Academia Journal of Environmetal Science 6(5): 000-000, August 2018
DOI: 10.15413/ajes.2018.0133
ISSN: ISSN 2315-778X

Research Paper

Restructuration of China's industrial system and quantitative analysis of its environmental impacts

Accepted 1st September, 2018

ABSTRACT

The industrial system (IS) is the main contributor to China's national economy and environmental impacts. In this study, a framework with four groups of industrial sectors, such as resource exploitation (RE), industrial material production (MP), product processing and manufacture (PM), and product maintenance and recycling (MR), is built up according to the life cycle process of a product, thus the IS is reorganized. On the basis of the statistics, both the economic structure of China's IS and the relationship between the IS and the external environment in 2015 are quantitatively analyzed. The main results show that the largest component of the IS is the PM phase, which contributes 0.69 of the IS. The main social services provided by the IS are providing building materials, electronic products, and household appliances. To reach such services, 1.38 billion tons of iron ore and 1.22 billion tons of limestone for cement are consumed. The MP phase uses 77.9% of the energy and emits the most of environmental pollutants. The PM phase has the highest eco-efficiency and drives the improvement of the eco-efficiency of the IS.

Key words: Industrial structure, life cycle, social service, resource consumption, eco-efficiency.

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INTRODUCTION

With the continuous deepening of global industrialization, the industrial system (IS), as the most powerful interaction between human society and natural ecosystems, has been paid much attention for a long time. The relevant statistics in many countries and regions show that the IS has brought considerable economic output, while it also consumes a large number of natural resources and discharges a lot of environmental pollutants. And according to its different internal structure, the degree of impacts is quite different. Therefore, minimizing the negative impacts of industrial activities on the environment through the adjustment and optimization of the industrial structure has become an important part of environmental management, as well as a hot topic in recent years.

China is the largest developing country, and the Chinese government has put forward a number of policies to promote all-round industrialization. The development of industry has been extensive and there has been a great expansion of scale, but also there has been an excessive dependence on resources inputs. In 2015, China's IS represented about 42.4% of the composition of its GDP; it also accounted for about 68.0% of the energy consumption and was responsible for the discharge of a large number of environmental pollutants (NBSC, 2016). As a result, the key to the sustainable development of China's IS is to promote the adjustment of industrial structure and the progress of production technology.

In the study of the impact of the IS on the external environment, the IS is usually regarded as a black box, and the input and output method is used to quantitatively analyze the energy consumption, the discharge of environmental pollutants and the economic output (Xu et al., 2011; Lin and Xie, 2015). In addition, Rahman et al. (2016) used the Toda Yamamoto technique to analyze the interrelationship between industrial production and energy consumption. Meng et al. (2018) used a structural decomposition algorithm to analyze the energy consumption of China's IS and evaluate its relationship with economic output. Guo et al. (2013) analyzed the impact of resource conservation and industrial production technology improvement on sulfur dioxide emissions using factor decomposition method. Shi et al. (2017) used COD as an example and focused on the emission of major industries in the IS. Moreover, the comparison of the industrial energy consumption intensity (Yang et al., 2013) and pollutant discharge intensity (Mao et al., 2012; Hu et al., 2016) between different provinces or cities has been very common, either. On the whole, the above researches have promoted people's understanding of the environmental impact of industrial activities. But the other impacts of the IS, such as the consumption of natural material resources and the product output, are still less. And the comprehensive analysis of the various impacts is also lacking at present.

The environmental impacts of a system actually depend on its internal structure. To better understand the impacts on the external, we need to have an extensive insight of the IS. In previous studies, the national economic structure was mostly expressed in three industries, and its relationship with energy consumption (Jiang and Shen, 2016), CO_2 emission (Li et al., 2018) and so on are analyzed. Some researches divide the IS into light industry and heavy industry and point out that increasing proportion of heavy industry will increase the pressure on the environment (Wu and Mao, 2010). Further, the analysis of the industrial structure on the basis of the industrial sectors has also gradually increased. Specifically, in China, the relationship between the industrial structure and the discharge of pollutants (Llop, 2007; Wang et al., 2014; Yang et al., 2015) or energy consumption (Wang, 2010; Mao et al., 2010) are discussed based on the division into 41 industrial sectors according to the industry classification standard. The research of Li et al. (2017) shows that the high-tech industry is certainly more and more important in low environmental pollution. Although these division methods are convenient for obtaining statistical data, they cannot reflect the lifecycle of a product from resources to the final service of human beings. Especially in recent years, human beings try to reduce resource consumption and waste discharge through closed material cycle, and in order to adapt to this new situation, reconstructing the IS is necessary.

In view of the life cycle analysis, a number of studies have analyzed the industrial metabolism of a region (Kapur et al., 2003; Chen and Graedel, 2012), an industrial park (Han et al., 2016; Fan et al., 2017), and an enterprise (Dai, 2009; Huang et al., 2013). The research on a specific industrial sector, such as the forestry industry (Koskela, 2011), iron and steel industry (Olmez et al., 2016), paper making industry (Yi et al., 2018), and garment manufacturing industry (Muthukumarana et al., 2017), has gradually increased in recent years, but the result is still limited to a particular element. And there is no example that applied such a division to the entire IS.

Most of the previous research work has been aimed at solving the problem of the impacts of IS on the environment (Xu et al., 2005) and, based on the 41 industrial sectors, the problem of measuring the relationship between the industrial structure and its impacts on the external environment has also been solved (Ramli and Munisamy, 2015). However, these research works have not taken the process of converting resources into services into consideration, and the difference between the impacts of each production step cannot be distinguished. In order to solve these problems, two of the major aims of this work are to restructure the IS and build up a framework of the relationships among the industrial processes, as well as to examine the relationship between each process and the society, economy, resources, and environment. A more comprehensive analysis of the industrial structure, industrial impacts, and relations between the internal and external environment will be carried out to provide the basis for the management of the IS.

DATA AND METHODS

Framing the industrial system and the external environment

The purpose of the IS is to provide services for humans. Meanwhile, the needs of these humans also drive the development of the IS. The different lifecycle stages of a product correspond to different industrial activities, which can be separated into four phases: resource exploitation, industrial material production, product processing and manufacture, and product maintenance and recycling. Furthermore, the resource exploitation activities can be further separated into energy exploitation and the exploitation of material resources. During the process of production, each phase will consume materials and energy and discharge different types of pollutants into the environment through industrial metabolism. On this basis, a simplified framework of the relationship between the IS and the external environment is shown in Figure 1. In Figure 1, E represents the end energy consumption, and the subscript m is the serial number of the types of energy; R represents the material resource consumption, and the subscript n is the serial number of the types of material resources; G represents the economic output; P represents the output of services, and the subscript l is the serial number of the types of services; Q represents the pollutant discharge, and the subscript j is the serial number of the types of pollutants. The grey dashed line in Figure 1 shows the recycling of components or materials after a product is scrapped, although if this flow actually

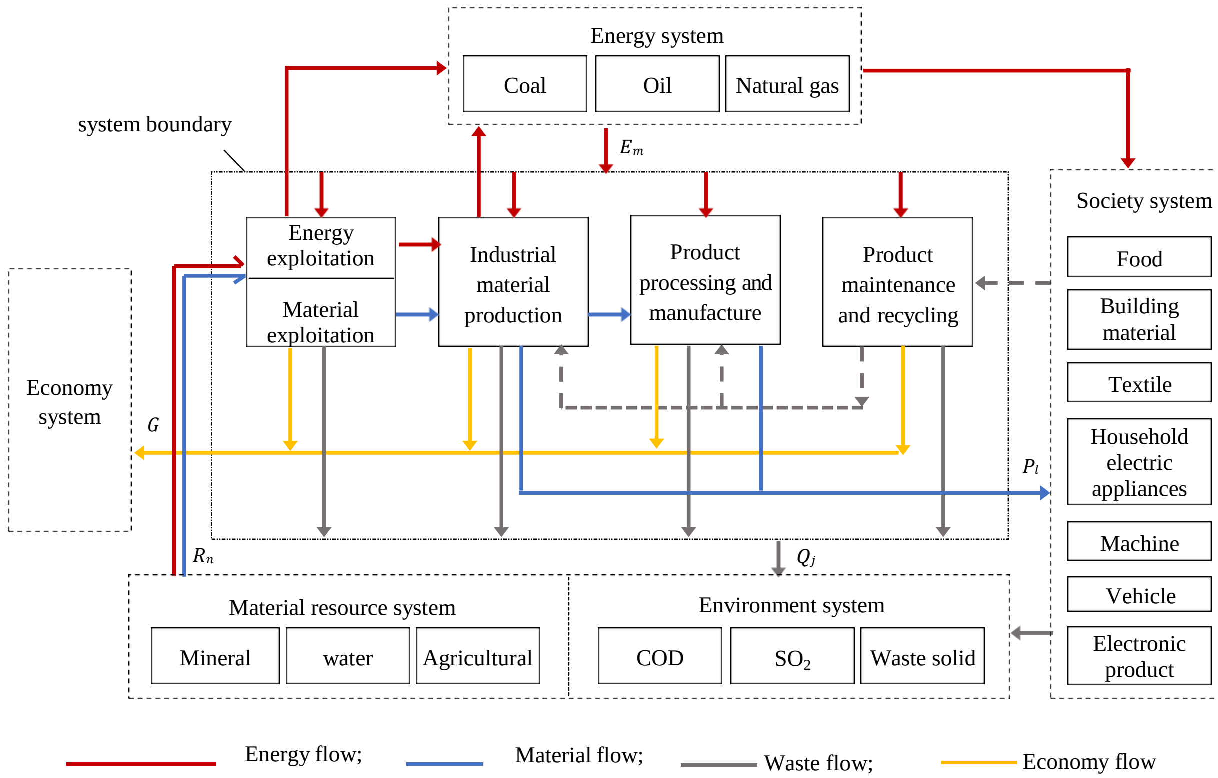


Figure 1: The framework of the relation between the industrial system and the external.

exists, it will not be considered in this study.

The compositions of the industrial system

The compositions

Considering the availability and comprehensiveness of the data, this study takes 2015 as the current year of research. In this year, *the national economic industry classification standard* (GB/T 4754-2011) was applied during the statistical process, which means the IS consists of 41 sectors. Based on Figure 1, the 41 industrial sectors are classified into the four industrial phases according to their role in the life cycle process of a product. Each industrial phase and industrial sector chooses the first or second letter of the main words in their name as their code, which are used hereinafter. For example, the code for the resource exploitation phase is RE, and the code for the mining and washing of coal industry is CMW. The code, function, and composition of each phase are shown in Table 1.

The structural coefficient

In a particular system, different components play different roles, so in terms of a specific impact, the contribution of each component is different. To ascertain the contribution of each component to the whole system, this study quantifies the industrial structure by defining the proportion of the total profit of a sector in the IS within a specific period as its structural coefficient, which can be calculated as follows:

$$f_i = G_i/G \quad (1)$$

where f represents the structural coefficient of a certain sector, and the subscript i is the serial number of the industrial sector; the other symbols have the same meanings as set out in the previous definition.

In addition, the sum of the contribution of the total profit 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 $\sum^n f_i = \sum^m F_I = 1$

The environmental impacts

The concept of the external impact comes from economics;

Table 1: The codes, basic functions and compositions of industrial phases.

Industrial phase	Code	Definition and function	Composition	
			Name of sectors	**Code**
Resource exploitation	RE	This phase is the starting point of the IS. It extracts primary energy and material resources from the environment and provides them for the next phases.	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	In this phase, natural resources are initially processed into power, fuel or other industrial materials, which can be used directly in the manufacturing industry.	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
Product processing and manufacture	PM	This phase reprocesses the resources and industrial materials produced in the first two phases. And it is the main phase providing services for human.	Manufacture of paper and paper products	PAM
			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

Table 1: Continued.

			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 equipments	RSM
			Manufacture of computers, communication and other electronic equipment	CEM
			Other manufacture	OTM
Product maintenance and recycling	MR	After being scrapped, the products are recycled through this phase.	Repair service of metal products, machinery and equipment	MEP
			Utilization of waste resources	WRU

it refers to the increase or decrease in the welfare of an economic entity caused by the behavior of another economic entity (Shen and He, 2002). When we apply this concept to the analysis of an IS, the impacts of the IS can be divided into the impacts on the economy, society, resources, and environment. As over-exploitation and the accumulation of pollutants are both burdens to the natural environment, and the impacts on the resources and environment are negative. Conversely, providing services and increasing economic outputs can bring benefits to humans, so the impacts on the economy and society are positive.

To compare the impacts of different phases on the external environment, we select the first 10 kinds of products to characterize the impact on the society according to their number. The most representative 10 kinds of resources, including mineral resources, water resources, agricultural resources, forestry resources, and animal resources, are selected as the input of raw materials to characterize the impact on the resources. The four kinds of impacts on the external environment and their representative parameters are shown in Table 2.

The relation between the industrial system and the environment

Eco-efficiency generally refers to the output generated per unit of environmental impact (Azar et al., 2002), which is often used as an indicator to characterize the relationship between a specific system and the external environment (Mao et al., 2010; Mao et al., 2013). In this study, to evaluate the relationship between the industrial structure and the impacts on the external environment, the energy efficiency and environmental efficiency are defined, respectively as:

$$e = G/ \equiv [\sum^{n} (f_i \times {e_i}^{-1})]^{-1} \quad (3)$$

$$q_i = G/ Q_1 \equiv [\sum_{i=1}^{n} (f_i \times {q_{ii}}^{-1})]^{-1} \quad (4)$$

where e represents the energy efficiency, which is the total profit generated per unit of energy consumption, with a unit of thousand yuan·tce^{-1}; q represents the environmental efficiency, which is the total profit generated per unit of pollutants discharged with a unit of million yuan·t^{-1}; and e_i and q_{ji} can be estimated according to the equations $e_i = G_i/E_i$ and $q_{ji} = G_i/Q_{ji}$, respectively. The other symbols have the same meanings as set out in the previous definitions.

Data sources

This study takes China as an example and chooses 2015 as the basic year. The data categories mainly relate to energy consumed, total profit, unused solid waste discharged, COD discharged, sulfur dioxide discharged, the output of major products, and major material resources consumed. The data for energy consumed, economic outputs, and pollutants discharged can be obtained from the *China Energy Statistics Yearbook* (NBSC, 2016), *China Industrial Statistics Yearbook* (NBSC, 2016), and *China Environmental Statistics Yearbook* (NBSC, 2016), respectively. The other data, such as the products produced and material resources consumed, can be obtained from the National Bureau of Statistics website.

Table 2: Impacts of industrial system on the external and their representative parameters.

Impact name	Definition	Representative parameters			
		Name	Indicator	Symbol	Unit
Impact on society	Products or services provided by the IS for human society.	Social services	Clothes	P_1	pieces·a^{-1}
			Cement	P_2	t·a^{-1}
			Mobile phone	P_3	units·a^{-1}
			Steel product	P_4	t·a^{-1}
			Computer	P_5	units·a^{-1}
			Feed	P_6	t·a^{-1}
			Laptop	P_7	units·a^{-1}
			Household electric fan	P_8	units·a^{-1}
			Color television	P_9	units·a^{-1}
			Air conditioner	P_{10}	units·a^{-1}
Impact on economy	The net economic benefits brought by IS.	Economic outcomes	Total profit	G	yuan·a^{-1}
Impact on resource	The consumption of material resources and energy which exploited from natural environment during the process of industrial producing.	Energy consumption	Coal	E_1	tce·a^{-1}
			Petroleum	E_2	tce·a^{-1}
			Coke	E_3	tce·a^{-1}
			Natural gas	E_4	tce·a^{-1}
			Electric power	E_5	tce·a^{-1}
		Material consumption	Iron ore	R_1	t·a^{-1}
			Limestone for cement	R_2	t·a^{-1}
			10 major non-ferrous metals	R_3	t·a^{-1}
			Gold ore	R_4	t·a^{-1}
			Sylvite	R_5	t·a^{-1}
			Industrial water use	R_6	m^3·a^{-1}
			Grain	R_7	t·a^{-1}
			Sugar	R_8	t·a^{-1}
			Timber	R_9	m^3·a^{-1}
			Sheep wool	R_{10}	t·a^{-1}
Impact on environment	In the process of industrial producing, a part of matter is discharged into and accumulate in the environment.	Pollutant discharge	Unused solid waste	Q_1	t·a^{-1}
			COD	Q_2	t·a^{-1}
			SO_2	Q_3	t·a^{-1}

RESULTS

Economic industrial structure

To ascertain the structural composition of the IS in China, the structural coefficient of each industrial sector in 2015 is calculated. Using the classification of the 41 industrial sectors described above, all of the sectors are presented in order of high to low in Figure 2.

As shown in Figure 2, the PM phase is the largest phase in the IS with a structural coefficient of 0.69. The top six sectors in this phase are AMM, CEM, EAM, AFP, GMM, and MEM, with a cumulative structural coefficient of 0.37, and their proportion of the PM phase is more than 50%. Furthermore, some sectors in the MP phase with high energy consumption and high pollution, such as EHP, CMM, and NMM, also occupy a prominent place in respect to economic growth. The structural coefficients of these three sectors are 0.08, 0.07, and 0.06, respectively.

The environmental Impacts

Impact on the society

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

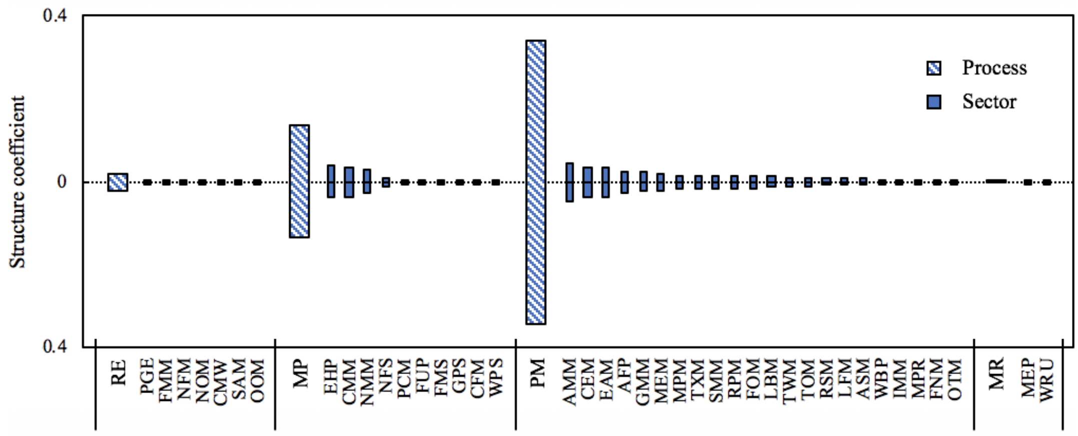


Figure 2: The economic structure of China's industrial system in 2015.

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

The name of product	Quantity of output	Units
Clothes	3.08	billion pieces·a^{-1}
Cement	2359.19	million t·a^{-1}
Mobile phone	1812.61	million units·a^{-1}
Steel product	1123.50	million t·a^{-1}
Computer	314.19	million units·a^{-1}
Feed	277.75	million t·a^{-1}
Laptop	174.36	million units·a^{-1}
Household electric fan	171.74	million units·a^{-1}
Color television	144.76	million units·a^{-1}
Air conditioner	142.00	million units·a^{-1}

As shown in Table 3, the outputs of the largest 10 products are all over 100 million units, but their typology shows that there is lack of diversification. At present, providing building materials, electronic products, and household appliances for humans is the main impact of the IS on the society. In addition, the output of some relevant intermediate products and components for the products with high output is also large. For instance, pig iron and crude steel are the raw material and intermediate product, respectively for the production of steel products, and their outputs are 691.41 and 803.83 million tons, respectively. The output of the components of electronic products is also far higher than other products; examples of these are integrated circuits, with an output of 108.72 billion units, and display devices, with an output of 173.65 million units.

Impact on the economy

In 2015, China's IS produced 6.62 trillion yuan of total profit. The statistics for the total profits of the four phases and 41 sectors are summarized in Figure 3, which are presented in the order from high to low in each phase.

The main impact of the IS on the economy is produced by the PM phase. Its total profit is 4.54 trillion yuan, which is 2.5 times that of the MP phase. The sector with highest economic output in the PM phase is AMM, the total profit of which is 624.33 billion yuan. In general, the impact of the PM phase on the economy is the greatest, not only because of the concentrated contribution of one or two sectors, such as the contribution of EHP and CMM in the MP phase, but also because there are more related sectors in this phase.

Resource consumption

Energy consumption: In 2015, the energy consumption of China's IS was 2,802.06 million tce. The main energy source, the consumption of which was 626.86 million tce,

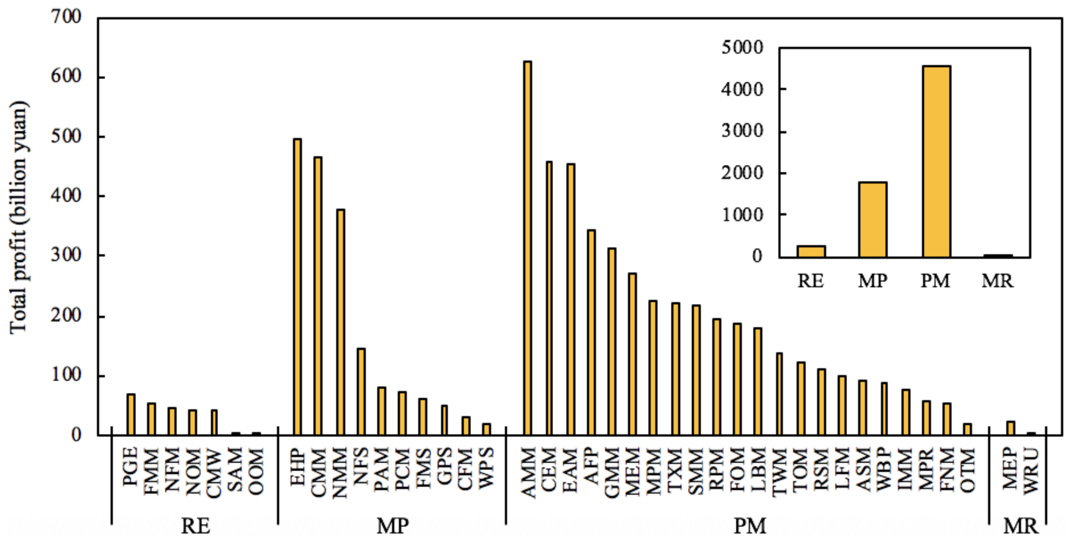


Figure 3: The impact of China's industrial system on economy in 2015.

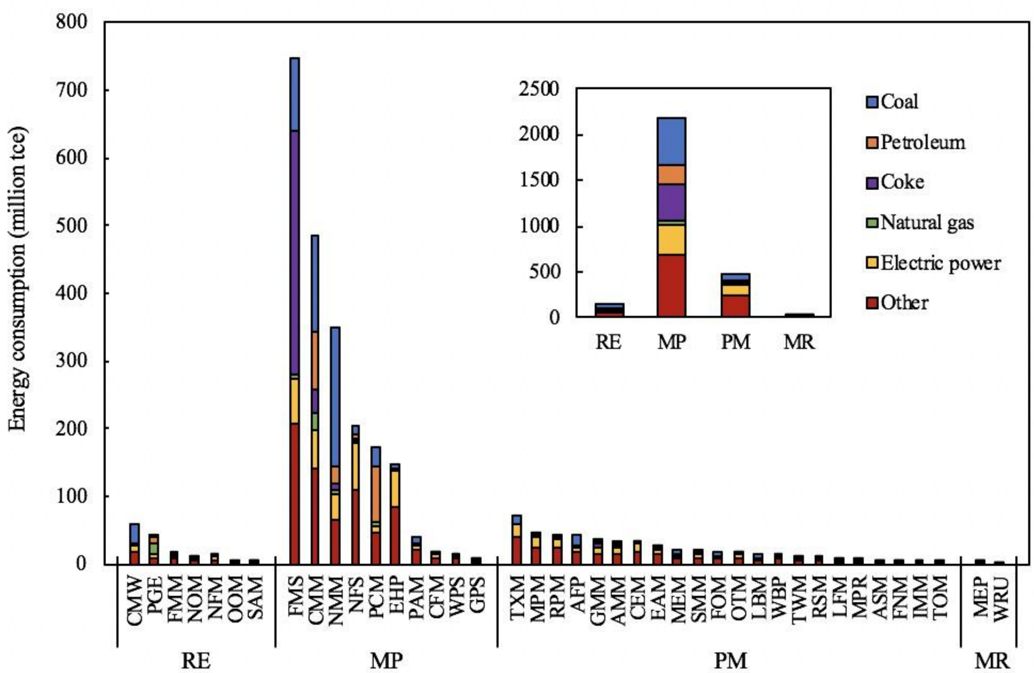


Figure 4: The energy consumption of China's industrial system in 2015.

is coal. Although the energy consumption of the IS is still dominated by the consumption of coal, it has been more diversified, with the consumption of oil, natural gas, coke, and electricity reaching 228.93, 72.71, 423.91 and 473.93 million tce, respectively. 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 high to low in each phase.

As shown in Figure 4, the energy consumption of the MP phase is as high as 2,182.05 million tce. It is obvious that this phase is responsible for 77.9% of the energy consumption and more than half of consumption of each type of energy in the IS. In this phase, the industrial sector that has the largest energy consumption is FMS, which consumes 747.31 million tce. The dominant sectors in the MP phase are CMM and NMM, and their energy

Table 4: The consumption of material resources in China's industrial system in 2015.

The name of resource	The type of resource	Quantity of input	Unit
Iron ore	Mineral resource	1.38	billion $t \cdot a^{-1}$
Limestone for cement	Mineral resource	1.22	billion $t \cdot a^{-1}$
10 major non-ferrous metals	Mineral resource	243.0	million $t \cdot a^{-1}$
Gold ore	Mineral resource	128.3	million $t \cdot a^{-1}$
Sylvite	Mineral resource	73.1	million $t \cdot a^{-1}$
Industrial water use	Water resource	13.35	billion $m^3 \cdot a^{-1}$
Grain	Agricultural resource	572.3	million $t \cdot a^{-1}$
Sugar	Agricultural resource	125.0	million $t \cdot a^{-1}$
Timber	Forestry resource	72.0	million $m^3 \cdot a^{-1}$
Sheep wool	Animal resource	427.0	thousand $t \cdot a^{-1}$

consumption totals are 483.35 and 350.60 million tce, respectively which are far larger than the other sectors. This shows that the impact of the IS on energy consumption has obvious centrality in both the phase distribution and the industrial sector distribution, and the MP phase has caused the greatest pressure on energy usage.

Material resource consumption: The material resources with the largest consumption are shown in Table 4 which reflect the impact of the IS on resources. Since the data for limestone for cement, gold ore, and sylvite in 2015 have not been published, the 2014 data is used in this study. As shown in Table 4, compared with the other four types of resources, there is less consumption of animal resources. There are some extremely large examples when it comes to the consumption of mineral resources. For instance, the quantities for the exploitation and utilization of iron ore and limestone for cement are 1.38 and 1.22 billion tons, respectively which are far higher than the quantities for other mineral resources.

Environmental pollutant discharge

In 2015, 2.56 million tons of COD, 14.01 million tons of sulfur dioxide, and 1,260.12 million tons of unused solid waste produced by the IS were poured into the environment. The statistics regarding the pollutant discharge of the four processes and 41 sectors are summarized in Figure 5 and are presented in the order of high to low in each phase.

As shown in Figure 5, the discharges of various environmental pollutants in different industrial phase are quite different, but each of them is centrally produced by a certain phase. Unused solid waste mainly emanates from the RE phase, and the most prominent sectors in this phase are FMM and NFM. The total amount of unused solid waste of these two sectors is 739.80 million tons, which is about 54 times that of the other 24 sectors in the PM and MR phases. The PM and MP phases, which contain 92.6% of the COD discharged in the IS, are the main sources of COD, and the total amount of their COD discharged is 2.37 million tons. The COD discharge of the AFP, CMM, and PAM sectors are obviously higher than the other sectors. The main source of sulfur dioxide is the MP phase, especially the GPS sector; the discharge of this sector is 5.06 million tons, which is 2.5 times that of FMS.

Eco-efficiency

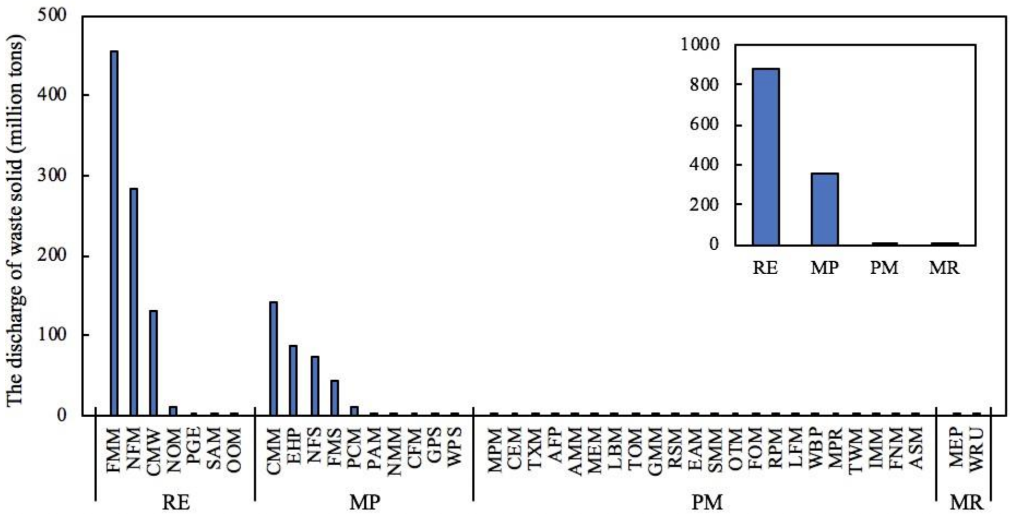
Energy efficiency

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 6 and are presented in the order of high to low in each phase.

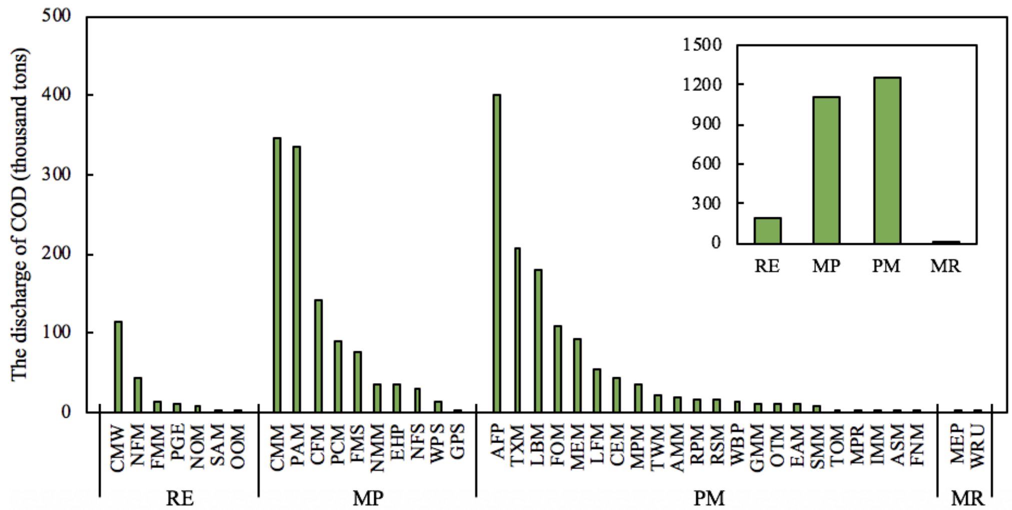
As shown in Figure 6, the energy efficiency of the PM and MR phases is far higher than that of the IS, but when we combine this outcome with the previous analysis, we find that the scale of the MR phase is very small; its energy consumption only accounts for 0.09% of the IS, so there is no need to pay much attention to this phase. Although the PM phase has a large scale, the structural coefficient of the TOM, IMM, and ASM sectors with the highest energy efficiency are all less than 0.02. As a result, these sectors can be seen to have a weak driving effect on the improvement in energy efficiency of the IS. Conversely, as the energy efficiency of the dominant EHP, CMM, and NMM sectors in the main energy consuming MP phase are 3.39 thousand $yuan \cdot tce^{-1}$, 0.97 thousand $yuan \cdot tce^{-1}$, and 1.08 thousand $yuan \cdot tce^{-1}$, respectively, it can be seen that their low energy efficiency is the main reason for the low level of the IS.

Environmental efficiency

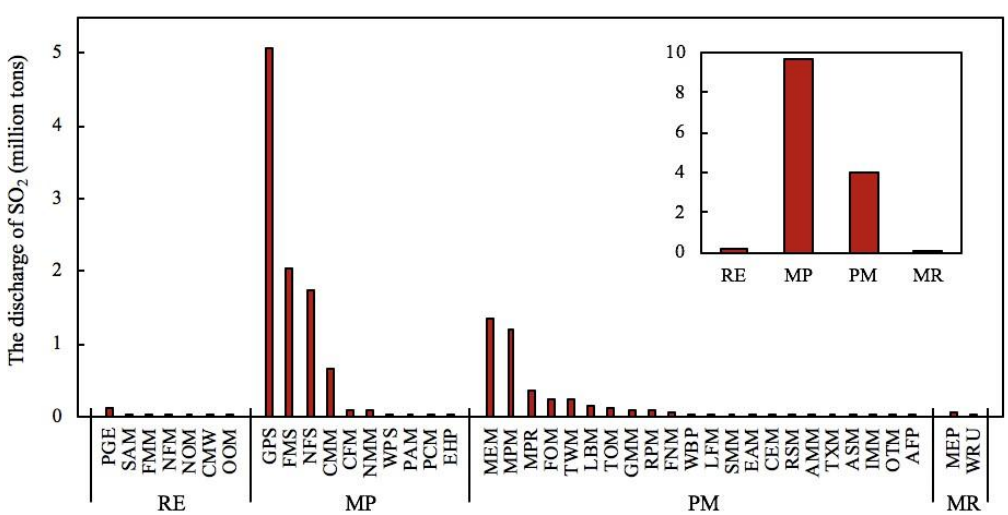
Similarly, to clarify the relationship between the industrial structure and the impact of the IS on the environment, the



(a) Unused waste solid



(b) COD



(c) Sulfur dioxide

Figure 5: The pollutants discharge of China's industrial system in 2015.

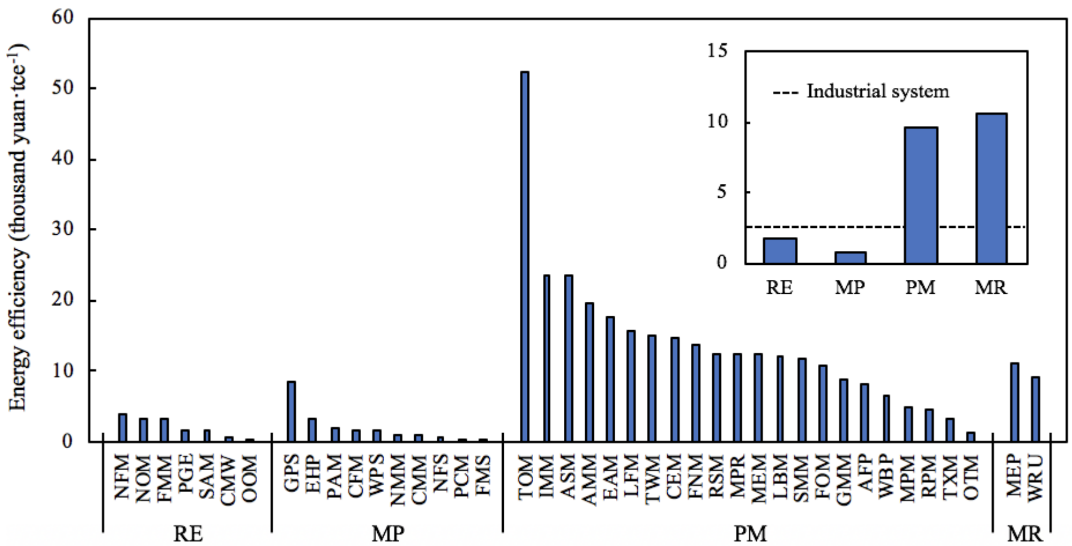


Figure 6. The energy efficiency of China's industrial system in 2015.

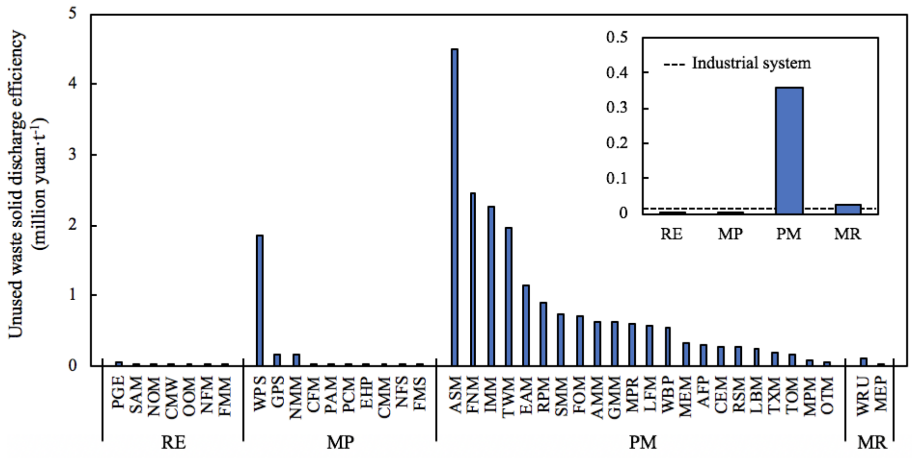
environmental efficiency related to the unused solid waste, COD, and sulfur dioxide pollutants of the 41 industrial sectors and the four phases is calculated. The results are summarized in Figure 7 and presented in the order of high to low in each phase.

Figure 7 shows that there are obvious differences in the position of a certain phase or a certain sector in the sorting of different types of environmental efficiency. The solid waste discharge efficiency of the PM phase is 0.36 million yuan·t^{-1}, which is 13.5 times that of the MR phase. The ARM sector's solid waste discharge efficiency is 51.66 million yuan·t^{-1}, which is far higher than that of the other sectors. The phase that has the highest COD discharge efficiency is the MR phase, with 6.26 million yuan·t^{-1}, and the COD discharge efficiency of the PM phase is also slightly higher than that of the IS. The two phases with the highest environmental efficiency regarding sulfur dioxide are the RE and PM phases. The environmental efficiency of AFP in the PM phase is 723.87 million yuan·t^{-1}, which is nearly 14 times as high as that of VMU. Although the environmental efficiency of EHP in the MP phase is 591.01 million yuan·t^{-1}, the overall level of the MP phase is low. It is obvious that all kinds of environmental efficiency in the PM phase are higher than the average level of the IS, especially in terms of the unused solid waste discharge efficiency, which is nearly 70 times that of the IS. Conversely, in the MP phase, which is the main source of pollutants, various types of environmental efficiency are lower than the average level of the IS. In addition, although the unused solid waste discharge of the RE phase is extremely high, there is no need to pay much attention to it, considering its low structural coefficient. In summary, the environmental efficiency related to the different pollutants of a certain sector should be taken into consideration if we want to improve the environmental efficiency of the IS through structural adjustment.

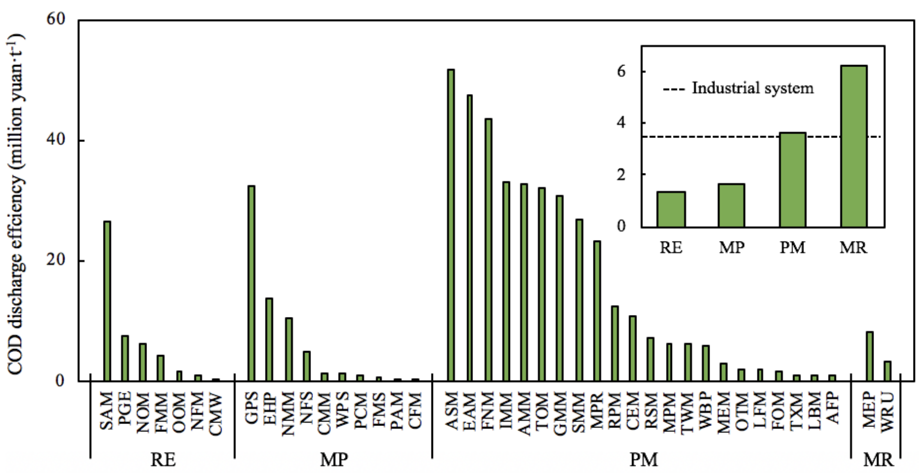
DISCUSSION

This study shows that the impact of China's IS on the society is mainly manifested in the provision of building materials, electronic products, and household appliances for human consumption, which is closely related to feedback in terms of human needs. With the rapid development of China in recent years, the Chinese people's desire to buy a house has fueled a huge building boom. The rise of local electronic brands has increased the domestic sales and exports of these products, so the production of computers and mobile phones has risen correspondingly. The analysis of the consumption of material resources shows that the manufacture of products also directly affects the consumption of related material resources, and in this regard, the consumption of iron ore and limestone for cement is far higher than that of other types of material resources.

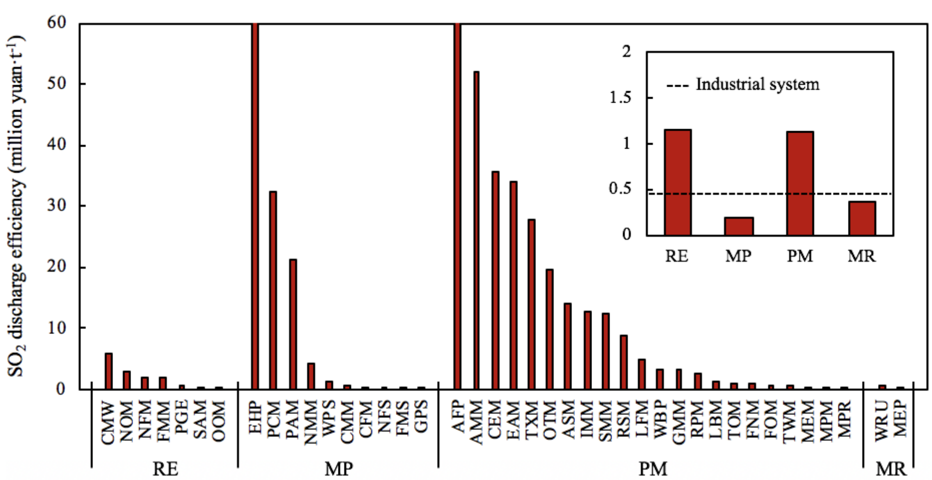
The analysis of the impact on the environment and energy in this study has been conducted differently to the other current research work on the IS in China. This study takes into consideration both the traditional division of industrial activities into 41 industrial sectors and the life cycle process of a product. On this basis, the 41 sectors are classified into different production phases according to their main industrial activities. As a consequence of the analysis of the differences in the impacts of the various phases on the external environment, and a further analysis of which specific sectors cause these differences, suggestions for improvement of the management of the IS



(a) Unused waste solid



(b) COD



(c) Sulfur dioxide

Figure 7: The environmental efficiency of China’s industrial system in 2015.

are proposed. Due to the innovation used with the classification methods, the results obtained in this study cannot be directly compared with the other existing research results.

The new method of dividing the industrial activities shows that the most prominent phases are the MP and the PM phases, which have contrasting characteristics. With high energy consumption and large amounts of discharged pollutants, the MP phase is an important phase to control the negative impacts of the IS whether they be from the aspect of the absolute quantity or efficiency. Furthermore, it has a high concentration in the distribution of the sectors. Therefore, the management of this phase can be carried out in the following three aspects: ① The economic proportion of EHP, CMM, and NMM should be properly cut down through structural adjustments to reduce the dependence on heavy industry in the development of the national economy. ② Because most of the sectors with high energy consumption levels are energy processing sectors, improving the energy conversion technology is also an effective way to reduce energy consumption; this can make the same input of primary energy produce a higher output of secondary energy. At the same time, improving the waste gas treatment technology in GPS, FMS, and NFS, as well as the waste water treatment technology in CMM and PAM, can reduce the amount of pollutants discharged into the environment. ③ Increasing the recycling of intermediate products or components through the dismantling of discarded products, instead of producing new ones from raw materials, is also an effective way.

The PM phase is the phase with the largest economic output in the IS, and it also consumes less energy and discharges less pollutants, so the development of this phase is necessary for the IS to increase its eco-efficiency. All types of eco-efficiency in this phase are higher than the average level of the IS, so it has a driving effect on the improvement of the eco-efficiency of the IS, which is mainly from the sectors with a high structural coefficient and high eco-efficiency, such as AMM and EAM. However, for some other sectors with a high eco-efficiency, such as FNM, ASM, and IMM, there is still a problem of insufficient pulling power because of their small structural coefficient. Additionally, because there are many related sectors in this phase, there is no obvious consistency in the distribution of sectors with different impacts. Therefore, improving the management of this phase through structural adjustments requires a complex consideration of all the factors to achieve the right balance. However, this study does not adopt any corresponding evaluation method; this is a matter than can be added to the future research in this area.

The MR phase is also worthy of attention, although the development of this phase started relatively late, and its scale is still extremely small. This phase directly promotes the internal circulation of the IS, and it can significantly reduce the production activities of the MP phase, thereby reducing the impacts on the environment. The analysis in this study also points out that all types of eco-efficiency in terms of the MR phase are high, so there is a tendency to strengthen the development of this phase.

Conclusions

(1) There has been a tendency for the development of the PM phase in China's IS, and dominant industrial sectors with economies of scale have arisen in this phase. In addition, the MP phase, which is a heavy industry process with high energy consumption and high discharges of pollutants, is also a leader in the economic growth of China, especially the EHP, CMM, and NMM sectors in it.

(2) The main products provided to humans are building materials, electronic products, and household appliances. The output of intermediate products and components of the finished products is large, but the input of the required material resources is also very large.

(3) With regard to the impacts of the IS on the environment and energy, there is an obvious centrality in both the component distribution and the industrial sector distribution. The MP phase is the main source of energy consumption and pollutant discharges, and the low eco-efficiency of its dominant sectors with high structural coefficients is the main reason for the low level of the IS. The management of this phase should be carried out in three aspects: industrial structural adjustment, upgrading of the pollutant treatment technology, and waste recycling.

(4) Because of its high structural coefficient and eco-efficiency, the PM phase has a driving effect on the improvement of the energy efficiency of the IS. However, the driving force of some sectors with high eco-efficiency in this phase is still insufficient.

Improving the management of this phase through structural adjustments requires a complex consideration of all the factors to achieve the right balance.

ACKNOWLEDGMENTS

This study was supported by the National Key Research and Development Program of China (No. 2016YFC0502802). The authors are gratefully to the International Science Editing (http://www.internationalscienceediting.com) for editing this manuscript.

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