annual average of 3,617,100 t increased to 124,371,900 t in 2016. The proportion of imports of forest products increased from 3.81% to 22.25%, which effectively alleviated the huge pressure on domestic demand for forest products.

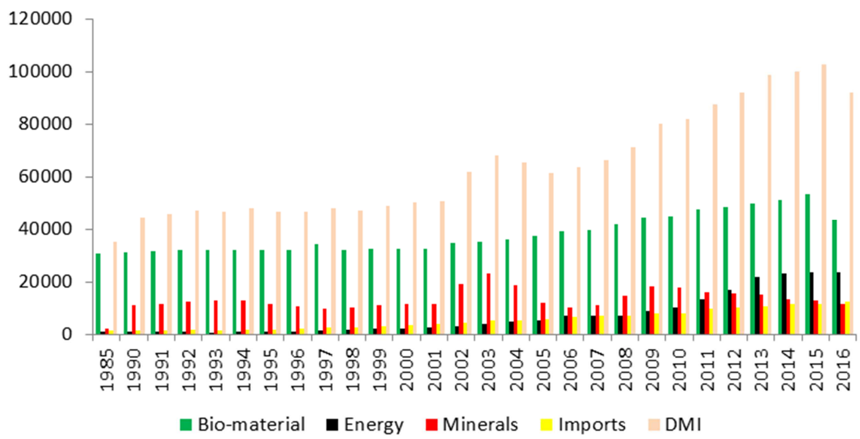

Figure 2. Sequence diagram of DMI and its components in forestry economic system.

Figure 2 showed that, in 1990-2016 years, in addition to the absolute proportion of biological substances, the total amount of minerals, energy materials and dissipative materials increased from about 10% to 30%. The average annual input of minerals was 136,319,200 t, of which the larger proportion was non-metallic minerals. The metal minerals appeared fast after 2000, and peaked in 2010 and then decreased to 27,559,100 t in 2016 with the annual average of 7,876,200 t. In 1985, the total amount of energy material input was 7,545,600 t, the annual average speed index of 7,688,200 t increased, up to 238,192,000 t in 2015, although 2016 also decreased, but the total consumption size was still relatively high. The proportion of dissipative material was the smallest, and its highest proportion was less than 1.2% during the whole observation period.

3.1.2. Dynamic Analysis of DPO

In the forestry economic system, the forest products at each processing stage were originally derived from wood and non-wood forest products. Tracing the waste material produced in its life cycle, in the short term, there were waste gases from fossil fuels, dust and waste water produced by the process of wood processing. In the long run, biomass forest products will eventually be burned or recycled, even if landfill will be decomposed by organisms and generate greenhouse gas emissions [15]. In this paper, the emissions produced during the processing of forest products were mainly accounted for exhaust gas and dust, and no attention was paid to wastewater.

Figure 3 described the emissions and CO_2 generated by energy consumption, and the dust emitted from timber processing process in forestry production. During the whole observation period, the total emission volume (DPO) showed a complete fluctuation period before 2000, and reached a periodic peak in 1995, with a discharge of 1,655,603,400 *t*. In the past 2000-2016 years, there had been a nearly linear growth trend, with an average annual growth rate of 16.68%, with an average annual increase of 200,510,000 *t*, and the emissions in 2016 were 3,512,823,600 *t*. Dust was the pollution emission caused by relatively backward technology in the sawing process, and it occupied an absolute proportion in DPO, the highest ratio was 99%, which dominated the trend of total emission. Secondly, with the increase of energy consumption, CO_2 emissions were also increasing. In 1985, CO_2 emissions were 17,583,000 *t*, and 502,394,200 *t* in 2015, with an average annual growth rate of 11.82%, with an average annual increment of 16,160,400 *t*. But in 2016, with the decrease of total material input, CO_2 emissions decreased by 12,120,900 *t*. Because of the large amount of dust emission, the change of other gas emissions was concealed in the time sequence of DPO. Although SO_2, CH_4, NO_x and smoke dust were smaller than CO_2 emissions, they were also exhaust gases generated by fossil energy consumption. The SO_2 and CH_4 emissions increasing from 144,200 *t* and 41,800 *t* in 1985, increased to 4,229,400 *t* and 1,196,100 *t* in 2015, with an annual average of 136,200 *t* and 38,500 *t*, and a slight decrease in 2016.

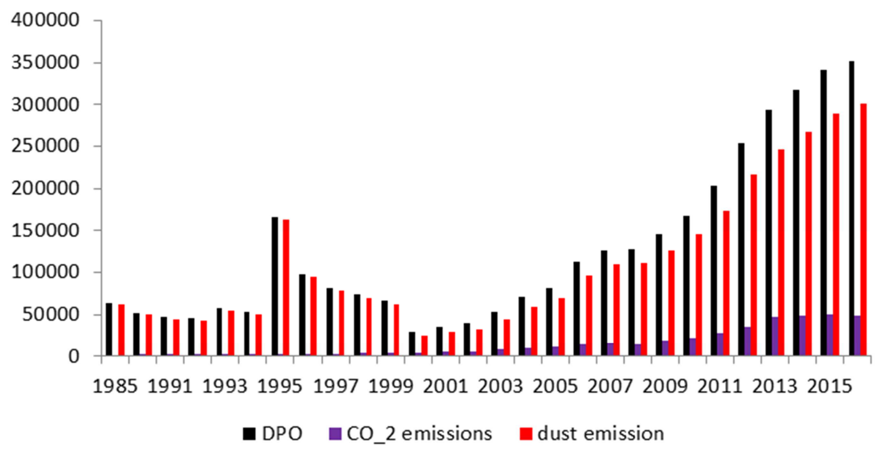

Figure 3. *Sequence diagram of DPO and its components emitted from forestry production process.*

3.2. Decoupling Analysis

3.2.1. Analysis of the Trend of Decoupling

According to the EKC curve hypothesis, the relationship between the direct material input index (DMI) of the forestry economic system and the per capita forestry GDP was described by the EKC curve, as shown in Figure 4, two variables showed the "inverted U" curve trend, which showed that as the growth of per capita forestry GDP, DMI seemed to cross the inflection point, and it was preliminarily entered the falling interval. The fitting equation of EKC curve and its estimated value were shown in Table 1, R^2 reaches 0.958. According to the estimated values of parameters, the EKC curve fitting model of two variables was expressed as follows:

$$\text{DMI} = 43000.822 + 30.646\text{gdp} - 0.004\text{dgp}^2 \quad (5)$$

The model fitted well the trend of EKC curve. The first order derivation of the model showed that when the per capita forestry GDP was 3176.52 yuan, DMI of forestry production reached the maximum value, which was about 1,016,994,040 *t*. Compared with the actual observed data, it could be found that this inflection point appeared between 2014 and 2015, and then entered the downward path of the EKC curve after 2015.

Table 1. Model and parameter estimation.

model	model summary					parameter estimation		
	R^2	F	df1	df2	Sig.	b0	b1	b2
Quadratic function	.958	286.970	2	25	.000	43000.822	30.646	-.004

Dependent variable: DMI
Independent variable: gdp

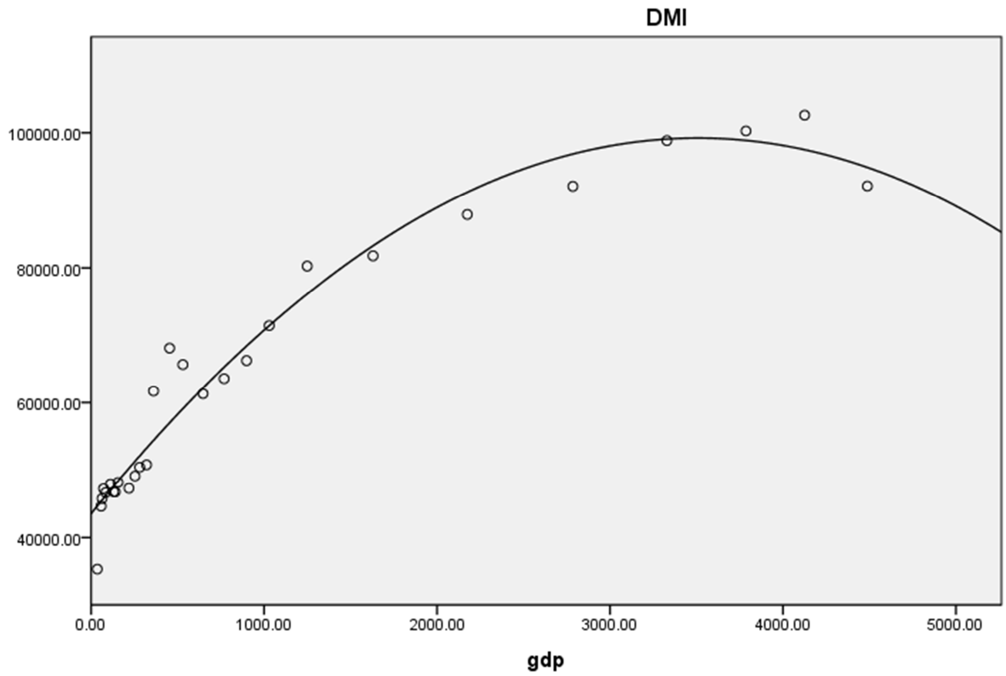

Figure 4. The EKC curve between DMI and per capita forestry GDP.

3.2.2. Analysis of Elastic Coefficient

According to the results of material flow accounting in forestry economic system, the decoupling elastic coefficients of DMI, DPO and GDP were calculated, and the results were showen in Table 2.

From the elastic coefficient sequence of DMI, Table 2 showed that the years of $0 < EC_{DMI} < 1$ were 1991, 1992, 1994, 1997, 1999-2001, 2003, 2006-2015. The growth rate of DMI in these years was less than that of the current forestry GDP growth rate, indicating that forestry economic growth was in a relative "decoupling" state. The year of $EC_{DMI} > 1$ was only in 2002, indicating that forestry economic growth was in a strong "coupling" state, but this state did not continue, and it soon improved in second years. The years of $EC_{DMI} < 0$ were 1993, 1995, 1996, 1998, 2004, 2005, 2016. The growth rate of forestry economy in these years was more than 0 and the input of direct material was negative. It indicated that the economic growth of forestry was in a strong "decoupling" state, especially in 2016, the absolute value of its elastic coefficient was more than 1, and the absolute decoupling was realized.

Table 2. The elastic coefficient of environmental pressure growth and forestry economic growth.

year	DMI growth rate	Forestry GDP growth rate	DPO growth rate	EC_{DMI}	EC_{DPO}
1991	0.0252	0.1138	-0.0596	0.2218	-0.5236
1992	0.0320	0.1487	-0.0228	0.2149	-0.1535
1993	-0.0123	0.1767	0.0887	-0.0696	0.5018
1994	0.0275	0.3449	-0.0492	0.0797	-0.1426
1995	-0.0245	0.1792	0.9683	-0.1368	5.4033
1996	-0.0002	0.0828	-0.2998	-0.0025	-3.6232
1997	0.0302	0.1232	-0.1148	0.2452	-0.9318
1998	-0.0180	0.4221	-0.0636	-0.0426	-0.1506
1999	0.0383	0.1686	-0.0714	0.2271	-0.4237
2000	0.0268	0.1154	-0.3151	0.2324	-2.7318
2001	0.0073	0.1505	0.0469	0.0483	0.3116
2002	0.2154	0.1329	0.0359	1.6206	0.2699

year	DMI growth rate	Forestry GDP growth rate	DPO growth rate	EC_{DMI}	EC_{DPO}
2003	0.1035	0.2646	0.1417	0.3911	0.5355
2004	-0.0359	0.1761	0.1586	-0.2039	0.9009
2005	-0.0659	0.2273	0.0808	-0.2900	0.3554
2006	0.0367	0.1949	0.2335	0.1883	1.1982
2007	0.0420	0.1745	0.0833	0.2407	0.4771
2008	0.0785	0.1520	0.0155	0.5166	0.1020
2009	0.1236	0.2189	0.1210	0.5645	0.5528
2010	0.0189	0.3111	0.1178	0.0608	0.3785
2011	0.0745	0.3409	0.1538	0.2186	0.4511
2012	0.0477	0.2869	0.1948	0.1662	0.6792
2013	0.0736	0.2012	0.1321	0.3659	0.6565
2014	0.0143	0.1433	0.0634	0.0998	0.4426
2015	0.0234	0.0950	0.0649	0.2459	0.6831
2016	-0.1024	0.0942	-0.0377	-1.0863	-0.3997

From the elastic coefficient sequence of DPO, Table 2 showed that the years of $0 < EC_{DPO} < 1$ were 1993, 2001-2005 and 2007-2015. The growth rate of DPO in these years was less than that of the year's forestry economic growth, indicating that the growth of forestry economy was in a relative "decoupling" state. The year of $EC_{DPO} > 1$ were 1995 and 2006, which indicating that the growth rates of DPO were greater than that of the year's forestry economic growth rate, indicating that the growth of forestry economy was in a strong "coupling" state, but this phenomenon did not continue to occur. The years of $EC_{DPO} < 0$ were 1991, 1992, 1994, 1996-2000 and 2016, the growth rate of forestry economic growth in these years was more than 0, while the growth rate of DPO was less than 0, indicating that the growth of forestry economy was in a strong "decoupling" state.

Comparing the elastic coefficient of input and output of forestry economic system, could be found that, in 1991-2016 year, the year with strong decoupling at both ends were 1996, 1998 and 2016, the year with relative decoupling at both ends were 2001, 2003, 2007-2015. Therefore, since 2007, more than 10 years, China's forestry economic development have being entered a healthy development track. The economic growth of forestry was relatively out of the aggravation of environmental impact, and realized the development trend of resource saving and environmental friendliness.

4. Conclusions

Based on the results of material flow accounting, this paper makes a dynamic study on the relationship between forestry economic growth and the scale of material consumption and discarded emission. The main conclusions are as follows:

The DMI of the forestry economic system expanded from 350 million *t* in 1985 and broke through 1 billion *t* in 2015, but suddenly dropped in 2016, mainly due to the large decrease of forest logging. Imported forest products accounted for a small proportion of DMI, but from 1985 to 2016, the proportion of imported forest products increased from 3.81% to 22.25%, effectively alleviating the growing domestic demand for forest products. In 2000-2016 years, the average annual growth rate of DPO increased to 16.68%, with an average annual increase of 200,510,000 *t*. Because dust removal technology was relatively backward, dust emissions occupied an absolute proportion in DPO, followed by CO_2 emissions. With the increase of energy consumption, CO_2 emissions were also increasing. However, in the trend of declining total material input, CO_2 emissions were reduced by 12.129 million tons in 2016.

By calculating the decoupling elasticity coefficient based on the material flow accounting, it was found that during the 1991-2016 year period, the years of strong "decoupling" at both ends of forestry economic growth were 1996, 1998 and 2016. If the trend of reduction of material input in forestry production could be hold on, it was estimated that 2016 would be the beginning year for forestry economic growth to enter sustainable development.

5. Limitations

Although the material flow accounting of the forestry economic system has filled the blank of the domestic material flow accounting in the forestry, it is only using the result of the material flow accounting to study the material transformation relationship between of the forestry economic growth and the natural environment, and the analysis is not enough. The research still needs to be further in-depth, for example, we should improve the material flow accounting method of forestry economic system, and evaluate the technical efficiency of forestry production from the perspective of environmental impact based on the accounting results, and so on.

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