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Economy-wide material input/output and dematerialization analysis of Jilin Province (China)

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Abstract In this paper, both direct material input (DMI) and domestic processed output (DPO) of Jilin Province in 1990–2006 were calculated and then based on these two indexes, a dematerialization model was established. The main results are summarized as follows: (1) both direct material input and domestic processed output increase at a steady rate during 1990–2006, with average annual growth rates of 4.19% and 2.77%, respectively. (2) The average contribution rate of material input to economic growth is 44%, indicating that the economic growth is visibly extensive. (3) During the studied period, accumulative quantity of material input dematerialization is $11{,}543 \times 10^4$ t and quantity of waste dematerialization is $5{,}987 \times 10^4$ t. Moreover, dematerialization gaps are positive, suggesting that the potential of dematerialization has been well fulfilled. (4) In most years of the analyzed period, especially 2003–2006, the economic system of Jilin Province represents an unsustainable state. The accelerated economic growth relies mostly on excessive resources consumption after the Revitalization Strategy of Northeast China was launched.

Keywords Material flow analysis · Dematerialization · Sustainable development · Effect decomposition

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Introduction

The worldwide resource shortage and environmental degradation have become one of the bottlenecks for economic development. To eliminate this bottleneck, developed countries have brought forward Factor 4 target, which calls for halving material into the economy system while doubling wealth (Weizsaecker et al. 1997). They attempt to make the environmental pressure maintain a controllable level even decline by improving resource productivity. In recent years, with the development of industrial ecology, dematerialization is conceived as a strategy to be implemented for sustainability. The study on dematerialization is becoming an attracting hotspot in resources science and environment science (Cutler and Matthias 1998; Ester et al. 2004; Farla and Blok 2000; Sun 2003). In China, in order to improve economy productivity, the 17th National Congress Report has pointed out that Chinese government would step up efforts to conserve energy and reduce waste discharge. Following the 17th National Congress Report, Comprehensive Working Scheme for Energy Conservation and Waste Reduction, which proposed the general goal and requirement on energy conservation and waste reduction, was established by the State Council of the People's Republic of China.

Dematerialization emphasizes on the decrease of material input and reduction of waste discharge from the original sources (Cutler and Matthias 1998). Thus, sustainable development could be achieved with least environmental cost. Research on dematerialization can help to find out factors influencing the societal metabolism and ways to realize the dematerialization, and thus relieve the rising environmental pressure due to economic development as well as population growth. Material flow analysis (MFA) focuses on the material exchange between economic system and surroundings (Steurer 1992; Environment Agency Japan 1992; Schutz and Bringezu 1993; EUROSTAT 2001). It provides a breakthrough point for dematerialization. It is an ideal choice to do some further work on dematerialization undertaken in material flow analysis.

MFA was developed in western countries in 1990s by a number of research institutes and organizations and has been a popular method for assessing material flow nowadays. As an important content in industrial ecology, dematerialization has permeated into all phases of product life cycle. However, research on dematerialization at a macroeconomic level is still scarce. In China, MFA study is still at the starting stage and few researches on dematerialization can be found. Researches undertaken in MFA are much fewer.

On the basis of present research at home and abroad, this paper focuses on dematerialization in Jilin Province undertaken in MFA. It is organized in five sections including this "Introduction" as section one. "Methodology" provides a brief overview of the MFA framework and establishes a dematerialization model. "Economy-wide material input/output in Jilin Province" characterizes two main materials accountings [direct material input (DMI) and domestic process output (DPO)] in the Jilin economy from 1990 to 2006. Then we discuss the relationship among material usage, economy, and population. "Dematerialization in Jilin Province" applies the dematerialization model to Jilin Province to test the dematerialization effect. The main conclusions will be listed in the "Conclusions" section.

Methodology

Material flow analysis

It is a frontier for ecological economics and regional sustainable development science to evaluate the impacts from human activities exerted on the natural ecosystem. Material input serves as a basic prerequisite for the survival and development of human beings. Social material metabolism, otherwise, probes into the coordinative development between national economy and environment by measuring their material exchange. In fact, this touches the essence of sustainable development already. However, this methodology has long been ignored. Since the beginning of 1990s, considerable progress has been made. Wuppertal Institute for Climate, Environment and Energy of Germany put forward the economy-wide material flow analysis (EW-MFA) framework as well as the concept of ecological rucksack (also called hidden flow). According to the framework, Austria (Steurer 1992), Japan (Environment Agency Japan 1992), and Germany (Schutz and Bringezu 1993) took the lead in investigating their resources and material flow. From then on, EW-MFA has attracted widespread attention and a growing number of scholars have tested the method.

The basic viewpoints of EW-MFA can be generalized as follows: in order for an economic system to function and produce goods as well as services to meet human needs, it behaves similarly to a living organism. It absorbs materials from the surrounding environment and transforms them into products. But ultimately all the materials are transformed into some kind of waste and emitted back into the environment, sooner or later. The quantity and quality of input materials or waste discharges are main reasons for some serious environmental problems. The former would bring disturbance to the environment and eventually cause environmental degradation, while the latter would create environmental pollution directly. EW-MFA divides all material inputs into different material flow accountings which can be served as indexes for sustainable development. By analyzing the relationship among different material flow accountings, EW-MFA reveals their flow characteristics and conversion efficiency in a certain region, and ultimately provides reasonable references for realizing regional sustainable development goal.

One of the most-used methodologies of MFA at the national level is adopted by EURO STAT, the statistical office of the European Union (EUROSTAT 2001). This methodology recommends 11 material flow accountings, among which direct material input (DMI) and domestic processed output (DPO) are the most two important accountings. DMI is defined to measure the input of materials into the domestic economy which are of economic value and are processed and used in production or consumption activities. This comprises fossil fuels (e.g., coal, petroleum, and natural gas), metallic minerals, non-metallic minerals, biomass (e.g., grains, livestock, and aquatic products), and imports. DPO is defined to account for wastes to the nature. It includes water pollutants, air pollutants, solid pollutants, and so on.

Dematerialization model based on MFA

There are three comprehensions on dematerialization in academic circles (Cutler and Matthias 1998): (1) absolute reduction in the quantity of materials required to serve economic function. Herman et al. argued that dematerialization declines over time in the weight of materials used in industrial end products. (2) Relative reduction in the quantity of materials required to serve economic function. Bemardini and Galli suggested that dematerialization should be the reduction of raw material intensity of economic activities, as measured as the ratio of material consumption in physical terms to gross domestic product (GDP) in deflated constant terms. (3) Replacement of lower quality materials by higher quality materials. Labys and Waddell considered that the dematerialization is a process that lower quality materials linked to mature industries undergo periodic replacement by higher quality or technologically more appropriate materials. In this paper, we define dematerialization as an absolute or relative decline of materials consumed or wastes produced in the process of economic activities. For the purpose of differentiation, decline of materials consumed is called (material) input dematerialization, while decline of wastes discharge is called (waste) output dematerialization.

If DMI was used to express the resources consumption and resources productivity (MPE) was defined as follows: MPE = GDP/DMI, we can gain the following identical equation:

$$\mathrm{GDP} = \mathrm{MPE} \times \mathrm{DMI} \tag{1}$$

If we neglect the cross terms, the following equations could be written after performing mathematic calculations:

$$\Delta\mathrm{GDP} \approx \mathrm{DMI} \times \Delta\mathrm{MPE} + \Delta\mathrm{DMI} \times \mathrm{MPE} \tag{2}$$

$$\begin{aligned}\Delta\mathrm{DMI} &= \frac{\Delta\mathrm{GDP} - \mathrm{DMI} \times \Delta\mathrm{MPE}}{\mathrm{MPE}} \\ &= \mathrm{DMI}\times\frac{\Delta\mathrm{GDP}}{\mathrm{GDP}} - \mathrm{DMI}\times\frac{\Delta\mathrm{MPE}}{\mathrm{MPE}}\end{aligned} \tag{3}$$

In Eq. 3, $\mathrm{DMI}\times\frac{\Delta\mathrm{GDP}}{\mathrm{GDP}}$ expresses the input rebound effect (MBE) due to the economic growth; while $\mathrm{DMI}\times\frac{\Delta\mathrm{MPE}}{\mathrm{MPE}}$ expresses the input dematerialization effect (MDE) due to the improvement of resources productivity. The difference between rebound effect and dematerialization effect is defined input growth effect (MGE). Only when dematerialization effect exceeds rebound effect could the absolute reduction in material input be realized.

The relationship among the three variables above is illustrated in Fig. 1.

According to the model above, input dematerialization effect can express the absolute reduction of DMI due to technical progress (i.e., the decline of material intensity). Ulteriorly, material input

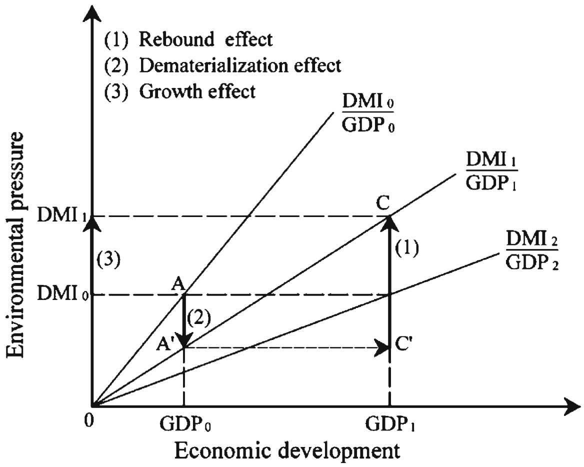

Fig. 1 Dematerialization effect analysis

dematerialization index (MDI) in the year of t is defined as the following equation:

$$MDI_t = \frac{MDE_t}{DMI_{t-1} + MBE_t} \times 100\% \qquad (4)$$

Where, MDE stands for the dematerialization effect of material consumption, while MBE means the rebound effect of resource consumption. Compared with dematerialization effect, MDI can express the relative reduction of DMI.

Similarly, if DPO was used to express the waste discharge and waste productivity (WPE) was defined as follows: WPE = GDP/DPO, we can calculate waste growth effect (WGE), waste dematerialization effect (WDE) and waste rebound effect (WBE). Waste dematerialization index (WDI) is subsequently able to be calculated.

Economy-wide material input/output in Jilin Province

The changing trend of material input/output in Jilin Province

First, data of EW-MFA in Jilin Province were collected from official statistics. Then the amounts of all input and output material flows in the economic system from 1990 to 2006 were calculated. Finally, 11 material flow accountings were achieved to describe the material metabolism in Jilin Province quantificationally. We only analyzed two most important accountings (DMI and DPO) to serve the purpose of our study.

Figure 2 presents an overview of DMI in Jilin Province.[1] Throughout the monitored period (1990–2006), DMI increases from $10{,}863 \times 10^4$ t to $21{,}841 \times 10^4$ t, with an average annual growth rate of 4.19%, which is 5.6% lower than the province's GDP growth rate. Jilin Province is one of the old industrial bases in China and high energy consumption industries (e.g., heavy chemical industry, cement industry, steel industry) play a very important role. So the fossil fuel dominates DMI in Jilin Province. Although its percentage has decreased by 8.5%, because of the relatively slow growth of its absolute volume, it still composes 46.6% of the total DMI at average. Construction material, the secondary dominant category, accounts for 26.2% of the DMI. With the improvement of living standard, especially the thriving urban construction, its amount increases rapidly (the average annual growth rate is about 8.88%, the highest growth rate among the four categories). Because of the important role of farming industry and forestry industry as well as the flourishing further processing of agriculture products, 23.55% of DMI in Jilin Province is biomass. This percentage is higher than most provinces in China. However, because of the decline of cultivated lands and limited increase of unit yield, the growth rate of biomass input is the lowest among the four categories (the average annual growth rate is about 1.46%). The category of mineral and industrial stuff only accounts for about 3.8% of DMI, with an average annual growth rate as high as 5.82%, only second to construction material growth rate among the four categories. The mineral in this paper refers to the output of ferrous metal and ten main non-ferrous metals, not ores, and industrial stuff only refers to crude salt. These in part lead to the small percentage of mineral and industrial stuff in DMI in Jilin Province.

[1] Every material category includes domestic extraction and imports.

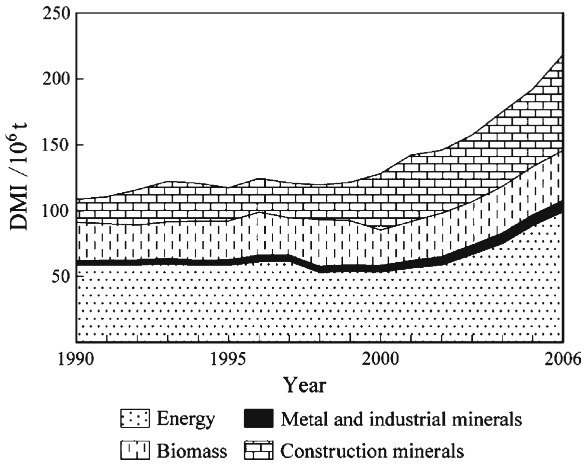

Fig. 2 Compositions and changes of DMI in Jilin Province

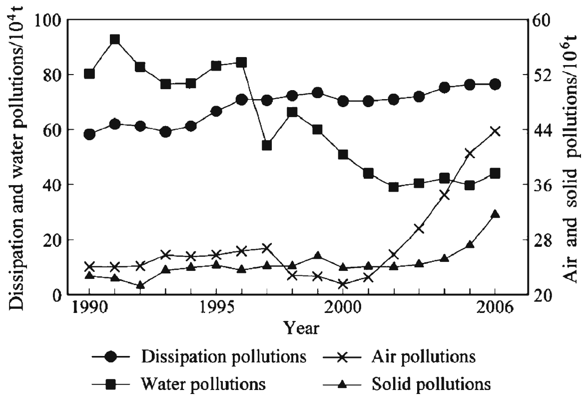

Fig. 3 Compositions and changes of DPO in Jilin Province

Figure 3 presents the compositions and changes of DPO in Jilin Province.[2] During the analyzed period (1990–2006), DPO increases from 4,815 × 10^4 t to 7,660 × 10^4 t, with an average annual growth rate of 2.77%. This rate is lower than that of material input growth, and even lower than that of GDP growth. Air pollution accounts for over half of the DPO (average 51%) and its growth rate is highest. This is the result of growing fossil fuel use. The share of solid waste is 46.4%, the second largest pollution source. Dissipation pollutions and water pollutions contribute little, accounting for 1.31% and 1.21% in DPO, respectively. As far as air pollution is concerned, 96.6% comes from CO_2 emissions. When it comes to solid wastes, industrial solid waste, whose average share is 71.7%, becomes the principal polluting source. Domestic garbage accounts for 28% of solid wastes, while medical waste contributes negligible.

Two phases are identified for the economy system of Jilin Province based on the annual growth rates of both DMI and DPO:

(1) 1990–2000: period of moderate growth in DMI and fluctuating change in DPO. During the period, DMI increased steadily at an average annual growth rate of 1.67%, while DPO fluctuated around a constant of 500 × 10^4 t. DPO in 2000 increased only 49 × 10^4 t compared to 1990.

(2) 2001–2006: period of sharp growth in both DMI and DPO. In 2006, the total DMI reached 21,841 × 10^4 t, 1.7 times of 2001 with an annual increase rate of 9.28%. The total DPO reached 7,660 × 10^4 t, 1.6 times of 2001 with an annual increase rate of 7.86%.

[2]In this paper, dissipation pollutions only include dissipation of fertilizer and pesticide, while water pollutions only refer to the harmful matter in wastewater (e.g., COD, NH_3-N).

There is a linear relationship between DMI and DPO. Regression equation is DMI = 3.578 × DPO − 5,297.04 ($r = 0.94$, $R^2 = 0.88$, adjusted $R^2 = 0.87$). With marked regression effect, the equation is meaningful in terms of statistics. It shows that Jilin Province maintains a traditional linear economic growth pattern characterized by high material input and waste output.

Structural decomposition analysis on material input/output in Jilin Province

Structural decomposition analysis (SDA) has been widely used to explain the changes that occur in any variable over time or space (Rutger and van den Jeroen 2002). This technique has been frequently utilized to tackle such topics related to the environment as energy and air pollution emissions recently (Mukhopadhyay and Forssell 2005; Jordi and Serrano 2007). Also, it is possible to find that SDA is applied to EW-MFA framework during the last decade (Wier and Hasler 1999). Using for reference from the classical IPAT model, we

Table 1 Average annual growth of MFA factors by SDA (%)

Period	DMI	DPO	P	GDP/P	DMI/GDP	DPO/GDP
1990–2006	4.19	2.77	0.55	9.20	−5.11	−6.41
1990–1996	2.31	1.14	0.93	9.57	−7.49	−8.55
1996–2001	2.70	−1.51	0.45	8.48	−5.75	−9.61
2001–2006	8.95	9.92	0.32	11.43	−2.54	−1.67

employed the SDA framework to find out reasons of DMI and DPO changing trend. In this paper, material flow analysis indicators were decomposed into three factors expressing society, economic, and technology to examine their impacts on material consumption and waste discharge. Specifically, we decompose DMI and DPO as follows:

$$\mathrm{MF} = P \times \frac{\mathrm{GDP}}{P} \times \frac{\mathrm{MF}}{\mathrm{GDP}} \quad (5)$$

Where, MF represents DMI and DPO; P refers to population; GDP/P stands for per capita GDP; MF/GDP is material intensity or waste intensity. MF represents the pressure on natural environment by human beings and economic activities; GDP/P represents the level of societal affluence and civil welfare; MF/GDP is used to measure the technology level.

The decomposition results, as represented in Table 1, show that the technology progress (the reciprocals, DMI/GDP and DPO/GDP,[3] descend by 5.11% and 6.41% per year) restrains the rapid increase of material input and waste discharge to a certain extent. However, this positive effect is offset by population (average annual growth rate is 0.55%) and civil welfare (average annual growth rate is 9.2%). The final result is that both material input and waste discharge have increased at average annual growth rates of 4.19% and 2.77%, respectively.

In 2001–2006, due to the considerable rise of civil welfare (GDP/P) and insignificant advances in technology (the least progress in the three periods: 1990–1996, 1996–2001, and 2001–2006), although the population growth rate slows down, environmental pressure increases sharply, which forms enormous obstacles to sustainable development.

[3] All figures refering to GDP are calculated in 1990 prices in this article.

Contribution of material input to economic growth

From the perspective of resources utilization, economic growth stems from two engines: increment of resources input and improvement of resources productivity. Since material input is a prerequisite for economic growth, excessive material input can promote economic growth to a certain degree. A proxy of this phenomenon is the unsustainable rapid growth resulted in extensive economic development style. However, scarcity of natural resources and the rationality of economic activities restrict unrestrained material input. In this case, improving resources productivity can also promote economic growth (equivalent to increasing material input). The above discussion can be expressed in mathematical equation as below.

If both sides of Eq. 2 are divided by GDP, a new equation is derived:

$$\frac{\Delta\mathrm{GDP}}{\mathrm{GDP}} \approx \frac{\mathrm{DMI} \times \Delta\mathrm{MPE}}{\mathrm{GDP}} + \frac{\Delta\mathrm{DMI} \times \mathrm{MPE}}{\mathrm{GDP}} \quad (6)$$

Because MPE = GDP/DMI, the following equation is derived from Eq. 6:

$$\frac{\Delta\mathrm{GDP}}{\mathrm{GDP}} = \frac{\Delta\mathrm{MPE}}{\mathrm{MPE}} + \frac{\Delta\mathrm{DMI}}{\mathrm{DMI}} \quad (7)$$

That is to say, economic growth rate is attributable to two main reasons: the increment rate of material input and improvement rate of material productivity.

Equation 7 was employed to analyze the contribution of material input to economic growth in Jilin Province. The results, as detailed in Table 2, indicate that resources input (expressed by DMI) contributes significantly to economic growth. The average contribution ratio is 44%, which is higher than those of Guangdong Province (37%) and the national average (35%), but similar

Table 2 Contribution of DMI and MPE to GDP in Jilin Province (%)

Year	Growth rate of GDP	Contribution of DMI	Contribution of MPE	Year	Growth rate of GDP	Contribution of DMI	Contribution of MPE
1991	5.95	31.20	67.55	1999	8.20	21.61	77.02
1992	12.17	40.24	56.97	2000	9.20	59.25	38.64
1993	12.70	42.71	54.34	2001	9.30	117.73	−15.98
1994	9.70	−12.89	114.33	2002	9.50	27.63	70.51
1995	9.70	−28.31	131.93	2003	10.20	77.91	20.46
1996	13.50	44.47	52.39	2004	12.20	90.64	8.43
1997	9.00	−31.32	135.13	2005	12.10	80.69	17.59
1998	9.10	−14.07	115.55	2006	15.00	91.08	7.85

As a result of neglecting the effect of cross-terms, sum of contributions of DMI and MPE do not equal to 100% accurately

to that of Liaoning Province (45%).[4] Except for the inhibitory effect in 1994–1995 as well as in 1997–1998, material input exhibits pull effect on economic growth. Especially in 2001, the contribution ratio exceeded 100%. All those indicate that the economy of Jilin Province is still at a stage when economic growth requires high material consumption, an evident extensive characteristic. It is noteworthy that coupled with the accelerated economic growth, the amount of material input has been ascending sharply since 2003. Meanwhile, average contribution of material input is as high as 86%, which is much higher than any former phase. Accelerated economic growth of Jilin Province is possible largely at the cost of resources exhaustion after the Revitalization Strategy of Northeast China was advanced.

The rising contribution of material input to economic growth is due to the economy characteristic of Jilin Province. At present, heavy chemical industry develops rapidly in Jilin Province. Especially in recent years, the growth rate of secondary industry is much higher than that of primary industry and tertiary industry. In the secondary industry, the most rapidly growing sections are steel, automobile, and cement. Whereas, the development of these sections requires more materials than others do.

[4]The data on DMI in Guangdong Province, Liaoning Province, and China are derived from references (Zhang et al. 2007; Xu et al. 2007; Gu and Wang 2005) and the data on GDP are derived from provincial and national statistical yearbooks. Thus, the contribution can be calculated through the above data.

Dematerialization in Jilin Province

Effect decomposition for dematerialization in Jilin Province

The decomposition results of dematerialization in Jilin Province are presented in Table 3. Rebound effect reflects the promoting contribution of GDP growth to input and output, while dematerialization effect reflects the inhibitory contribution due to the improvement of economic efficiency.

As GDP has been continuously growing without regression all through the analyzed period, both input and output rebound effects are positive, exhibiting positive driving effects to material consumption and waste discharge. As a consequence, both material input and waste output rebound effects present an enlarging trend.

Material productivity in 2001 and waste productivity in 2005 declined, which aggravated material consumption or waste discharge in the corresponding years. Except for these 2 years, the improvement of productivity exhibits inhibitory effects on material consumption or waste discharge. However, since 2001, input dematerialization effect and output dematerialization effect achieved only 35.2% and 34.6% of the average level before 2000. The dematerialization effect has evidently shrunk.

Possible reasons for the shrinking dematerialization effect include: (1) Jilin Province is a developing region and it is not enough to finance resources conservation and waste reduction perpetually. (2) The technical level is low and develops slowly. (3) Circular economy makes little progress and encounters numerous obstacles.

Table 3 Dematerialization effect analysis in Jilin Province (10^4 t)

Year	Direct material input			Domestic process output		
	Rebound effect	Dematerialization effect	Growth effect	Rebound effect	Dematerialization effect	Growth effect
1991	645.86	436.27	209.58	286.25	310.21	−23.97
1992	1,346.50	767.08	579.42	583.17	697.64	−114.47
1993	1,473.87	800.92	672.95	595.85	200.58	395.27
1994	1,187.15	1,357.22	−170.06	492.02	473.93	18.09
1995	1,171.82	1,545.94	−374.12	493.42	418.39	75.03
1996	1,586.59	831.14	755.45	696.29	702.09	−5.80
1997	1,121.09	1,514.98	−393.89	463.67	392.79	70.88
1998	1,101.78	1,273.15	−171.37	474.90	928.50	−453.59
1999	979.82	754.69	225.13	396.24	263.64	132.60
2000	1,119.17	432.47	686.70	456.29	561.92	−105.63
2001	1,192.52	−190.62	1,383.14	452.23	552.47	−100.24
2002	1,352.12	953.44	398.68	453.61	121.56	332.05
2003	1,489.47	304.77	1,184.70	519.93	97.31	422.62
2004	1,923.04	162.14	1,760.90	672.45	88.14	584.31
2005	2,118.19	372.66	1,745.53	736.53	−56.10	792.63
2006	2,882.40	226.23	2,656.17	1,033.12	233.97	799.14

The material circulation utilization rate decreased somewhat. Possible reasons for expanding growth effect could be summarized as follows: (1) As the economic stock increasing, growth rate appears constant, while absolute growth accelerates gradually. (2) The economic growth rate is certainly higher than before.

Except for some years, rebound effect is higher than dematerialization. Therefore, the growth effects are positive in most years, suggesting that DMI and DPO are increasing in most years. What is worse, rebound effect is growing, while dematerialization effect is shrinking. These deteriorate the increasing trend of material consumption and waste discharge. The environmental pressure situation will be much severer in the future.

Analysis on the dematerialization in Jilin Province

According to the definition of dematerialization in "Dematerialization model based on MFA" and results in "Effect decomposition for dematerialization in Jilin Province", we can calculate that the accumulative reduction quantity of material input and waste discharge are $11{,}543 \times 10^4$ t and $5{,}987 \times 10^4$ t, accounting for 4.9% and 6.6% of DMI and DPO, respectively. The dematerialization effect is just passable.

According to the dematerialization model, we can calculate the material input dematerialization index and waste dematerialization index. The results show that both indicators vary considerably. MDI fluctuates from −1.36% to 11.67%, while WDI fluctuates from −0.82% to 16.3%, with the variation coefficient of 0.744 and 0.712, respectively. It indicates that relative dematerialization effect differs notably over years and dematerialization effect fluctuates in a wide range. Therefore, it is necessary to detach short-term interferential component from long-term trend component in the time series of MDI and WDI so as to observe their underlying change trend in the course of economic development. H-P filtering wave is a usual trend decomposition method for economic variable.

Assuming Y_t is a time series of MDI containing trend component $\left(Y_t^T\right)$ and interferential component $\left(Y_t^I\right)$, then Y_t is able to be formulated as following:

$$Y_t = Y_t^T + Y_t^I \tag{8}$$

After the trend component of MDI (Y_t^T, underlying MDI) is achieved by H-P filtering wave operation, the material input dematerialization gap (MDG) in the year of t is defined as follows:

$$\mathrm{MDG}_t = \left(Y_t - Y_t^T\right) \times \left(\mathrm{DMI}_{t-1} + \mathrm{MBE}_t\right) \qquad (9)$$

MDG refers to the difference between actual dematerialization amount and underlying dematerialization amount. It can reflect the periodic fluctuant trace of dematerialization effect and the realization degree of potential dematerialization. If MDG > 0, it means that (1) actual MDI is larger than underlying MDI; (2) controlling work for material input is fruitful; (3) dematerialization effect is distinct; (4) the potential of dematerialization has been fulfilled; and (5) economic growth is accompanied with low material input, and vice versa.

In the same way, the underlying waste dematerialization index and waste dematerialization gap (WDG) are calculated. The meaning of WDG is similar to that of MDG.

The estimation of MDG and WDG can help policy makers ascertain the potential space of material input and waste discharge; so that they could set down more scientific and rational control goals for material input and output. In the long run, it aims to estimate environmental pressure and forecast the sustainable development state.

The MDG, WDG, underlying material input dematerialization index, and underlying waste dematerialization index are shown in Fig. 4.

As illustrated in Fig. 4, the underlying material input dematerialization index and underlying waste dematerialization index all increase slightly in the initial stage but then tend to fall as times goes on. The main reason is the low technology level. Over the past dozen years, the resources productivity and waste productivity substantially increased 144% and 208%, respectively, which is a tremendous progress. Under the current technology level in Jilin Province, it is difficult to make more progress, so that the elasticity of productivity is reduced and the dematerialization potential is becoming smaller and smaller.

Besides, the variation trace of underlying MDI is largely similar to that of underlying WDI (the correlation coefficient is as high as 0.99). It further shows that DMI and DPO are highly correlative. The difference is that the underlying waste dematerialization index is 1.44% higher than underlying material input dematerialization index on average. On the one hand, this can be viewed as the reflection of its outstanding environmental protection work on the one hand. On the other hand, deep-rooted limitation in environmental protection policy thereby emerges: similar to the case of China, the primary goal of environmental protection policy in Jilin Province is pollution-control. As far as the resources circulation field is concerned, market regulation plays the principal role while government intervention plays a subordinate role. So there is a serious waste phenomenon in resources consumption. However, there is a strong positive relationship between material input and excessive waste discharge, so resources waste eventually lead to pollution. Environmental protection policy in China at the current stage can only be called a temporary solution rather than a permanent cure.

Because the productivity improvement is the main cause of dematerialization, the variation trends of underlying material input dematerialization index and underlying waste dematerialization index are similar to that of resources

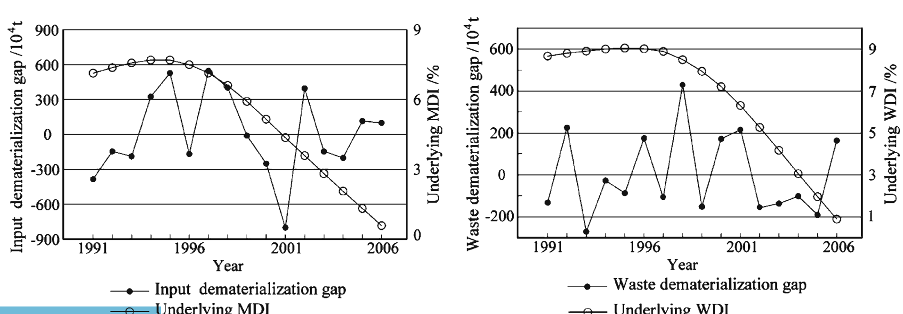

Fig. 4 Dematerialization gap and underlying dematerialization index of input and output in Jilin Province from 1991 to 2006

productivity and waste discharge productivity. Both resources productivity and waste discharge productivity are comparatively low in 1990–2006 in Jilin Province. In 2003, for example, resources productivity and waste discharge productivity were 111$/t and 316$/t, respectively. Resource productivity was only 28% of European Union or 9% of Japan (Xu et al. 2007), indicating that there is still large potential for further exploitation. Therefore, although underlying materialization index is comparatively low at present, Jilin Province still enjoys a great potential of dematerialization in the long run. In the near future, however, with the rapid process of urbanization, expansion of industry, and growth of fixed assets investment, high energy consumption and high pollution industries (e.g., heavy chemical industry, cement industry, and steel industry) also develop quickly and subsequently lead to the increase of the material input and waste discharge. Furthermore, with the improvement of living standard, people are pursuing a high-quality life. The consumption style of people in Jilin province is shifting from subsistence level to luxury level (During the period of 2001–2006, per capita annual purchases of major commodities in urban households and rural households have increased 11.2% and 15.4%, respectively, much higher than before). Household consumption aggravates the environmental pressure. Therefore, we predict that the amount of material input and waste discharge of Jilin economic system would persistently keep increase in the near future.

During 1991–2006, there were 9 years in which the material input dematerialization gap was below zero, while there were 10 years in which waste dematerialization gap was less than zero. These findings show that potentials of material dematerialization and waste dematerialization have not been fulfilled in most years. However, the total dematerialization effect is inspiring: The total material input dematerialization gap and waste dematerialization gap are more than zero (100.4×10^4 t and 42.4×10^4 t, 0.88% and 0.71% higher than the potential, respectively). So we can draw the conclusion that dematerialization potential has been exploited adequately, although economic growth exhibits a characteristic of high material consumption and high pollution in some years.

Relationship between dematerialization and sustainable development

The ultimate goal of sustainable development is to reach a state where the general quality of life (commonly expressed by GDP) continues mounting up while environmental pressures keep going down. So the more materials are put into economic system, the more wastes are discharged from economic system, which will more possibly result in unsustainable development of economy. Based on the principle above, we can test whether or not an economic system is sustainable according to the coupling relationship among economic performance, environmental pressure and material/waste productivity (Fig. 5).

According to the classification standard illustrated in Fig. 5, we find that weak unsustainable development dominates the economic system in Jilin Province. In terms of material input, Jilin's economy was on strong unsustainable status in 2001, while it was on sustainable status in 1994–1995 as well as 1997–1998. In other years, material input increment was accompanied by productivity improvement and economic growth. Therefore, Jilin's economy was on weak unsustainable status in those years. In terms of waste discharge, it was on strong unsustainable status in 2005, while it was on sustainable status in 1991–1992, 1996, 1998 as well as 2000–2001. It was

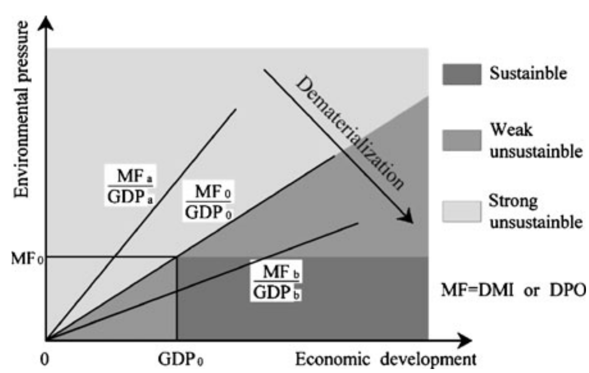

Fig. 5 Relationship between dematerialization and sustainable development

weak unsustainable in other years. Since 1990, the percentages of strong unsustainable, weak unsustainable and sustainable status among the analyzed years were 6.25%, 62.5%, and 31.25%, respectively.

Conclusions

A dematerialization model was established undertaken in MFA framework in this paper. We obtained the following results by applying it to Jilin Province.

1. Our study indicates that Jilin's economy maintains high material input and high waste output pattern. Such conclusion is technically backuped by the fact that (a) DMI and DPO show a gradual upward trend. (b) There is a linear relationship between DMI and DPO. (c) Jilin is still in a stage when economic growth requires excessive material input. The average contribution of material input to economic growth is higher than the national average as well as those of eastern developed provinces. (d) The resources productivity is very low, which is less than 1/3 of that in developed countries.
2. The dematerialization work is fruitful and the potential has been fulfilled. However, underlying dematerialization indexes present a gradual downward trend.
3. Unsustainable characteristics has been strengthened in Jilin Province since 2001: (1) DMI and DPO increase sharply. (2) The effect of technology progress is much weaker than before and the contribution of material input to economic growth has improved rapidly. (3) Dematerialization gaps are usually less than zero. The potential of dematerialization has not been fulfilled. These characteristics become much more obvious after 2003. Accelerated economic growth of Jilin Province is achieved largely at the cost of resources exhaustion after the Revitalization Strategy of Northeast China was launched.

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References

Cutler, J. C., & Matthias, R. (1998). Indicators of dematerialization and the materials intensity of use. *Journal of Industrial Ecology, 2*(3), 15–50. doi:10.1162/jiec.1998.2.3.15.

Environment Agency Japan (1992). *Quality of the environment in Japan 1992*. Tokyo, Japan: Environment Agency Japan.

Ester van der, V., Lauran van, O., & Igor, N. (2004). Dematerialization, not just a matter of weight. *Journal of Industrial Ecology, 8*(4), 121–137. doi:10.1162/1088198043630432.

EUROSTAT (2001). *Economy-wide material flow accounts and derives indicators: A methodological guide.* Luxebourg: EUROSTAT.

Farla, J. C. M., & Blok, K. (2000). Energy efficiency and structural change in the Netherlands, 1980–1995: Influence of energy efficiency, dematerialization and economic structure on national energy consumption. *Journal of Industrial Ecology, 4*(1), 93–117. doi:10.1162/108819800569203.

Gu, X. W., & Wang, Q. (2005). *The environmental stress: Indicators and application* [*in Chinese*]. Beijing, China: Metallurgical Industry Press.

Jordi, J. R., & Serrano, M. (2007). Income growth and atmospheric pollution in Spain: An input-output approach. *Ecological Economics, 63*(1), 230–242. doi:10.1016/j.ecolecon.2006.11.012.

Mukhopadhyay, K., & Forssell, O. (2005). An empirical investigation of air pollution from fossil fuel combustion and its impact on health in India during 1973–1974 to 1996–1997. *Ecological Economics, 55*(2), 235–250. doi:10.1016/j.ecolecon.2004.09.022.

Rutger, H., & van den Jeroen, B. (2002). Structural decomposition analysis of physical flows in the economy. *Environmental and Resource Economics, 23*(3), 357–378. doi:10.1023/A:1021234216845.

Schutz, H., & Bringezu, S. (1993). Major material flows in Germany. *Fresenius Environmental Bulletin, 2*(8), 443–448.

Steurer, A. (1992). Stoffstrombilanz Osterreich 1988. In *IFF social ecology papers no. 26*. Vienna, Austria: IFF Soziale Okologie.

Sun, J. (2003). Dematerialization in Finnish energy use, 1972–1996. *Energy Economics, 25*(1), 23–32. doi:10.1016/S0140-9883(02)00012-9.

Von Weizsaecker, E., Lovins, A. B., & Lovins, L. H. (1997). *Factor four: Doubling wealth-halving resource use.* London England: Earthscan Publications Limited.

Wier, M., & Hasler, B. (1999). Accounting for nitrogen in Denmark: A structural decomposition analysis. *Ecological Economics, 30*(2), 317–331. doi:10.1016/S0921-8009(99)00004-X.
Xu, M., Jia, X. P., Shi, L., & Zhang, T. Z. (2007). Accounting and analyzing material metabolism in the economic system of Liaoning Province. *Resources Science, 29*(5), 127–133 (in Chinese).
Zhang, Y. B., Xia, Z. X., Chen, X. G., & Peng, X. C. (2007). Dynamics of regional sustainable development based on material flow analysis. *Resources Science, 29*(6), 212–218 (in Chinese).