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Assessing China's Waste Management Activities Using a Computable General Equilibrium Model

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In the last 30 years, China's rapid economic development has been accompanied by serious environmental pollution problems. In 2007, the overall waste management cost is estimated to have reached about 230.5 bil CNY and 0.87 % of China's Gross Domestic Product (GDP). To reduce the heavy environmental burden and realise the transformation of economic structure, the government proposed to pursue sustainable development in the 13th National Five-Year Plan (2015 - 2020). The objective of this paper is to evaluate the social-economic features of China's waste management activities in different sustainable scenarios. To achieve this goal, this paper established a Social Accounting Matrix (SAM) distinguishing the waste management sectors from open sources, and then constructed a country-level dynamic multi-sectoral Computable General Equilibrium (CGE) model. Using this model, this paper analysed the situation of China's waste management sectors in three Shared Socio-Economic Pathways (SSPs) until 2030. The simulation results showed that in a high sustainable scenario, the waste management cost will rise to 323.7 bil CNY in 2030, and its weight of GDP will drop to 0.23 %. In a middle road scenario and a rocky road scenario, the GDP losses in 2030 are 355.8 bil CNY and 376.9 bil CNY with a weight of 0.27 % and 0.30 %.

1. Introduction

Along with decades of rapid economic growth, China's environmental problems are becoming more and more serious. In Beijing, the PM2.5 air pollution makes masks one of the most popular sale item in the last few years. In response to the environmental issues, China, as well as other countries, are seeking a way for a more sustainable pathway of development. In China, the government announced to build a resource-saving and environment-friendly society. In the global scale, the United Nations proposed the 2030 Agenda with 17 specific Sustainable Development Goals (SDGs).

China's sustainable development is facing huge uncertainties. Since the world's financial crisis in 2007, China's economic growth has slowed down and is expected to stay at a relatively low pace. Besides, the whole society is ageing and the government is also adapting its population policy. Other uncertainties come from other aspects, like capital growth rate, technology improvement and so on. In such different sustainable development scenarios, waste management sectors will present different features and it is very important to have a deep understanding of it.

Some developers of integrated assessment model (IAM) have tried to integrate waste management activities into IAM models to do scenario analysis. Masui et al. (2000) developed a CGE model to discuss the various ways of waste management and its impacts on CO_2 reduction in Japan. Cambridge Econometrics (2014) combines IAM and raw material flow analysis to discuss the situation in European countries. Pauliuk et al. (2017) investigate some major IAMs from an industrial ecology perspective and suggest that adding the industrial ecology linkages to IAMs allows for more robust mitigation scenarios.

This paper develops a country-level dynamic multi-sectoral CGE model to assess the environment management sectors in China in different sustainable development scenarios. Section 2 gives a brief introduction of the model structure. Section 3 presents simulation results in three sustainable scenarios. Section 4 is the part for conclusion and discussions.

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2. Model Structure

2.1 Formulation of Input-Output Table and SAM

This paper mainly uses data inputs from national input-output (IO) table, national social accounting matrix (SAM) and pollutant data from an open data set, China Environmentally Extended Input-Output Table (CEEIO) which is developed by Liang et al. (2017). China's national IO is published by the National Bureau of Statistics (NBS) every five years, and the latest one is the version of the year 2012. There is still no complete open data of the national SAM table and detailed pollutant data for that year. Considering the data accessibility and completeness, this paper uses the year 2007 as the base year and all the data can be obtained from open data sources.

China's IO statistics (in 42 sectors or 135 sectors) and environmental statistics (in 45 sectors) are investigated in different scopes of sectors. For the consistency of data and simplicity of the model, this paper considers 20 sectors and 20 commodities, as shown in Table 1. Besides the original data from NBS, this paper adds three waste management sectors: wastewater management, gas pollutant management and solid waste management.

Table 1: Sectors and commodities in the IO table

Sector	Commodity Notation	Explanation
Coal mining and processing	CMP	Coal products
Oil industry	Oil	Oil products
Gas production and supply	GAS	Gas
Electricity production	ELE	Electricity
Farming, forestry, animal production and fishery	FFAF	Agriculture products
Mining	MIN	Mining products
Food industry	FOOD	Food products
Textile	TEX	Textile products
Chemistry industry	CHIN	Chemical products
Non-metallic mineral industry	NMP	Non-metallic mineral products
Metal processing industry	MPI	Metal processing products
Metal industry	MEIN	Metal made products
Other industries	Other	Other industrial products
Water production and supply	WATER	Water
Construct	CONS	Construction
Transport	TRANS	Transport service
Service industry	Service	Service
Wastewater management	WPM	Water pollutant treatment
Gas pollutant management	GPM	Gas pollutant treatment
Solid waste management	SWM	Solid waste treatment

The waste management sector is introduced by following the theory of Green Input-Output Table of Lei (2000). Since in the original national IO Table, the waste management is integrated into each sector, we need to separate and establish an aggregated waste management sector. Considering the data accessibility, we only consider three general types of waste management: wastewater, gas pollutant and solid waste. From the national environmental accounting report, the overall input for managing wastewater, gas pollutant and solid waste in 2007 are 65.4, 137.0 and 28.2 bil CNY in 2007. Zhao and Lei (2010) give the intermediate input coefficients for these three waste management sectors. For the sake of simplicity, we assume that the waste management costs are the same among different sectors. With the waste generation and discharge data from China Environment Yearbook and CEEIO, we can estimate the intermediate demand for waste management in each sector, and then formulate the three waste management accounts.

We also need to calculate the carbon emission coefficients. We assume all the carbon emissions come from the consumption of fossil fuel goods: coal, petroleum and natural gas, and the emission coefficient is the carbon emission amount divided by monetary consumption amount of each kind of fossil fuel. The carbon emission amount by each source of fossil fuel is the physical consumption amount multiplying by the low heat value, and carbon emission factor per value of energy generated and an adjustment coefficient. The physical consumption amounts of each fossil fuel goods come from the National Energy Balance Table. The low heat value and the emission factor come from the IPCC GHG Inventory Guidelines. The adjustment coefficient is calibrated to match the real carbon emission of China in 2007. The monetary consumption amount is the total output value from the IO table. We can then get the carbon emission coefficients for each kind of fossil fuel.

Based on the IO table and the SAM in Fan et al. (2010), this paper then formulates the SAM for the base year, as shown in Table 2.

Table 2: SAM structure

	Sector	Commodity	Labour	Capital	Household	Ent.	Gov.	Saving	Stock	Row
Sector		Outputs								
Commodity	Intermediated demand				Household demand		Gov. demand	Fixed Capital	Stock change	Export
Labour	Labour input									
Capital	Capital input									
Household			Labour income	Capital income		Transfer	Transfer			Transfer
Ent.				Capital income						
Gov.	Production tax				Income tax	Income tax				
Saving					Household saving	Ent. saving	Gov. saving			Row saving
Stock								Stock change		
Row		Import					Transfer			

2.2 A Dynamic CGE Model

Based on the SAM, this paper uses the Mathematical Programming System for General Equilibrium (MPSGE) framework to build a static CGE model in GAMS. As Figure 1 presents, the energy sectors are separated from other production sectors. According to Yan et al. (2015), the substitution elasticity between labour and capital is set to be 0.36 and the elasticity among energy products is set to be 1. As for other intermediate inputs, this paper assumes they conform to Leontief production functions. For the part of export and import, a Constant Elasticity of Transformation (CET) function and Armington condition are set in the model. We then construct a dynamic model based on the static CGE model. We assume a linear relationship between capital stock and capital endowment. The total capital stock is updated by year, taking the depreciation and investment into consideration. According to Li (2016), the depreciation rate of capital goods is 5.73 %.

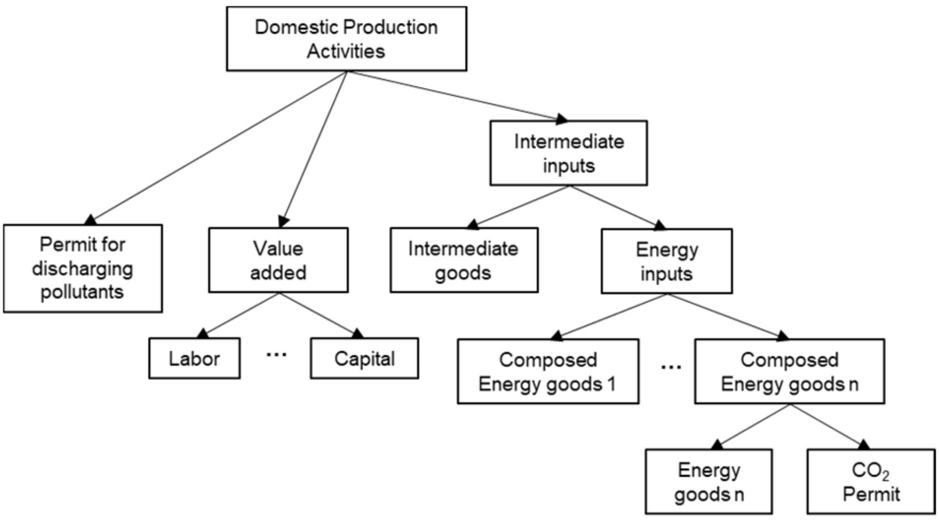

Figure 1: Production structure in CGE

3. Scenario design and simulation results

3.1 Scenario design

This paper learns from the SSPs (O'Neill et al., 2014) to build three sustainable scenarios. The SSPs are developed by the climate change research community to facilitate the integrated analysis of future climate or environment-related issues. There are five different scenarios in the original SSPs framework. Since SSP4 and SSP5 emphasise on the future challenges for mitigation or adaptation and we do not consider the difference of mitigation and adaption in this paper, we only consider SSP1, SSP2 and SSP3 in this paper, and they represent a high sustainable scenario, a middle road scenario and a low sustainable scenario. Figure 2 shows the basic assumptions of population and GDP in the scenarios of SSP1, SSP2 and SSP3.

SSP1: A high sustainable scenario with relatively low population growth.
SSP2: A middle road for sustainable development.
SSP3: A low sustainable scenario with relatively high population growth.

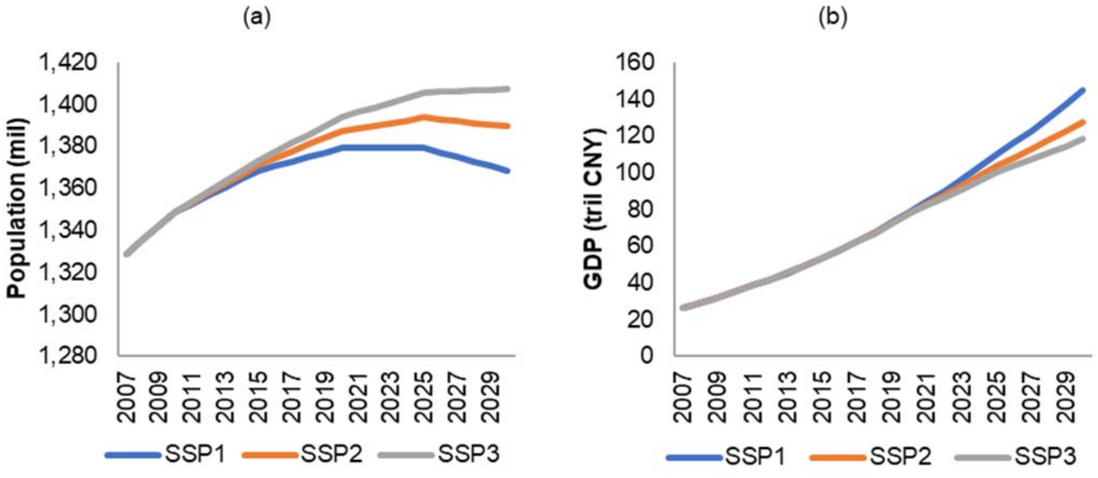

Figure 2: Scenario parameters indicating (a) population and (b) GDP from year 2007 to 2030

Other assumptions include the technology efficiency improvement in production sectors and waste management sectors. It is noted that the real condition might be different from the SSP scenarios due to a lot of uncertainties in the governmental policies and economic situations.

3.2 Simulation results

In this section, we present and discuss some of the main simulation results. Figure 3 shows the simulation result for total CO_2 emission amount and CO_2 intensity of GDP.

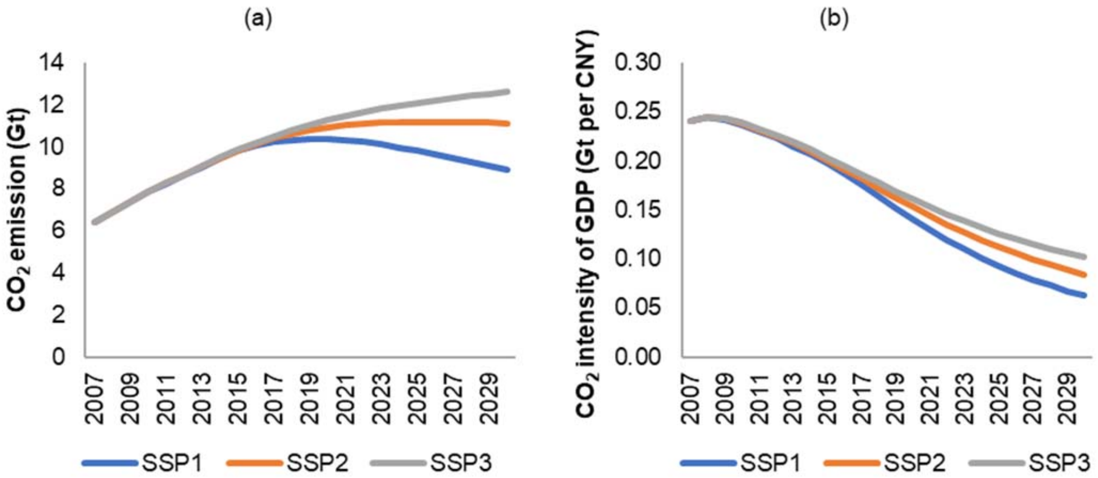

Figure 3: (a) CO_2 emission and (b) CO_2 intensity of GDP from year 2007 to 2030

The GDP is measured in the monetary unit of bil CNY in 2007 level. As for the carbon emission, in China's Nationally Determined Contributions (NDC) in the Paris Agreement, the government promised to decrease

CO_2 intensity by 40 to 45 % in 2020 and by 60 to 65 % in 2030, compared to the level in 2005. We have taken China's NDC into consideration and make sure the governmental goal is achieved in all the scenarios.
The results show that SSP1 has the lowest CO_2 emission amount and CO_2 intensity of GDP, and CO_2 emission might peak around 2019. In the case of SSP3, it has the highest CO_2 emission amount and CO_2 intensity of GDP, the CO_2 emission will not peak before 2030. SSP2 shows the middle situation of SSP1 and SSP3. Figure 4 shows the waste management cost and its percentage of GDP in three scenarios. As shown in the graph, in the low sustainable scenario SSP3, the waste management cost is the highest in terms of both absolute value and relative percentage of GDP. In the high sustainable scenario SSP1, the total waste management cost will rise to 323 bil CNY and the percentage of GDP will decrease to 0.23 % by 2030. While in the least sustainable scenario SSP3, the total waste management cost will rise to 377 bil CNY with a percentage of 0.30 % of GDP by 2030.

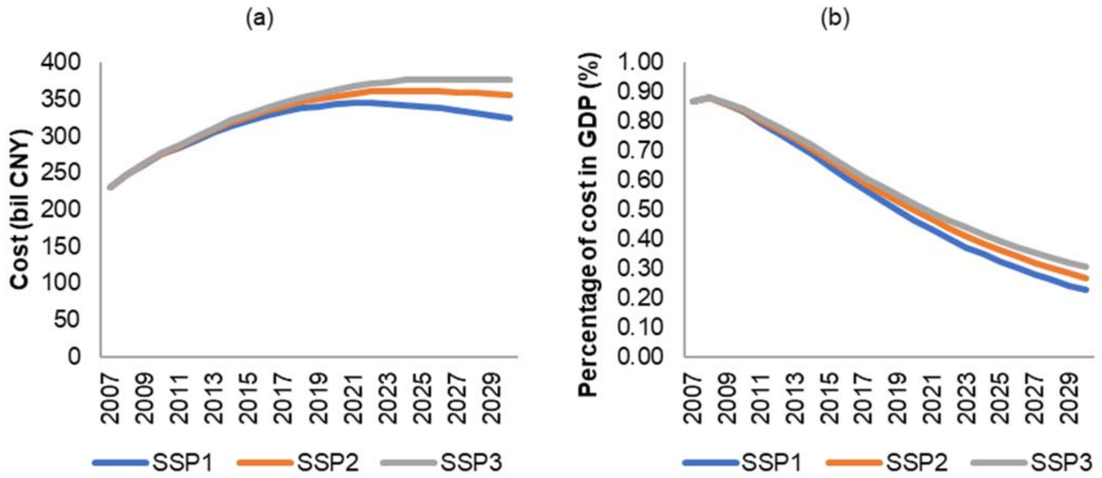

Figure 4: (a) Waste management cost and (b) Percentage of waste management cost in GDP from year 2007 to 2030

Besides the three basic scenarios, we have also studied how the technology improvements in waste management sectors can help reduce the cost. Existing studies show that technology improvement is a crucial factor to solve the pollution problems (Han and Zhou, 2017). In this paper, we use the intermediate coefficients change to represent the technology improvements. It means that in one sector, if the demanded intermediate input for waste management decreases, we can think waste management technology improves for that sector. Take the middle road scenario SSP2 for an example. The simulation result is as shown in Figure 5.

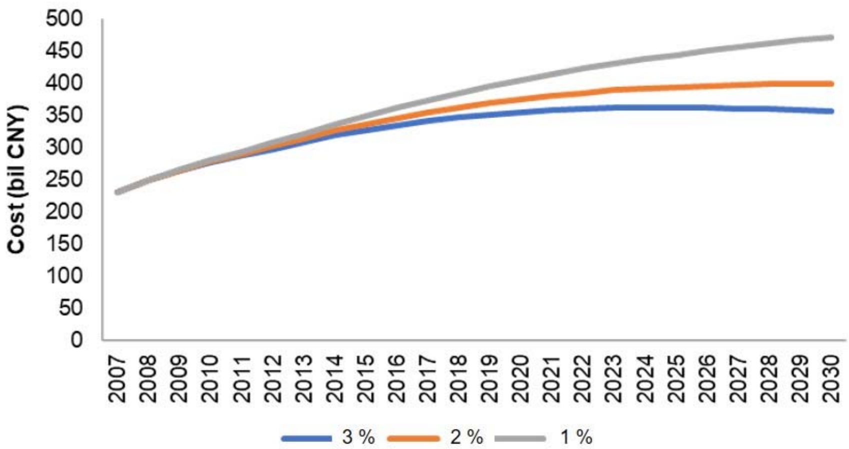

Figure 5: Technology improvement can reduce waste management cost – take SSP2 as example

In SSP2, if the technology improvement rate reaches 3 % per year on average, the waste management cost will be 356 bil CNY by 2030. However, if the technology improvement rate is only 1 % per year on average, the cost will be 472 bil CNY by 2030.

4. Conclusions

This paper introduces a dynamic multi-sectoral CGE model to assess the future waste management activities in China. The results show that waste management cost will be around 0.30 % of the total GDP by 2030 in a low sustainable scenario, and will decrease to 0.23 % of GDP by 2030 in a high sustainable scenario. The technology improvement is a key factor to lower the waste management cost. With 1 % more efficiency improvement per year, the total waste management cost can be about 58 bil CNY lower in 2030 in a middle road scenario. The total carbon emission will be lower in a high sustainable scenario and the peak time for carbon emission is as early as 2019.

This paper can be extended from several aspects in the future. First, we can distinguish different ways of waste management and study their social-economic and environmental influences. Second, we can design more policy scenarios to study the future situations of waste management sectors. Finally, we can also consider the rebounding effects or other factors that may influence the consumption when the recycling activities increase.

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