Material Flow & IPAT Analysis and Regional Sustainable Development: A Case Study in Hainan Province

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Abstract: In this study, the MFA and IPAT analysis methods have been used to calculate the natural material input and material output of the environmental-economic system in Hainan Province during the period from 1990 to 2005, and the results have been compared with the corresponding data of Guangdong Province. This study demonstrates that the MFA and IPAT analysis methods are good tools for evaluating the degree and discovering the mechanism of sustainable development in a region, as well as improving the quality of monitoring, controlling and decision-making of the regional development. These methods play important roles in improving the material input and output efficiency, reducing the intensity of resource-use and material output, and improving the potential of regional sustainable development.

The analysis result indicates that DMI has an uprising trend with average annual increase of 6.50%, while the growth rate was moderate and RPO has a declining trend with an annual 1.25% decrease. Material input growth rate is far less than the GDP growth rate (annual average growth of 15.63%). Rapid economic growth of Hainan Province dependents on the natural resource input to a certain extent, meanwhile it also produces a certain amount of waste. The calculations of material input and output intensity and efficiency indicate that material input intensity was increased and the output intensity was decreased, while the material input efficiency and output efficiency had been gradually improved between 1990 and 2005 in Hainan Province. From the rapid economic growth and, a relatively gentle of material input and reduction of material output, we can tell that Hainan Province has initially achieved the sustainable development of the natural resource and environment. From the analysis result of material input and output of environmental-economic system, we can also see that Hainan's sustainable development is still immature. The decomposition analysis of the DMI and the RPO, shows that, from 1990 to 1997, the input of natural resources of Hainan environmental-economic system had a minimum growth, but the output had a slight increase; From 1997 to 2005, the growth rate the of natural resources input had a big increase, but the output was in decline. Obviously, the sustainable development of Hainan Province was not stable during two different phases. Therefore, the sustainable development of Hainan should be further strengthened.

Keywords: Material Flow Analysis; Sustainable Development; Hainan Province; Guangdong Province

I. Research Method

MFA is a systematic analysis on the material flow and storage of the specific system within a certain time and space. It was originally initiated in Europe in 1990s. It was mostly used in the material flux of the whole country or the regional social and economic system. The method of MFA is the foundation and core of the circular economy plan and construction for a country or a region. It evaluates the efficiency of usage and the cost and profit of the social economic activity. The indexes of MFA are important references for the construction of the economic target system as well as the evaluation of the circular economy. Those indexes are very valuable to provide a novel and straight forward thinking approach, research method and decision-making support for the sustainable development [1-4].

The MFA consists of six indexes including: Input, Output, Consumption, Balance and Intensity. According to the European Union Logistics Analysis Frame, the definition of Direct Material Input, DMI is the material flow with certain economic value, which is imported from the outside of the environmental-economic system, and directly participates the system operation. It includes fossil fuel such as coal, petrol, natural gas and etc, metal and nonmetal mineral, agricultural products and import substances. It mainly focuses on the impact to the resource caused by the social and economic life of human being. On the contrast, the definition of Regional Processed Output, RPO is the overall waste introduced to the environment from the operation of the environmental-economic system including water pollution, air pollution and solid waste. It mainly describes about the environmental impact caused by material output [5]. RPO is an important index to indicate the input and output of environmental-economic system.

The intensity of the material input or output of environmental-economic system means the DMI or RPO per population unit respectively. The more material input and output a population unit has, the higher intensity of the material consumption and material output will be, and vice versa. The efficiency of material input or output means the DMI or RPO needed to produce a GDP unit respectively. The less material input and output for a GDP unit, the higher efficiency of material usage and output will be, and vice

versa. For any environmental-economic system, its sustainable development cannot be continued until the intensity of material input and output is low and at the same time, the efficiency of material input and output is high.

In order to further investigate the factors which affect the material input and output, on the top of MFA, this study is applying the method of IPAT to analyze the impact caused by those factors. The basic of this principle is a formula about: environmental pressure equals the product of population, national welfare and technique I=P·A·T. In this formula, I represents pressure index DMI or RPO; P represents population; A represents GDP i.e. GDP/P which indicates the affluence standard of a society; T, i.e. I/GDP which stands for the usage efficiency of the economic system (DMI/GDP) or material output efficiency (RPO/GDP), is used to measure the technical standard [6]. By applying IPAT principle, the index of DMI and RPO can be broken down into a multiplier of three factors: population, welfare and technique. So we can further analyze the contribution to the changed of environmental pressure index from the each individual factor.

In this study, starting with the quantity mass, we chose input & output, intensity and efficiency as three indexes (Table 1),

Table 1 Material Input and Output Indexes of Hainan Environmental-economic System

Indexes	Categories	Description
Material input	Fossil fuels	Direct mining of coal, oil, natural gas
	Minerals	Direct extraction of metal, nonmetal mineral production
	Biological materials	Agriculture, forestry, animal husbandry, fishery biological yield
	Import substances	The amount of resources imported from outside the province
Material output	SO_2, soot, Industrial dust emissions	The emissions of SO_2, soot , industrial dust in the process of Production and life
	COD emission	The total emissions of COD in the industrial wastewater and urban domestic sewage
	Industrial solid waste emissions	The total emissions of industrial solid waste

established an account of material input and output of Hainan environmental-economic system between 1990 and 2005, and analyzed the material flow of Hainan environment-economic system. By doing these, we evaluate the sustainable development index of Hainan. We reveal the characteristics of the material input and output within Hainan Province and the intensity and efficiency of the material input and output, find out the direct cause of the environmental pressure and propose the solution on reducing the environmental pressure.

II. Research Region and Data Resource

This study chose Hainan Province as the research object. Hainan Province lies in the most southern part of China. It is the only province of Tropical Island in China. On December 31st, 2009, "Several Opinions on Promoting the Development of Hainan Province as an International Tourism Island" was issued by the State Council, in which it proposed a strategic goal to build Hainan Province as a world-class sea-island tourism destination and ecological civilization region. In the light of this strategic plan, the research on the control and decision making of sustainable development of Hainan Province is very meaningful. In addition, unlike other provinces, Hainan Province has a clear system border line. Therefore, the MFA/IPAT study of Hainan is very unique due to its special geographical condition.

The original data resources of input and output of Hainan Province include Hainan Statistic Annual Book (1991-2006), the website of State Statistics Bureau (www.stats.gov.cn) and Bulletin of Hainan Environmental Condition. Some missing data points were estimated based on interpolation method. The corresponding data of Guangdong Province for the compression were from the literature [5].

Ⅲ. Results and Discussions

The Variation Trend of Material Input and Output
Figure 1 indicates the relative changes of the value of DMI, RPO and GDP of each year between 1990 and 2005, with the values of year 1990 as the reference value of 100. From 1990 to 2005, the average annual increase of GDP in Hainan is 15.63%, while the average annual increase of DMI is 6.5%. Comparing with GDP, the DMI curve is flat. During the whole period of time, PRO showed a slow decline with 1.31% average annual decrease rate.
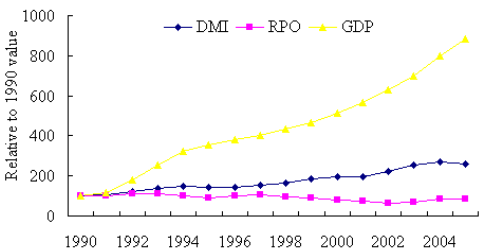

Fig.1 DMI, RPO and GDP Variation Trends of Hainan from 1990 to 2005

Figure2 shows the changes of DMI inputs between 1990 and 2005. In term of the structure of DMI inputs, the average weight of fossil fuels, minerals, biological materials and import substance in DMI input are 9.74%, 24.96%, 36.70% and 28.60% respectively. In terms of the changes over the time course, all the above four elements show uprising trends. The average growth rate of fossil fuel, minerals,

biological materials and import substance in 15 years are 11.87%, 4.76%, 3.95%, and 10.08% respectively.
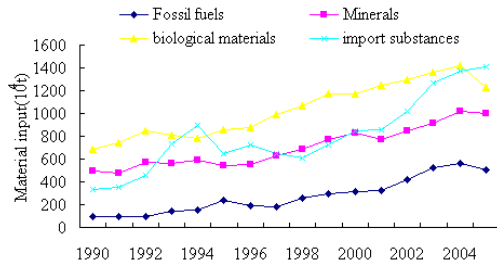

Fig.2 Components of DMI in Hainan from 1990 to 2005

The reason of the slow growth of DMI in environmental-economic system of Hainan mainly contributes to the slow growth of biological material input which takes up most part of DMI as well as the low growth rate of other materials. For example, the growth rate of fossil fuel was relatively the largest among the four elements, but its portion in DMI was the smallest. So the overall impact of fossil fuel was so little and not obvious. The analytic result of the input amount and change rate of the import materials indicates that environmental-economic system in Hainan Province had a dependency on imported materials and the demand is growing rapidly.

From the analytic results of the structure of RPO outputs (shown in Figure 3), the outputs of COD, SO$_2$, soot, industrial dust, industrial solid waste in 15 years accounted RPO for 66.33%, 13.85%, 9.18%, 10.45% and 0.20% respectively. From the time series analysis, COD, soot showed a downward trend in 15 years. An average annual decline are 2.32% and 3.80%; SO$_2$, industrial dust showed an rising trend with the average annual growth rate of 3.61% and 0.73% respectively, changing in solid waste output amount is not obvious.
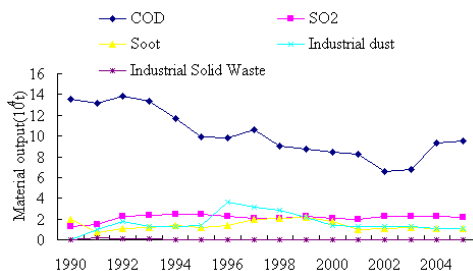

Fig.3 Components of RPO in Hainan from 1990 to 2000

The RPO decline in environmental-economic system, mainly related to the decline of COD emissions accounted for RPO, which showed the strengthened management capacity of the Hainan Province as well as the escalation of its industrial structure.

Between 1900 and 2005, the economic standard of Hainan environmental-economic system is uplifting, to some extent, it relied on the input of natural resources. However the material output of environmental-economic system correlates to the nonlinearity of material output. The

environmental-economic system of Hainan has demonstrated its initial trend of sustainable development.

The Strength of the Material Input and Output
Per capita DMI and per capita RPO of the Environmental-economic system show the strength of the material input and output respectively. We can see from Figure Ⅳ and Figure Ⅴ that Hainan's per capita DMI was obviously lower than that of Guangdong provenience during 1990 to 2005. This means the strength of Hainan material input was higher than Guangdong provenience. At the same time, the per capita DMI in Hainan tend to upward and during this period the per capita RPO in Hainan is evidently lower Guangdong provenience, this shows that the strength of material output is lower in Hainan than that in Provenience. The per capita RPO in Hainan fluctuate in the 15 years and show the trend of descent. We can divide the change of per capita DMI and RPO in this 15 years into different stages, the per year change rate is showed in Table 2.
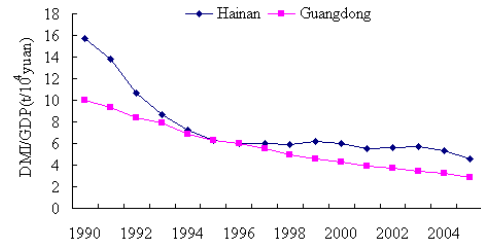

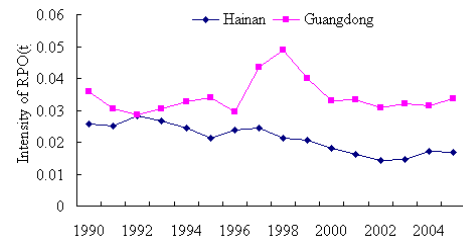Fig.4 Comparison of DMI/GDP between Hainan and Guangdong

Fig.5 Comparison of Intensity of RPO between Hainan and Guangdong

Table 2. Average Annual Change Rate of Intensities about DMI and RPO in Phases of Hainan Province

Stages	1990-1994	1994-1998	1998-2005	1990-2005
DMI	+9.00%	+0.60%	+5.07%	+4.88%
Stages	1990-1997	1997-2005		1990-2005
RPO	-0.70%	-4.51%		-2.75%

The Efficiency of the Material Input and Output
The DMI/GDP and RPO/GDP of the environmental-economical system refer to the input of material and the efficiency of output. As Figure 5 and Figure 6 showed, during 1990 to 2005 the DMI/GDP in Hainan provenience were higher than Guangdong provenience, this meant that the input efficiency were lower than that of the Guangdong provenience. The input efficiency were increased from 1990

to 1995 in Hainan and the level were almost the same with Guangdong provenience till the end of 1995, but the input efficiency increased lower than Guangdong provenience from 1995 to 2005 and the distance of the material using efficiency between Guangdong and Hainan were large till the end of 2005. The DMI/GDP in Hainan provenience began to decreased, which showed that the material input efficiency in 15 years of Hainan were increased. The RPO/GDP during 1990 to 1994 and in the year 1996 in Hainan are higher than Guangdong and showed that during this period the material output efficiency are lower than that of Guangdong provenience. But the PRO/GDP in Hainan in the 15 years showed the trend of decrease and this meant that the material output efficiency in the 15 year was increased step by step. The change of the DMI/GDP and RPO/GDP can be divided into two stages—the change rate of the annual average was showed in Table 3.
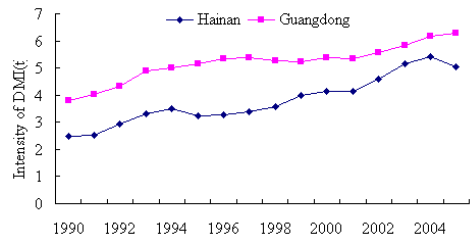

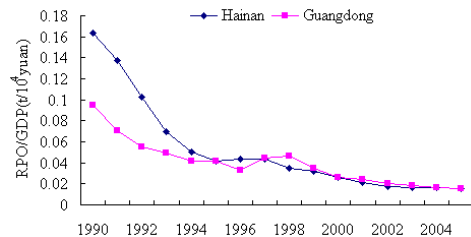Fig.6 Comparison of DMI /GDP between Hainan and Guangdong

Fig.7 Comparison of RPO/GDP between Hainan and Guangdong

Table 3. Average Annual Change Rate of Efficiencies about DMI/GDP and RPO/GDP in Phases of Hainan

Stages	1990-1995	1995-2005	1990-2005
DMI/GDP	-16.80%	-3.10%	-7.90%
RPO/GDP	-24.12%	-9.40%	-14.60%

The difference of the intensity and efficiency of material input and output between Hainan and Guangdong Province due to the differences in population, economy quantity, industrial structure and consumer structure . For example, the per capita GDP of Guangdong was 2.4 time of one of Hainan in 1990, while 1.97 time in 2005. Although the absolute value of per capita GDP of Hainan is less than one of Guangdong, the difference in between has been decreasing. The fast growth of economy is direct related to the level of the optimization of industrial structure. For instance, Guangdong is one of the biggest provinces in term

of the manufactory industry, but the manufactory industry is the smallest portion in whole industrial structure in Hainan. To a certain extent, the fast economy growth of Hainan depended on the input of natural resource, along with the decline of the portion of manufactory industry, the portions of the second and third industry increased. The improvement of internal technology of each industry slowed down the increasing rate of input, which further decreased the corresponding pressure to the output. The different consume structure and the environmental protection and management in Hainan and Guangdong are also the major reasons to influence the different intensity and efficiency of output for each province.

The IPAT Resolving Analysis of Material Input and Output
According to the theoretical model: $I=P \cdot A \cdot T$. we can resolve DMI and RPO, calculate the annual changing rate of this three resolving quota and find out the contribution of every factor in the changing of material input and output. According to the characteristics of the material input and output, we can take 1997 as a boundary line and analysis by two periods (Table 4).

Table 4. Average Annual Change Rate of the Material Input and Output-related Factors for Various Stages

Indexes /Stages	1990-2005	1990-1997	1997-2005
DMI	+6.50%	+6.14%	+6.81%
RPO	-1.25%	+0.82%	-3.03%
P	+1.54%	+1.535%	+1.544%
GDP/P	+13.88%	+20.12%	+8.69%
DMI/GDP	-7.90%	-12.97%	-3.22%
RPO/GDP	-14.60%	-17.33%	-12.14%

During 1990 to 2005, the increase of the level of the material input of Hainan environmental-economical system (DMI/GDP decreased 7.9% per year) restrain the increasing of the input of the natural material. But the population pressure and the increasing of national welfare (1.54% and 13.88% respective) help to the increase of the natural resources input (6.50% per year). Although the population pressure and the national welfare were increased, the level of the material output was raising, so the material output of the system were reduced and the pressure to the environment were eased.

During 1990 to 1997, national welfare increase most (20.12% per year), the population pressure were lightener than the other period, and the increase rate of the resources were least (6.14% per year). As far as output was concerned, though the increasing rate of the material output were most (RPO/GDP decrease 17.33% per year), the resource output show a little trend of increase because the increase rate of the output level was less according to the increase of national welfare.

During 1997 to 2005, the national welfare kept a lower increasing rate (8.69% per year) although the population pressure was increased. The resource input increase rate were largest (6.81%) because of the level of material input increased least. As far as output was concerned, because of the national welfare increasing rate was least the decreasing rate of the resource output (3.03% per year) although the increasing rate of the material output was least (RPO/GDP decreased 12.14% per year).

In the analysis we just made , we can understand the increasing of the technical level (DMI/GDP or RPO/GDP) as following: in micro aspect, we think that by using clearer production method and increasing the technical method of production the material and the pollution of the production can be decreased. In macro aspect, we think that by the bettering of the production construction and the increasing of the consumer construction, the material input increasing rate and the material output lower in every unit GDP's producing.

The analysis on the industrial structure changes of Hainan Province from 1990 to 2005 can reveal their impact on the DMI / GDP and the RPO / GDP changes. Figure 8 shows us, the industrial structure of Hainan Province had been gradually adjusted from 44.63:19.72:35.65 for the first, second and third industry respectively in 1990, to 32.97:26.06:40.97 in 2005. Vertical contrasting showed that the proportion of primary industry declining, secondary and tertiary industries were increasing the proportion (in which the proportion of secondary industry and tertiary industries is still relatively minimal). It showed first industry was change to the second and tertiary industries, in Hainan Province's industrial structure is being upgraded. To get the same output in the creation, e a service-oriented tertiary industry input less material than that of the first and secondary industries. The building of Hainan international tourism island will have a profound impact on the development of tourism, it will also further the upgrading of the industrial structure in Hainan. The proportion of primary industry gradually to the second and tertiary industries, as well as optimization of the internal structure of various industries can reduce the regional economic development. Using of natural resources will reduce and the pressure to the environment. We can see impact of the industry construction on DMI from what we have analysis. The proportion of primary industry in three industries decreased from 44.63% (1990) to 32.97% (2005) but it is still a large proportion. This is related to the low increasing rate of the input of the biological material which is the most part of DMI. In addition, the proportion of secondary industry kept increasing from 1990 to 2005 (but its share in the three industries is still the smallest). This can be showed by the increasing rate of the fossil fuels and minerals which make up the DMI.
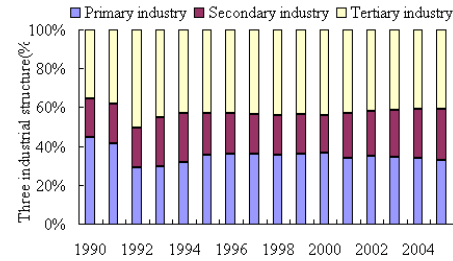

Fig.8 Three Industrial Structure of Hainan Province from 1990 to 2005

The relatively slow status of material input growth can reduce the material output pressure of the system. Also, the promotion of consumption structure can reduce material output pressure of the system to a certain extent. The region rapid economic growth and industrial structure adjustment and optimization will lead to the acceleration of the consumption structure upgrading. The regional environmental protection and governance capacity is strengthened, such as the construction of new industrial province, industrial access thresholds, environmental planning in advance, rural sewage treatment plants and environmental protection facilities which is one of the series of livelihood projects. As these favorable factors working together, the growth of material output in Hainan environmental-economic system was becoming more and more flat or even decrease. For environmental-economic system, the reduction of material output which is one of the requirements of sustainable development will substantially reduce the pressures to the environment.

IV. Conclusion

The MFA results of Hainan environmental-economic system between 1990 and 2005 shows that: DMI has an uprising trend with average annual increase of 6.50%, while the growth rate was moderate and RPO has a declining trend with an annual 1.25% decrease. Material input growth rate is far less than the GDP growth rate (annual average growth of 15.63%). Rapid economic growth of Hainan Province dependents on the natural resource input to a certain extent, meanwhile it also produces a certain amount of waste. The calculations of material input and output intensity and efficiency indicate that material input intensity was increased and the output intensity was decreased, while the material input efficiency and output efficiency had been gradually improved between 1990 and 2005 in Hainan Province.

From the rapid economic growth and, a relatively gentle of material input and reduction of material output, we can tell that Hainan Province has initially achieved the sustainable development of the natural resource and environment. From the analysis result of material input and output of environmental-economic system, we can also see that Hainan's sustainable development is still immature. The

decomposition analysis of the DMI and the RPO, shows that, from 1990 to 1997, the input of natural resources of Hainan environmental-economic system had a minimum growth, but the output had a slight increase; From 1997 to 2005, the growth rate the of natural resources input had a big increase, but the output was in decline. Obviously, the sustainable development of Hainan Province was not stable during two different phases. Therefore, the sustainable development of Hainan should be further strengthened.

With the maintaining rapid economic growth, Hainan Province should strengthen the research and formulation of industrial policy, access to systems and development strategies. To improve the material input and output efficiency of environmental-economic system and reduce resource use intensity and material output intensity, it should also focus on the transformation about the national economic level of technology and lifestyle improvement. All of these can protect ecological environment and enhance sustainable development capacity of Hainan Province.

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