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Research Paper

Comparative analysis of three major cities' industrial systems and their environmental impacts in the Pearl River Delta

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Abstract. The Pearl River Delta, as a leading region in China's economic and industrial development, analyzing the characteristics of the industrial system (IS) of its major cities can play a role in predicting the trend of industrial development of other cities. In this study, a framework of the relation between the IS and the external environment and an evaluating index system are built based on the life cycle process of a product. According to the statistics, the current characteristics of the ISs in Guangzhou, Shenzhen and Dongguan are quantitatively analyzed and compared. The results show that there has been an obvious homoplasy in the development of three cities' ISs. For all of them, the high-tech manufacture industry is the pillar industry which leads the development of regional economy, and it has a strong driving effect on the improvement of eco-efficiency of the IS. The main social services provided by the IS includes building materials, household appliances and wearing apparel and accessories. Shenzhen's IS with higher net economic output; lower energy consumption and pollutant discharge plays a better demonstration and leading role in the development of the entire urban agglomeration.

Keywords: City, life cycle, industrial structure, environmental impact, eco-efficiency.

INTRODUCTION

With the continuous deepening of global industrialization, the industrial system (IS) as the most powerful interaction between human society and natural ecosystems, have been paying much attention for a long time. There's no doubt that industry has a strong driving effect not only in the process of regional urbanization but also in the economic development of a city. But at the same time, the relevant statistics in many cities show that the IS is the main source of natural resources consumption and environmental pollutants discharge. Considering the dual nature of the impacts of the urban IS on the external, a lot of previous studies have been conducted from within the system to find a balance between positive impacts and negative impacts (Ye *et al*., 2013). And this topic is exactly an important part of environmental management as well as a hot topic in recent years.

The Pearl River Delta is located in the coastal area of southern China. Since the policy of reform and opening up was carried out in China, it has developed the industry vigorously based on its geographical advantages adjacent to Hong Kong and Macao, as well as the support of national policies. It has successfully transformed from a rural area dominated by labor-intensive manufacturing industry to a metropolis dominated by advanced technology manufacturing industry. In 2015, the gross industrial output value of this region reached 10.16 trillion yuan, and represented about 40% of the composition that of the whole province

(Statistics Bureau of Guangdong, 2016). However, there is still obvious polarization in the development of industry in the nine cities of this region (Zhou *et al*., 2015). The data shows that the high-tech manufacturing industry in Shenzhen, the central city, has brought about 70% of the economic growth of the IS, while some cities far from the center, such as Jiangmen, rely mainly on materials processing industry with high energy consumption and high pollutants discharge. Some studies pointed out that the central cities in a region can diverge and lead the surrounding cities significantly after gathering most kinds of resources and production factors (Leng, 2009; Gao and Zhou, 2009; Solé and Viladecans, 2010). Therefore, the analysis of the characteristics of the IS in the major cities of a region, on the one hand, can provide a basis for the management of their own. But more importantly, it can predict and guide the industrial development of other cities in the Pearl River Delta region.

The study of the external impacts of urban IS is mostly focused on the environmental impact. Previous studies have analyzed the resource consumption of urban industry (Rahman *et al*., 2016; Oguntonaa and Aigbavboa, 2017; Dunkelberga *et al*., 2018). As a major energy-consuming country, some scholars in China has also made numerous researches on China’s key cities. For example, Jia *et al.* (2018) analyzed the situation of industrial energy consumption in Nanchang, and put forward the countermeasures to reduce the pollution emissions caused by industrial energy consumption. With regard to the pollutant discharge, Hu *et al*. (2016) took the total amount and intensity of pollution as the measurement indicators and analyzed the characteristics of industrial pollutant emissions in 286 cities in China. In recent years, industrial carbon emissions have also become a hot research topic all over the world. González *et al*. (2016) analyzed the CO_2 emissions from the ceramic industry in the Guadalquivir Basin, and proposed that improving the composition of raw materials could reduce carbon emissions. Ye *et al*. (2013) accounted for the industrial carbon emissions of 16 cities in the Yangtze River Delta from 2005 to 2009. Xu *et al*. (2018) analyzed CO_2 emissions from industrial activities in 18 cities in China, and proposed relative mitigation strategies for each city. It can be seen that the above research has exactly promoted people's understanding of the environmental impact of the whole IS. But there are still lots of problems need to be dealt with. On the one hand, the comprehensive analysis of the various impacts is also lacking at present; on the other hand, the IS is usually regarded as a black box in these studies, and the external impacts are seldom reflected when it comes to each component in the system.

To have a better extensive insight of the IS and provide basis to the management, it is very necessary to deconstruct the IS. At present, based on the classification of primary, secondary and tertiary industries (Qi and Zhang, 2015; Yu, 2015), or of heavy and light industries (Liu *et al*., 2018), or of the industrial scale (Ma and Yu, 2017), most of the researches on urban industrial structure are focusing on its evolution, its relationship with the industrial impacts on the external, and its adjustment. Jiang and Deng (2015) discussed the evolution of Shanghai's industrial structure from 1978 to 2012, and compared it with New York, London and Tokyo. The results showed that Shanghai was transforming to a service-oriented city, but there was still a big gap between Shanghai and the cities of developed countries in the degree of de-industrialization. Li *et al*. (2018) pointed out that the industrial structure had a positive impact on CO_2 emissions in the short term. In order to reduce the industrial impacts on the environment, the scale of the high-tech industries was supposed to be expanded (Lin and Xu, 2018). The above researches on industrial structure do not go deep into the industrial sector level, and the deconstruction analysis of the IS is not yet adequate. Only a few studies on the industrial structure of major cities are based on the industrial division of various sectors, and fewer based on the life cycle of a product. For example, Wu and Mao (2010) discussed the proportion of each of the 41 industrial sectors in China's 5 major cities. Juraschekab *et al*. (2018) took Sydney as an example to analyze the industrial value creation oriented by the life cycle of a product.

Overall, although the characteristics of IS in many cities have been analyzed, the comparative analysis of the major cities in the Pearl River Delta region is still rare, which can be supplemented in this study. In addition, in order to solve the problems mentioned above, the aims of this work are to analysis the industrial impacts more comprehensively, not only on the environment, but also on the economy and society. And the relationship between the internal of the IS and the external environment will be carried out based on the life cycle of a product. The research conclusions will provide important practical significances to the IS management of the major cities in the Pearl River Delta region, as well as the prediction of the industrial development of the surrounding cities.

METHODOLOGY

In the previous research of the author, the IS was reconstructed according to the life cycle process of a product. And a set of indicators to evaluate the characteristics of the IS from the internal structure, the external impacts, and the relation between the IS and the environment these three aspects were established (Song *et al*., 2018). This article still adopts this methodology and makes a brief review here.

The framework and the compositions

The IS can be divided into resource exploitation, industrial material production, product processing and

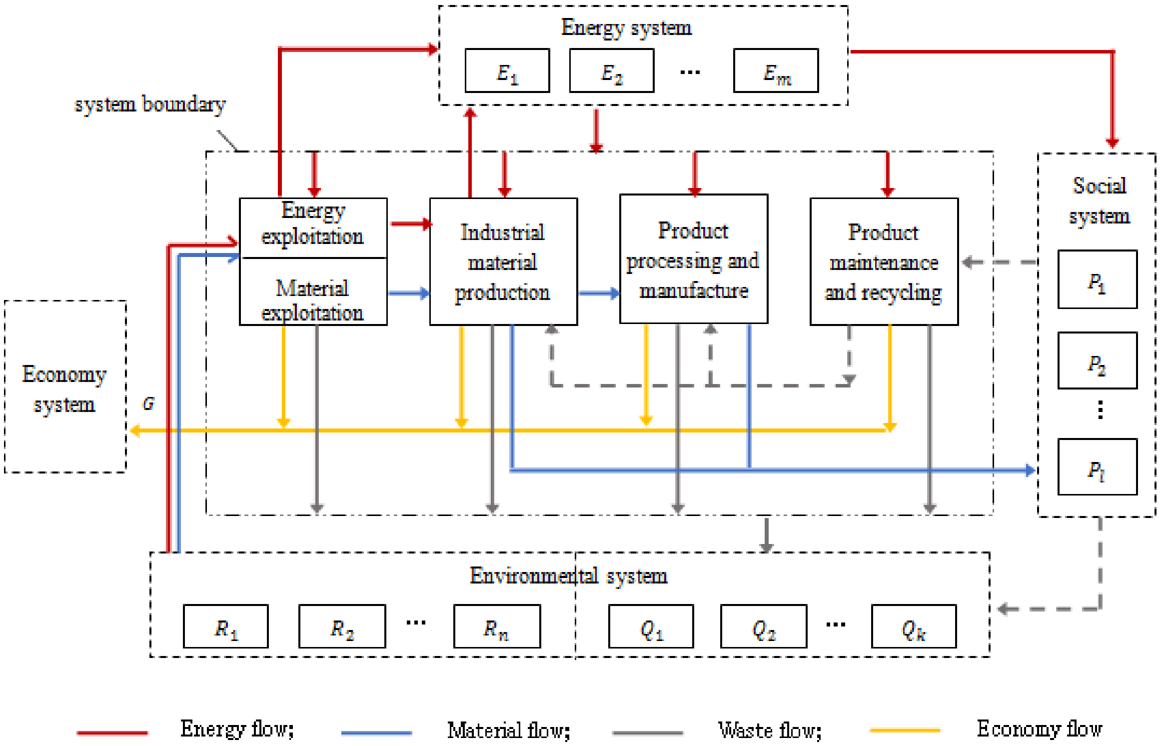

Figure 1. The framework of the relation between the industrial system and the external. *E*: energy consumption; *R*: material resource consumption; *G*: economic output; *P*: output of services; *Q*: pollutant discharge; the subscript *m, n, l, j*: the serial number of types.

manufacture, and product maintenance and recycling these four phases according to the life cycle process of a product. And the external impact of the IS also can be considered from the society, economy, resource and environment these four aspects. On this basis, a simplified framework of the relation between the IS and the external environment is shown in Figure 1. The grey dashed lines show the recycling of components or materials after a product is scrapped, although this flow actually exists, it will not be considered in this study.

Based on *the national economic industry classification standard* (GB/T 4754-2011), the 41 industrial sectors are classified into the four industrial phases according to their role in the life cycle process of a product. The code and composition of each phase are summarized in Table 1.

The evaluation index system

The structural coefficient

The industrial structure is the proportional relationship among the components of an IS in a certain period of time. It can reflect the allocation and mutual restriction of labor, capital and natural resources in various industrial sectors, and also determines the consumption mode of means of production (Chen, 2007). This study takes the structural coefficient as an index to reflect the degree of dominance of each component in an IS, which can be calculated as follows:

$$f_i = V_i / V \quad (1)$$

Where f represents the structural coefficient of a certain sector, *V* represents the gross industrial output value, and the subscript *i* is the serial number of the industrial sector.

In addition, the sum of the contribution of the gross industrial output value of each sector in the same phase is the structural coefficient of this phase:

$$F_I = \sum_{i=1}^{n} f_i \quad (2)$$

Where F represents the structural coefficient of a certain phase, the subscript *I* is the serial number of the industrial phase, and $\sum_{i=1}^{n} f_i = \sum_{I=1}^{m} F_I = 1$.

The environmental impacts

The IS in a region is double-edged when it comes to its external impacts. On the one hand, it brings convenience

Table 1. The codes and compositions of industrial phases.

Industrial phase	Code	Composition	
		Name of sectors	**Code**
Resource exploitation	RE	Mining and washing of coal	CMW
		Extraction of petroleum and natural gas	PGE
		Mining and processing of ferrous metal ores	FMM
		Mining and processing of non-ferrous metal ores	NFM
		Mining and processing of non-metal ores	NOM
		Mining of other ores	OOM
		Support activities for mining	SAM
Industrial material production	MP	Manufacture of petroleum, coking and processing of nuclear fuel	PCM
		Smelting and pressing of ferrous metals	FMS
		Smelting and pressing of non-ferrous metals	NFS
		Production and supply of electric power and heat power	EHP
		Production and supply of gas	GPS
		Production and supply of water	WPS
		Manufacture of raw chemical materials and chemical products	CMM
		Manufacture of chemical fibres	CFM
		Manufacture of non-metallic mineral products	NMM
		Manufacture of paper and paper products	PAM
Product processing and manufacture	PM	Processing of food from agricultural products	AFP
		Manufacture of tobacco	TOM
		Manufacture of foods	FOM
		Manufacture of liquor, beverages and refined tea	LBM
		Manufacture of medicines	MEM
		Manufacture of textile	TXM
		Manufacture of textile, wearing apparel and accessories	TWM
		Manufacture of leather, fur, feather and related products and footwear	LFM
		Processing of timber, manufacture of wood, bamboo, rattan, palm and straw products	WBP
		Manufacture of rubber and plastics products	RPM
		Manufacture of metal products	MPM
		Manufacture of furniture	FNM
		Printing and reproduction of recording media	MPR
		Manufacture of articles for culture, education, arts and crafts, sport and entertainment activities	ASM
		Manufacture of general purpose machinery	GMM
		Manufacture of special purpose machinery	SMM
		Manufacture of electrical machinery and apparatus	EAM
		Manufacture of measuring instruments and machinery	IMM
		Manufacture of automobiles	AMM
		Manufacture of railway, ship, aerospace and other transport equipment	RSM
		Manufacture of computers, communication and other electronic equipment	CEM
		Other manufacture	OTM
Product maintenance and recycling	MR	Repair service of metal products, machinery and equipment	MEP
		Utilization of waste resources	WRU

Table 2. Impacts of industrial system on the external and their indexes.

Impacts	Definition	Index
Impact on society	Products or services provided by the IS for human society.	Output of industrial products
Impact on economy	The net economic benefits brought by IS.	Total profit
Impact on resource	The consumption of material resources and energy which exploited from natural environment during the process of industrial producing.	Energy consumption
Impact on environment	In the process of industrial producing, a part of matter is discharged into and accumulate in the environment.	Pollutant discharge

to human society. On the other hand, it consumes natural resources and discharges wastes into the environment. In order to describe the external characteristics of the IS more comprehensively and make it comparable among different regions, this study select some indicators from society, economy, resources and environment these four aspects to quantitatively analyze the external impacts of the IS, which are summarized in Table 2. As to the impact on resource, because the data of material resources consumption in Guangzhou, Shenzhen and Dongguan are difficult to obtain, this study only takes the energy consumption into consideration.

The relation between the industrial system and the environment

Previous studies pointed out that the external impact of a particular system often depends on its internal structure (Llop, 2007; Ramli and Munisamy, 2015), and the relationship between them is often characterized by eco-efficiency in the study of IS (Mao *et al*., 2010; Mao and Ma, 2013). In this study, the energy efficiency is also used to evaluate the relation between the industrial structure and the energy consumption. And the calculation formula is as follows:

$$e = V/E \equiv [\sum_{i=1}^{n}(f_i \times e_i^{-1})]^{-1} \tag{3}$$

Where e represents the energy efficiency, which is the gross industrial output value generated per unit of energy consumption, with a unit of thousand yuan·tce^{-1}; and e_i can be estimated according to the equations $e_i = G_i/E_i$. The other symbols have the same meanings as set out in the previous definitions.

Selection and data sources of the major cities

Combined with the results of previous survey, this study takes Guangzhou, Shenzhen and Dongguan as examples and chooses 2015 as the basic year. Among them, Guangzhou is the capital of Guangdong Province. Its functions as an administrative and transportation center make its ability in radiation and demonstrating stronger. Shenzhen is the first special economic zone in China. Its modern industrial development in just 30 years has made it a miracle of industrialization. Dongguan is a famous industrial city with prominent manufacturing industry. The economic growth and industrial development of these three cities are very typical, and studying the characteristics of their ISs can play a role in predicting the industrial development trend of other cities.

The data categories mainly relate to the gross industrial output value, energy consumed, total profit, waste discharged, and the output of major products. These regional data can be obtained from *Guangzhou Statistics Yearbook* (Statistics Bureau of Guangzhou, 2016), *Shenzhen Statistics Yearbook* (Statistics Bureau of Shenzhen, 2016), and *Dongguan Statistics Yearbook* (Statistics Bureau of Dongguan, 2016), respectively.

RESULTS

Industrial structure

In order to ascertain the structural composition of the regional IS, the structural coefficient of each industrial sector in these three cities in 2015 are calculated, respectively. Using the classification of the 41 industrial sectors described above, all of the sectors are presented in order of Guangzhou from high to low in Figure 2.

As shown in Figure 2, there is almost no related industrial sector in the RE phase in the three cities. But the MP phase, with the second largest scale, has a certain role in promoting the economic growth of the regional IS. The PM phase is the largest phase in the IS of three cities with structural coefficients all greater than 0.65. Especially in Shenzhen, the structural coefficient is as high as 0.91. The pillar sectors are AMM, CEM and EAM in Guangzhou, CEM in Shenzhen, and CEM and EAM in Dongguan. It can be seen that the development of ISs in Guangzhou, Shenzhen and Dongguan all show obvious concentration and scale effect, and the order of

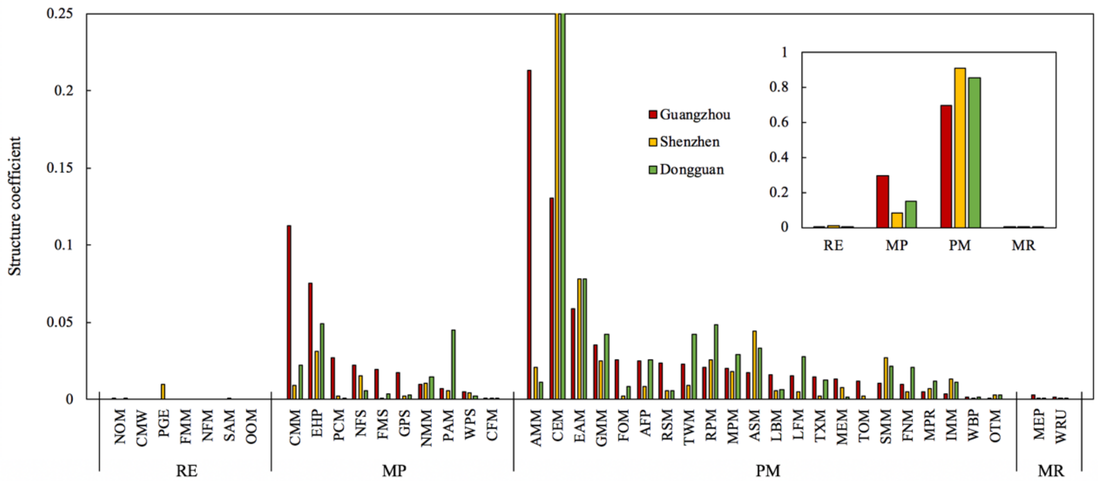

Figure 2. The structure of industrial system in 2015.

concentration degree from high to low is Shenzhen > Dongguan > Guangzhou. In addition, which is different from the other two cities, some sectors in the MP phase in Guangzhou, such as CMM and EHP, also occupy a prominent place in respect of the economic growth. The structural coefficients of these two sectors are 0.11 and 0.08, respectively.

Environmental impacts

Impact on the society

The first 10 kinds of products with the largest output are chosen to reflect the impact of the IS on the society, and these are summarized in Table 3.

As shown in Table 3, the IS of three cities have both similarities and differences in their impacts on society. On the one hand, providing household electric appliances, electronic products, and wearing apparel and accessories for humans is the main impact of the IS of the three cities on the society, which shows the characteristics of combination of high-tech products and light industrial products. Meanwhile, the output of the related subassemblies is also far higher than other products; examples of these are electronic components, hard drives, semiconductor integrated circuit, etc. On the other hand, for the same products, the productivity of the three ISs are quite different. For instance, the output of electronic components of Dongguan's IS is 1138.50 billion units, which is 10 times that of Shenzhen's IS and more than 400 times that of Guangzhou's IS.

Generally speaking, the order of productivity from high to low is Dongguan > Shenzhen > Guangzhou, the order of development degree of high-tech manufacturing from high to low is Shenzhen > Dongguan > Guangzhou, and the order of industrial product diversity from high to low is Guangzhou > Dongguan > Shenzhen.

Impact on the economy

In 2015, the IS of Guangzhou, Shenzhen and Dongguan produced 109.86, 183.19 and 40.75 billion yuan of total profit, respectively. The statistics for the total profits of the four phases and 41 sectors are summarized in Figure 3, which are presented in the order of Guangzhou from high to low in each phase.

As shown in Figure 3, although the phase with highest economic output of the three ISs are all the PM phase, there are great differences in absolute values due to the differences in the management ability and market competitiveness of industrial enterprises in different regions. Among them, the total profit of Dongguan's IS is lower than that of the other two cities, and is less than 40% of Guangzhou and 25% of Shenzhen. The total profit of the PM phase in Shenzhen's IS has reached 153.55 billion yuan, far higher than that of the other two cities. And the difference between phases is even more significant. As for specific sectors, considering the operation and revenue generation, the dominant sector of Shenzhen's IS is CEM. It brings economic benefits as high as 107.07 billion yuan, accounting for nearly 70% of that of the PM phase. In Guangzhou, the impact of AMM, CMM and EHP on the economy are the greatest, the total profit of these three sectors are 33.02, 15.31 and 12.98 billion yuan, respectively. In addition, the total profits of FMS in Guangzhou and RSM in Dongguan are negative, which is worth paying attention to.

Energy consumption

In 2015, the energy consumption of ISs in Guangzhou, Shenzhen and Dongguan were 25.71, 16.51 and 13.29 million tce, respectively. The main energy sources that the three regions rely on are quite different. The energy consumption of the ISs in Guangzhou and Dongguan are

Table 3. The impact of industrial system on the society in 2015.

Type	Name	Unit	Output		
			Guangzhou	Shenzhen	Dongguan
Subassembly	Tires	billion units	16.51	—	—
	Electronic components	billion units	2.84	111.91	1138.5
	Hard drives	million units	—	44.4	—
	Semiconductor integrated circuit	billion units	—	13.11	—
	Discrete semiconductor device	billion units	—	—	51.75
	Antifriction bearing	million pairs	—	—	394.27
Building material	Cement	million ton	7.81	—	—
	Steel products	million ton	6.58	—	—
Wearing apparel and accessories	Garments	million pieces	584.09	216.28	1456.09
	Leather shoes	million pairs	77.5	—	167.96
Household electric appliances	Air conditioners	million units	11.54	—	—
	Color TV sets	million units	6.94	—	—
Electronic products	Mobile phone	million units	—	—	236.43
	Micro computers	million units	—	27.79	—
	Telephone sets	million units	—	23.62	33.26
Other light industrial products	Cigarettes	billion pieces	66.55	18.9	—
	Furniture	million pieces	11.27	—	53.86
	Beer	million kiloliter	—	445.6	—
	Watches	million units	—	76.59	—
	Alcoholic beverages	million kiloliter	—	—	347.67
	Lighting installations	million units	—	—	263.93

"—" indicates that the output of the product is not the top 10 in this region.

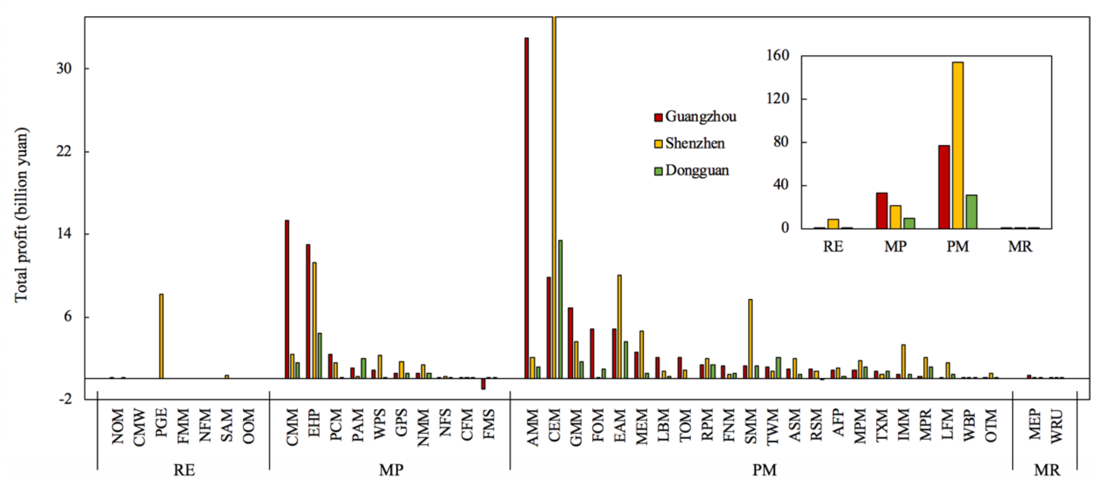

Figure 3. The impact of industrial system on economy in 2015.

still dominated by the consumption of coal, while the IS in Shenzhen mainly consume natural gas and electricity. To clarify the main sources of the impact on resource in different regions, the statistics for the energy consumption of the four phases and the 41 sectors are summarized in Figure 4 and are presented in the order of

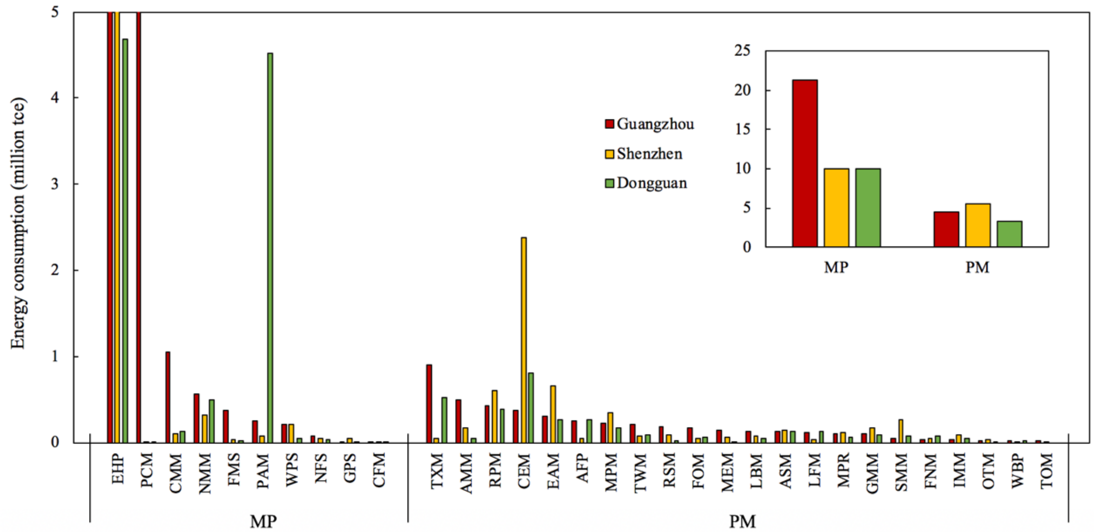

Figure 4. The energy consumption of industrial system in 2015.

Table 4. The pollutant discharge of industrial system in 2015.

Type	Unit	Output		
		Guangzhou	Shenzhen	Dongguan
Waste water	million ton	186.08	191.00	204.29
COD	thousand ton	17.04	—	—
NH_3-N	thousand ton	1.01	—	—
Waste gas	billion cu.m	355.10	231.23	321.9
SO_2	thousand ton	47.85	4.10	—
NO_x	thousand ton	41.02	10.70	—
Smoke and dust	thousand ton	9.23	1.10	14.40
Waste solid	million ton	4.63	1.20	4.86
# Comprehensive utilization	million ton	4.41	1.19	4.31

"—" indicates that there is no relevant statistics.

Guangzhou from high to low in each phase.

As shown in Figure 4, the energy impact produced by the ISs in the three regions all mainly comes from the MP phase, but the sheer quantity and the gap between phases are obviously different. In Guangzhou, the sheer quantity of energy consumption and the gap between phases are the largest among the three regions. And the energy consumption of MP phase is as high as 21.26 million tce, which is about five times that of PM phase and twice that of the MP phase in other two cities. As to the specific industrial sectors, the energy consumption of the MP phase in the three regions shows highly concentration. And the most prominent sector in this phase in the three cities are all EHP, which consume 11.32, 9.19 and 4.68 million tce, respectively. In addition, the other sectors that contributed more to this phase are PCM in Guangzhou and PAM in Dongguan, with energy consumption 7.37 and 4.52 million tce, respectively. It is worth noting that the impact of the PM phase on energy consumption in Shenzhen also has obvious centrality in the industrial sector distribution, which is unlike the other two regions. The sector (CEM) is responsible for 42.8% of the energy consumption in the PM phase.

Environmental pollutant discharge

As the pollutant discharge data of specific industrial sectors in three cities are not published, this study only takes the pollutant discharge of the overall ISs into consideration. And the statistics in respect of the pollutant discharge of the three cities are summarized in Table 4.

The available statistics in Table 4 show that the discharge of various types of pollutants from Shenzhen's IS, especially industrial waste gas and some specific pollutants in waste gas, are lower than those from Guangzhou and Dongguan. In addition, Shenzhen's IS only produced 1.20 million tons of industrial waste solid in

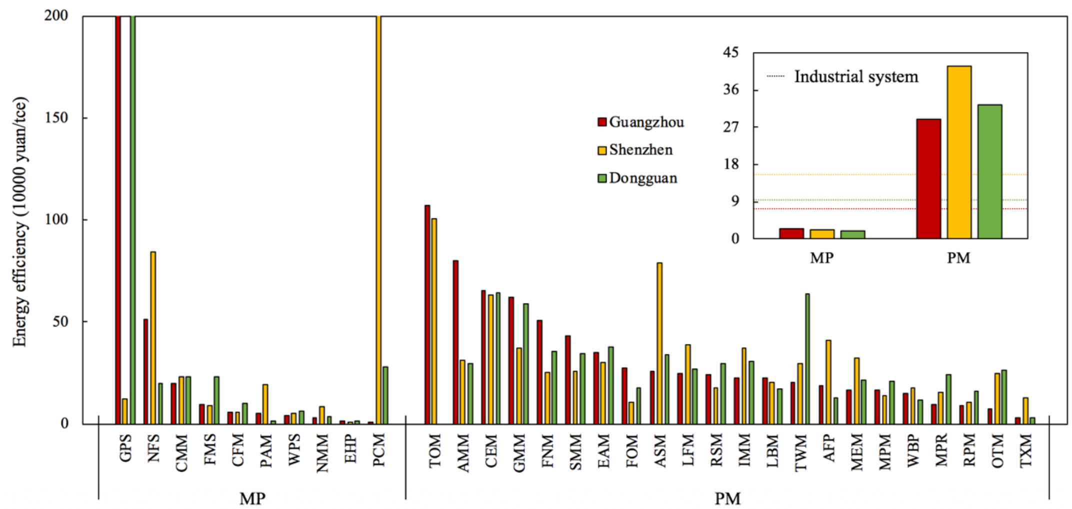

Figure 5. The energy efficiency of China's industrial system in 2015.

2015, which is less than one fourth of that of the other two cities. The comprehensive utilization of the produced waste solid in Guangzhou and Shenzhen are great. And the waste solid discharging and accumulating in the environment are less than 5% of produced ones, especially in Shenzhen, only 0.1%. By contrast, Dongguan still has a relatively high discharge of industrial waste solid with 549.18 tons, which has caused a bit of a burden to the environment.

Eco-efficiency

Based on the analysis of the industrial structure and the energy consumption of each component, the energy efficiency of the 41 industrial sectors and the four phases are calculated according to the methods previously mentioned. The results are summarized in Figure 5 and are presented in the order of Guangzhou from high to low in each phase.

As shown in Figure 5, the energy efficiency of the whole IS is 7.17 10000 yuan·tce^{-1} in Guangzhou, 15.47 10000 yuan·tce^{-1} in Shenzhen, and 9.59 10000 yuan·tce^{-1} in Dongguan. The PM phase has the highest energy efficiency in the three regions, which is much higher than the overall level of the IS. And in Shenzhen, the energy efficiency of the PM phase is as high as 41.79 10000 yuan·tce^{-1}. Above analysis of the internal structure in this study shows that the scale of the PM phase in the three regions are all large, so increase in the same amount of energy consumption can lead to greater growth of output. That means, the PM phases have a strong driving effect on the improvement in energy efficiency of the IS, and the order of driving effect from high to low is Shenzhen > Dongguan > Guangzhou. The energy efficiency of the dominate sectors, for example, AMM and CEM in Guangzhou, CEM in Shenzhen, and CEM and EAM in Dongguan, are far higher than the overall level of their PM phase. As a result, these sectors also have strong driving effects on the improvement in energy efficiency of the PM phase. Conversely, there is no need to pay attention to some sectors with high energy consumption in the MP phase, such as EHP in Shenzhen and Dongguan, PCM in Guangzhou and PAM in Dongguan, as their structural coefficients are lower than 0.05. But what must be noted is that the EHP of the MP phase in Guangzhou is also the leading sector which drives the economic growth in this region, and it's extremely low energy efficiency with 1.23 10000 yuan·tce^{-1} may be the main reason why the level of Guangzhou's IS is lower than the other two regions.

Uncertainty of data

Although the data of various regions in this study are all from their statistical yearbook, there inevitably exists some disappointed situations, just like data missing and bad data quality. For example, the total amount of energy consumption of IS in Guangzhou and Shenzhen are lack, and they are estimated by the unit value-added energy consumption and various types of energy consumption, respectively. But in fact, it is not accurate enough. What's more, the data of industrial pollutants discharge in the three regions is only at the overall level of the IS, and the data of some types of wastes are still missing. So, it is impossible to analyze the main sources of the environmental impact as well as the relationship between the internal structure and the environmental impact.

DISCUSSION

Based on the methods established by the author before, this study takes Guangzhou, Shenzhen and Dongguan, these three cities with the fastest economic development in the Pearl River Delta urban agglomeration in China, as examples to analyze the current situation of their IS. The results show that the characteristics of the ISs in Guangzhou, Shenzhen and Dongguan are similar and more prominent than China's IS.

First of all, the statistics show that the centrality and scale effect of the industrial phase distribution and the industrial sector distribution in these three cities are more obvious than those of China. It is mainly manifested on that AMM, CEM, EAM and other high-tech industries account for a very high proportion of the economy of the PM phase in the three regions. And the output of related products, such as mobile phones, microcomputers and so on, are also in the forefront. As we all know, the Pearl River Delta, with a large geographical advantage, is the first area to carry out the policy of reform and opening up in China. As a consequence, a large number of overseas and domestic advanced enterprises gathered in this area and brought good opportunities for it in industrial development. On this basis, as the core area of the Pearl River Delta, the urban belt composed of Guangzhou, Shenzhen and Dongguan is an important area to promote industrial transformation and upgrading. Under the leadership and promotion of the national and provincial governments, the high-tech industries in these three cities have been greatly developed.

On the contrary, there is almost no related industrial sector in the RE phase in the three cities. Iron and steel, non-metallic mineral and other industrial materials production industries, which are the backbone of China's economy, are also not outstanding in these three cities. According to the statistical data, it is related to the lack of energy, mineral resources and other material resources in the three regions. And it shows that the natural resources and industrial materials, which are necessary for promoting the development of high-tech industrial production in these cities, are either brought in from other areas of China or imported. But this dependence has greatly limited the industrial development of these three cities by the quantity and price of raw materials. For example, the total profits of FMS in Guangzhou and RSM in Dongguan in 2015 are negative, according to the analysis of the internal structure, it shows that the two sectors have a certain contribution to promote the regional industrial growth. This is a typical phenomenon of increasing production but not increasing income, which may be related to the high price of raw materials.

Secondly, the current industrial structure of the three cities is more reasonable than that of China, which mainly manifested on the fact that the PM phases and their pillar sectors in the three cities consume less energy while bringing high net economic income. What's more, their roles in promoting the eco-efficiency of the IS are stronger than that of China. This is strongly related to the driven method of industrial development, which is innovation instead of resource in these three cities.

Although the characteristics of the ISs in the three cities are similar, the degree is quite different. Shenzhen, with its long-term municipal planning at the beginning of the reform and the city orientation of the "Science and Technology Innovation Center", has shown the obvious characteristics of "two high, two low" in its IS currently, namely, high technology, high output, low energy consumption and low pollution. This city has a good demonstration and leading role in the development of the entire urban agglomeration, and can promote the transformation of the industrial development of the surrounding cities in a point-to-area way. In Guangzhou, the energy consumption of the MP phase is higher than that of the other two cities, so it is still possible to reduce the negative impact of it's IS through structural adjustment. And the management of Guangzhou's IS can be carried out in the following aspect: the economic proportion of CMM and EHP should be properly cut down to reduce the dependence on heavy industry in the development of the regional economy. On the one hand, it can reduce energy consumption; on the other hand, it can increase the eco-efficiency of the IS. Dongguan, a city known as the "factory of the world", has the highest capacity of production among the three cities. But the net economic output is far lower than the other two cities, while the environmental impact is more serious. Therefore, the management ability and market competitiveness of industrial enterprises of this city should be strengthened. At the same time, improving the waste treatment technology can reduce the amount of pollutants discharged into the environment. And increasing the recycling and comprehensive utilization of waste solid, is also an effective way to lighten the burden on the environment.

Because the data is difficult to obtain, the analyses of environmental impact, material resources impact, and the relation between industrial structure and external impact are not deep and comprehensive enough, which is the shortcoming of this article. In addition, Guangzhou, Shenzhen and Dongguan, as the cities most affected by the policy of reform and opening up in the Pearl River Delta region and even in China, their industry has developed rapidly since the 20th century. However, this study only makes a static analysis of the characteristics of the three ISs in 2015, their dynamic changes are not took into consideration; thus can be added to future research.

CONCLUSIONS

1. The scale of the RE phase is extremely small in Guangzhou, Shenzhen and Dongguan. Conversely, there has been an obvious tendency for the development of the high-tech manufacture industry in these cities. And the order of centrality in the industrial phase distribution as

well as the industrial sector distribution from high to low is Shenzhen > Dongguan > Guangzhou.

2. With regard to the positive impacts of the IS, providing household electric appliances, electronic products, and wearing apparel and accessories for humans is the main impact of the IS of the three cities on the society. Dongguan, with the highest capacity of production and the lowest net economic output among the three cities, changing the mode of management and enhancing industry competitiveness are two important ways to promote the benign development of its IS.

3. With regard to the negative impacts of the IS, the energy impact produced by the ISs in the three regions all mainly comes from the MP phase, especially the EHP sector. And the order of pollutant discharge from high to low is Dongguan > Guangzhou > Shenzhen.

4. Because of their high structural coefficient and eco-efficiency, the PM phase and the dominate sectors in it have strong driving effects on the improvement of the energy efficiency of the IS. And the order of driving effect from high to low is Shenzhen > Dongguan > Guangzhou. For Guangzhou, decreasing the economic proportion of some sectors with high energy consumption is the key point to further promote the energy efficiency of its IS.

5. Compared with the other two cities, Shenzhen's IS with higher technology, higher output, lower energy consumption and lower pollution, has a better demonstration and leading role in the development of the entire urban agglomeration.

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