sustainability

MDPI

Article

Uncover Cost-Benefit Disparity of Municipal Solid Waste Incineration in Chinese Provinces

Shitong Yu and Huijuan Dong *

School of Environmental Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China; yst950507@163.com

* Correspondence: donghj@sjtu.edu.cn

Received: 13 December 2019; Accepted: 12 January 2020; Published: 18 January 2020

Abstract: Incineration has been regarded as a promising method to respond to municipal solid waste (MSW) challenges. However, its high cost and health impacts are the main barriers to the development of incineration. This study aims to investigate the cost-benefit of MSW incineration in 31 Chinese provinces to identify the regional disparity of incineration policy in China. Life cycle environmental impacts and costs were analyzed using the life cycle assessment software Gabi 8.0 and method CML-2001. Results show that MSW disposal costs, Global Warming Potential (GWP) and Eutrophication Potential (EP) will decline significantly with the increase in incineration rate for all Chinese provinces, while the environmental impacts of Human Toxicity Potential (HTP), Ozone Layer Depletion Potential (OLDP) and Terrestric Ecotoxicity Potential (TETP) increase the trend. Economically developed and populated provinces such as Guangdong, Jiangsu, Zhejiang and Shandong have both a higher incineration volume and incineration potential. As for the cost-benefit analysis, developed provinces such as Guangdong, Chongqing, Shanghai and Tianjin exhibit the highest cost-benefit in toxic impacts of HTP, TETP and ODP. Northern provinces such as Jilin, Xinjiang, Heilongjiang and Hebei have the lowest cost-benefit in toxic impacts but have the highest cost-benefit in GWP and EP. Finally, policy remarks on incineration cost, priority provinces, integration of sorting and incineration are also discussed.

Keywords: life cycle assessment; life cycle costing; Chinese provinces; municipal solid waste incineration; environmental benefit

1. Introduction

In the past ten years, the amount of municipal solid waste (MSW) clean-up in Chinese urban areas has risen from 154.4 million tons in 2008 to 215.2 million tons in 2017 [1]. With the increase of MSW, incineration and resource recycling has received more and more attention, becoming one of the emerging issues in China. The government has set an ambitious target to significantly improve the incineration rate to more than 50% in the 13th Five-Year National MSW Harmless Treatment Facilities Construction Plan [2]. However, due to its shortcomings in environmental pollution and potential health risks compared with landfill [3,4], incineration only gradually replaced landfill from 10.2% in 2008 to 39.3% in 2017 [1]. Another main barrier for the implementation of incineration is its relatively higher cost compared to landfill [5,6]. Therefore, it is meaningful to know how much implementing incineration will cost and whether its cost-benefit analysis is favorable from a life cycle perspective.

Life cycle assessment (LCA) and life cycle costing (LCC) are two main methods used to assess the comprehensive benefits of waste management [7]. A large number of LCA models have been established to evaluate the environmental impact of different waste disposal strategies, but most based on the data of different international countries. Some research focused on environmental benefits in Italy [8–11], in Sweden [12–14], in Denmark [15,16] and France [17], and results showed that incineration was a preferable choice than landfill in terms of wide-ranging environmental performance. The studies that focus on MSW management cases in China are limited. At the national scale of China, some studies focus on the environmental benefits of different incineration technologies such as grated firing incinerators and fluidized bed incinerators [18], while some researchers compared the comprehensive environmental benefits of different MSW treatment scenarios like landfill, incineration and compost-based on the actual processing of data in different Chinese cities [19–21]. Studies on life cycle costing analysis have also been conducted since the economic cost is also essential for policymakers [22]. Some researchers have calculated the financial costs of different waste disposal including landfill and incineration [23,24], while others integrate the environmental impact and economic costs for comprehensive analysis [25–27]. In spite of this, studies on the life cycle cost of incineration are still limited, and the environmental impact and economic cost in these studies are analyzed separately.

In summary, existing studies pay much attention to the environmental benefit, and few have taken into consideration the MSW treatment cost to do a comprehensive cost-benefit analysis. Moreover, existing studies focused more on the life cycle assessment of waste management for a specific city or region, neglecting the difference of regional disparity. Considering that the socio-economic situations, population size and MSW components have a significant regional disparity, the caloric value and characteristics of MSW will vary a lot [28]. Besides, the waste incineration development stage in different regions of China is also unbalanced. For example, the area with the highest incineration rate in Jiangsu Province is over 70%. However, in the northwestern regions of China, such as Shaanxi and Qinghai, all municipal solid waste is treated by landfill [1]. As a consequence, incineration potential and cost-benefit will show a great regional disparity in different provinces, and it is meaningful to clarify regional disparity and support the policy implications of incineration in different provinces. Under such a circumstance, this study aims to do a life cycle cost-benefit analysis to comprehensively assess the environmental benefits and economic costs of MSW incineration in 31 Chinese provinces. The remainder of the paper is structured as follows: Section 2 introduces the methods of LCA and LCC of incineration, and data sources for 31 provinces. Section 3 details the results of incineration potential, electricity generation, life cycle assessment results and cost-benefit disparity of 31 Chinese provinces. Section 4 discusses policy implications, and Section 5 draws the conclusions.

2. Methods and Data Source

2.1. Life Cycle Assessment of MSW Incineration Environmental Performance in 31 Chinese Provinces

Life cycle assessment is a widely used tool to evaluate different environmental impacts and consumption of resources throughout the life cycle of a product, from the production of raw materials to the disposal of waste [29]. According to the Society of Environmental Toxicology and Chemistry and the ISO standard, four procedures are contained in the life cycle assessment, which consists of goal and scope definition, inventory analysis, impact assessment and interpretation [30–32].

2.1.1. Goal and Scope Definition

In this study, the goal and scope definition phase, system boundary of the LCA model for MSW incineration and landfill are shown in Figure 1. For MSW incineration, the processes of waste incineration, flue gas cleaning, leachate disposal, slag and fly ash landfill and waste incineration power generation are contained in incineration LCA boundary, while only on-site landfill and leachate disposal are included in MSW landfill scope. In addition, the functional unit selected in this study is the annual amount of MSW incineration for 31 Chinese provinces, which is shown in Table S1 in supplementary materials.

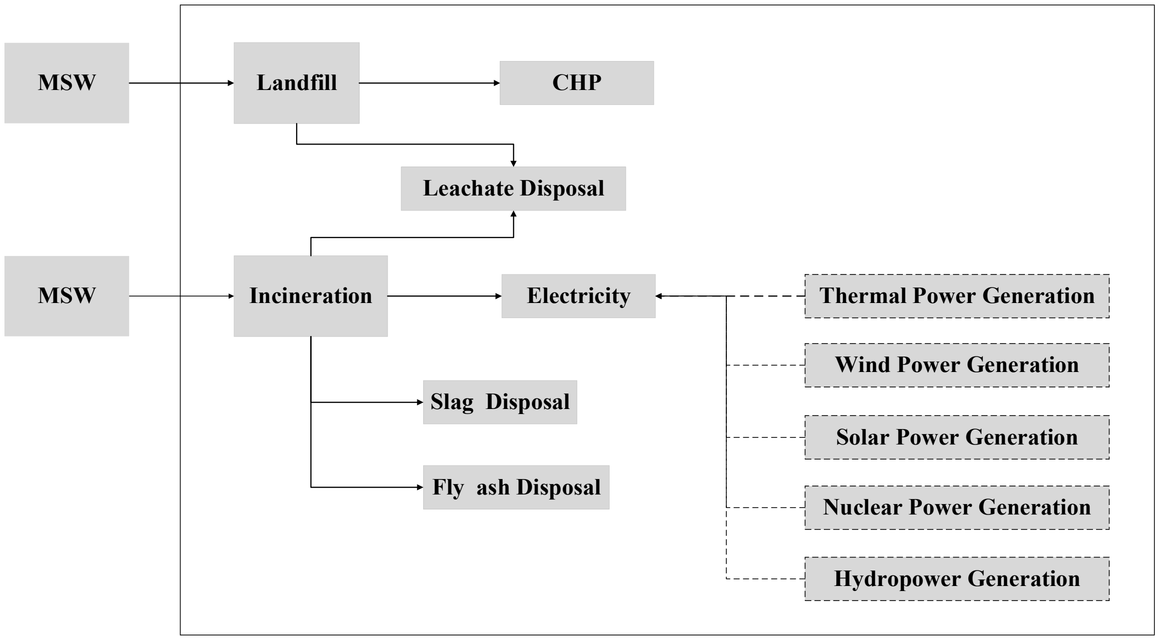

Figure 1. System boundary of MSW incineration and landfill.

2.1.2. Inventory Analysis

After defining the boundary of incineration and landfill, the next step is to collect corresponding data for inventory analysis of 31 provinces. Although there are 34 provincial-level administrative regions in China, the data of Taiwan, Hong Kong, and Macau are unavailable, thus, only the cost-benefit analysis of municipal solid waste disposal in 31 Chinese provinces was calculated. Some of the common input and output data of the life cycle inventory for MSW incineration is shown in Table S4 in the supplementary materials obtained from references [33–37], and landfill inventory data is derived from the Gabi 8.0 database. It is assumed in this study that the values of unit MSW incineration (without conversion of waste to energy) and landfill are the same for all Chinese provinces, while the differences are the amount of MSW incineration, the amount of unit electricity production and the local power generation structure for different provinces. Alongside, some data also need to be calculated for different provinces. For example, the calorific value of MSW in different provinces reveals a significant difference due to the diversity in municipal solid waste composition, which results in a large discrepancy in the amount of electricity generated by unit MSW incineration. In addition, power generation structure for different provinces also varies a lot, which greatly affects the environmental impact on the substitution of traditional electricity generation structure from incineration. The technical route of LCA for 31 Chinese provinces is provided in Figure 2.

(1) Calculation of MSW calorific value and electricity generation

The average value of MSW components for 31 Chinese provinces and provincial cities are obtained by referring to different data sources, shown in Table S2 in supplementary materials [38–54]. For all the Chinese provinces, the dominant components of MSW are kitchen waste, paper, plastic and rubber, textile, wood and bamboo, glass, metal and lime soil, and the MSW components in different regions show different characteristics.

Then the calculation of the calorific value of MSW is further calculated based on the MSW components in Table S2. However, the composition in is the weight percentage of the wet basis content, which needs to be converted to dry basis content first by Equations (1) and (2).

$$C_i(dry) = C_i(wet) \times \frac{100 - C_i(w)}{100 - C(w)} \tag{1}$$

$$C(w) = \sum C_i(w) * C_i(wet) \tag{2}$$

where $Ci(dry)$ and $Ci(wet)$ are the dry basis content and the wet basis content of component i, respectively. $C_i(w)$ is the moisture content of component i, and $C(w)$ is the total moisture content.

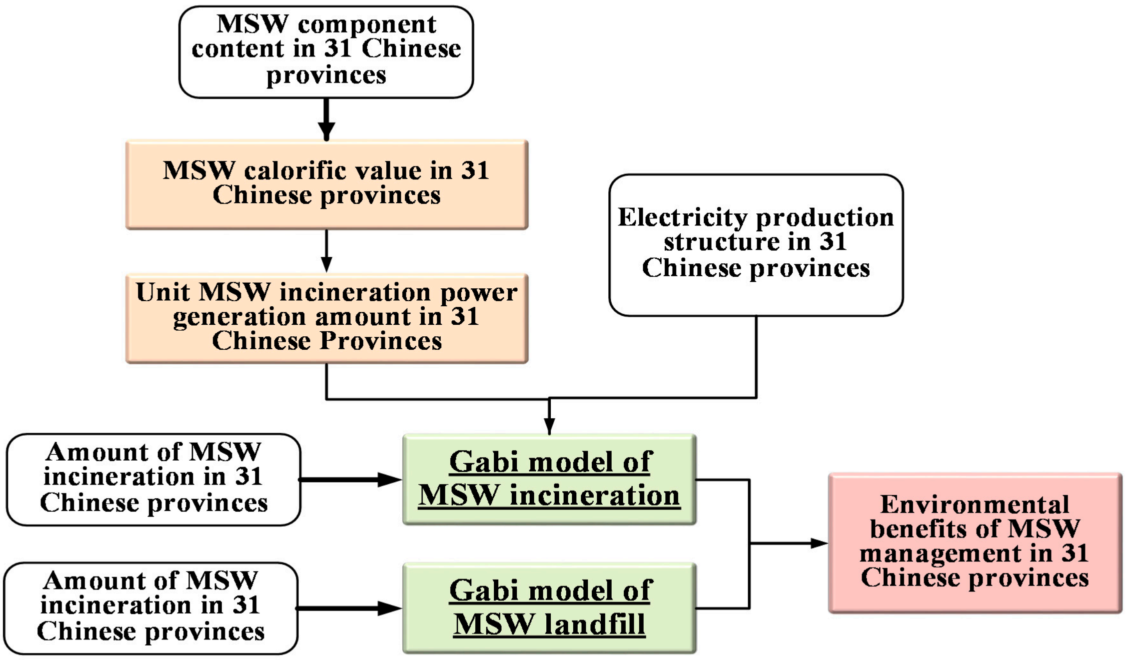

Figure 2. Technical route of life cycle environmental impact for 31 Chinese provinces.

According to the high-level calorific value from CI/T313-2009 Methods for Sampling and Analysis of Domestic Waste in Table 1, wet basis high calorific value ($Q(h)$) of MSW can be calculated according to Equation (3).

$$Q(h) = \sum Q_i(h) \frac{C_i(dry)}{100} \times \frac{100 - C_i(w)}{100} \tag{3}$$

where $Q_i(h)$ is the dry basis high calorific value of component i, and the values are shown in Table 1.

Table 1. High-level calorific value and hydrogen content of different components.

MSW Components	High-Level Calorific Value (kJ/kg)	Hydrogen Content (%)	Moisture Content (%)
Kitchen waste	4650	6.4	68.2
Paper	16,600	6.0	43.2
Plastic	32,570	7.2	43.5
Rubber	23,260	10.0	43.5
Textile	17,450	6.6	43.5
Wood bamboo	18,610	6.0	44.2
Glass	140	/	2.4
Metal	700	/	5.4
Lime soil	6980	3.0	29.6

Then, wet basis low calorific value ($Q(l)$) is further obtained by Equation (4).

$$Q(l) = Q(h) - 24.4 \times (C(w) + 9H \times \frac{100 - C(w)}{100}) \tag{4}$$

where H is hydrogen content of MSW.

The amount of municipal solid waste incineration power generation can be finally calculated based on the low calorific value of MSW and the thermal efficiency of the incineration plant. According to reference [55], the thermal efficiency of MSW incineration is usually 15%–30%; thus, the average 23% is adopted in the study. The amount of electricity production is calculated by Equation (5)

$$E = 0.23\,Q(l) \tag{5}$$

where E is the amount of annual incineration power generation.

(2) Power generation structure in 31 Chinese provinces

In China, thermal power generation, wind power generation, solar power generation, nuclear power generation and hydropower generation are five main compositions of power generation structure. Table S3 in supplementary materials shows the power generation structure in 31 provinces and cities nationwide, and different regions present different electricity structures. For most areas, thermal power generation is the most dominant contributor to electricity generation, however, in Hubei, Guangxi, Sichuan, Yunnan, Tibet and Qinghai, hydropower generation is higher than thermal power generation, which means hydropower is more crucial in these regions. Also, wind power and solar power account for a small proportion of all the regions, while nuclear power is only produced in Liaoning, Jiangsu, Zhejiang, Fujian, Guangdong, Guangxi and Hainan, and the proportion does not exceed 25%.

2.1.3. Life Cycle Impact Assessment Method

In this study, CML-2001 is chosen to conduct the environmental impact assessment of waste management considering that CML-2001 is a more selected assessment method in the Gabi software, which can reduce the complexity of the model and make it easy to operate. In CML-2001, ten different environmental impact indicators are usually included, while only six representative indicators are chosen in this study, namely, Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Human Toxicity Potential (HTP), Ozone Layer Depletion Potential (ODP) and Terrestric Ecotoxicity Potential (TETP), because these indicators already cover the impact on climate, air, water, human health and the ecological environment. Moreover, the other four indicators are also toxicity indicators and denote the same trends with HTP and TETP. Therefore, only six indicators are selected in this paper to attain more concise results. The evaluation results are calculated according to the software Gabi 8.0.

2.2. Life Cycle Costing of MSW Incineration and Landfill of 31 Chinese Provinces

Life Cycle Costing (LCC) first appeared in the mid-1960s and was adopted to be used in the construction investment field. It is a tool to compare cost evaluation over a specified time, and all relevant economic factors are taken into account [56]. In this study, investment cost, operating cost, waste disposal cost and benefits of MSW incineration are included in life cycle costing.

Investment cost ($C_{Inv.}$) refers to the investment required to incinerate one ton MSW during the period of waste incineration power plant and landfill operation, and it can be calculated based on Equation (6).

$$C_{inv.} = \frac{P1}{y \times m} \tag{6}$$

where $P1$ is the initial investment in MSW incineration plants or landfills, y is the operating year, and m is annual MSW disposal capacity.

For operating cost ($C_{ope.}$), five part fees are included, which are material cost ($C_{mat.}$), maintenance cost ($C_{mai.}$), labour cost ($C_{lab.}$), energy cost ($C_{ene.}$), and depreciation cost ($C_{dep.}$) (Equation (7)). The data is derived from the EIA report [57].

$$C_{ope.} = C_{mat.} + C_{mai.} + C_{lab.} + C_{ene.} + C_{dep.} \tag{7}$$

For disposal cost ($C_{dis.}$), it contains treatment cost of slag, fly ash and leachate. Moreover, the corresponding treatment costs are from references [58–60], respectively. The waste disposal cost ($C_{dis.}$) is calculated by Equation (8).

$$C_{dis.} = C(slag) + C(fly\ ash) + C(leachate) \tag{8}$$

As for benefits, it means the revenue from selling electricity or heat through MSW incineration. According to the Notice of the National Development and Reform Commission on Improving the Price Policy of Waste Incineration Power Generation [61], the national unified power grid price is 0.65 RMB/kWh when the electricity production per ton of MSW is less than 280 kWh, and the excess is the same as the price of local coal-fired power generation (P_2). While the price is different for different areas and the price data is obtained from the Notice of the National Development and Reform Commission on Reducing the On-Grid Price of Coal-Fired Power Generation and the Price of Electricity for General Industrial and Commercial Use. The incineration benefit (B_1) can be calculated as Equation (9).

$$\begin{cases} \mathrm{B1} = 280 \times \mathrm{E} & \mathrm{E} \leq 280\ \mathrm{kW.h/t} \\ \mathrm{B2} = 280 \times 0.65 + (\mathrm{E} - 280) \times \mathrm{P2} & \mathrm{E} > 280\ \mathrm{kW.h/t} \end{cases} \tag{9}$$

where E represents incineration power generation amount of one ton MSW.

The life cycle costs of waste management in Chinese provinces can be calculated as follows.

$$C(I) = C_{inv.}(I) + C_{ope.}(I) + C_{dis.}(I) - B1 \tag{10}$$

$$C(L) = C_{inv.}(L) + C_{ope.}(L) + C_{dis.}(L) \tag{11}$$

$$C(total) = C(I) \times M(I) + C(L) \times M(L) \tag{12}$$

where $C(I)$ is the total cost of incineration, and $C(L)$ is the total cost of landfill. $M(I)$ and $M(L)$ are the amount of annual MSW incineration and the annual MSW landfill, respectively.

2.3. Scenario Setting

Two different scenarios are set in this study which consists of S1 and S2. S1 is based on actual waste incineration and landfill volume in different regions of China in 2017, while S2 is based on the assumption that all MSW collected is 100% incinerated. All wastes treated by incineration are used for power generation in this study. The results of the life cycle assessment of S1 and S2 are calculated according to Gabi 8.0.

2.4. Cost-Benefit Analysis of Waste Management in China

Cost-benefit analysis is a combination of environmental impact and costs to evaluate the comprehensive benefits of municipal solid waste management scenarios. The cost-benefit (CB) is calculated by Equation (13).

$$CB = \frac{E(S1) - E(S2)}{C(S1) - C(S2)} \tag{13}$$

where $C(S1)$ and $E(S1)$ are the life cycle costs and environmental impact of scenario1. $C(S2)$ and $E(S2)$ are the life cycle costs and environmental impact of scenario 2.

3. Results

3.1. Incineration Potential of 31 Chinese Provinces

Incineration potential refers to the difference between the amount of municipal solid waste clean-up and the amount of current incineration. As shown in Figure 3, the incineration potential for 31 Chinese provinces exhibit great regional disparity. The incineration potential of Guangdong

Province was the highest, with a value reaching up to 17.3 million tons (Mt). Moreover, the incineration potential in Henan, Liaoning, Shandong, Hunan and Zhejiang provinces were also high, about 8.3 Mt, 8.0 Mt, 6.9 Mt, 6.4 Mt and 6.3 Mt, respectively, indicating that the prospects for MSW incineration in these areas were huge. For Tibet, Gansu, Qinghai, Ningxia, Hainan and Tianjin, they have the lowest value of MSW incineration potential, less than 2.0 Mt. The main reason was that both the amount of MSW generation and the incineration rate were lower. Most of the low potential provinces are less developed, especially in the northern and western provinces of China. In summary, MSW in China has a high incineration potential, and the prospects for future MSW incineration are extensive.

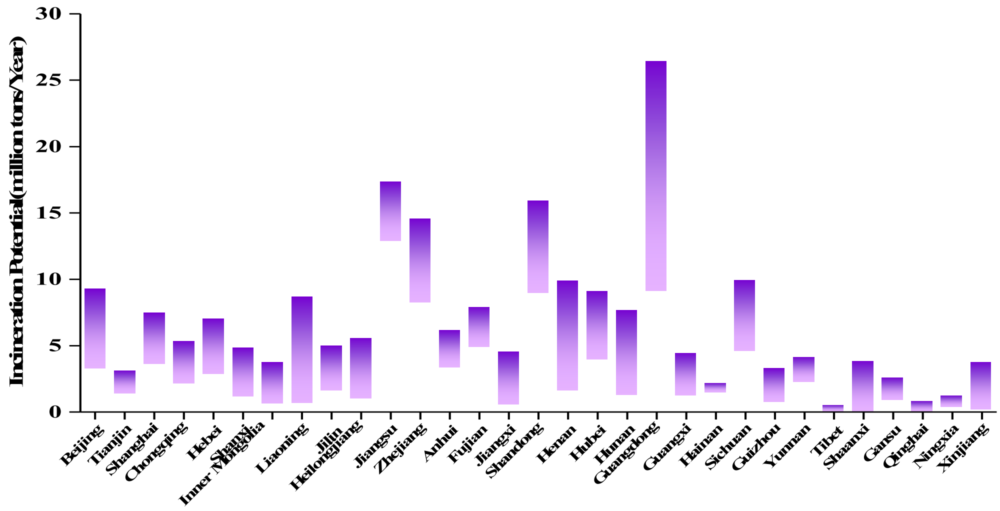

Figure 3. Incineration potential of 31 provinces in 2017.

3.2. Amount of Incineration Electricity Generation in 31 Chinese Provinces

Because of the difference in calorific value and the incineration volume, the discrepancy in the annual amount of MSW incineration power generation in different provinces is much more obvious under the similar thermal efficiency. Figure 4 shows the current incineration electricity generation situation in 2017 and further potential under 100% incineration. It can be seen that the eastern coastal areas had the highest existing incineration electricity. Particularly, the Guangdong Province had the highest annual MSW incineration power generation in 2017, which can reach 3.03 billion kWh, followed by the Shandong Province and Jiangsu Province, with an annual incineration power generation of 2.11 billion kWh and 2.09 billion kWh, respectively. The reason was that the MSW incineration amount in these provinces was much higher. Besides, with the larger incineration potential, the incineration power generation potential of Guangdong and Shandong also ranked higher, about 5.78 billion kWh/year and 1.64 billion kWh/year, indicating that they had a large space for MSW incineration power generation. Moreover, actual amounts of annual power generation for Zhejiang, Beijing, Fujian and Shanghai in 2017 were also high, about 1.61 billion kWh/year, 1.05 billion kWh/year, 1.04 billion kWh/year and 1.01 billion kWh/year, respectively. While the results of their incineration power generation potential presented different trends. For example, Beijing, Liaoning, Henan and Zhejiang had high incineration electricity potential, with the annual amount of about 2.97 billion kWh/year, 1.90 billion kWh/year, 1.25 billion kWh/year and 1.23 billion kWh/year, respectively. Furthermore, two main reasons for the regional disparity of incineration electricity were the high volume of annual MSW incineration and MSW calorific value. Another finding was that, although the current incineration power generation for less developed western provinces such as Xinjiang, Tibet, and Qinghai was low, their further incineration potential was also very low compared to the eastern and middle part of China. Existing incineration electricity of provinces of Shaanxi and Qinghai was zero due to completely landfill treatment of MSW, but their power generation potential was also very low. In general, the annual incineration power generation in southern China was generally higher than that in northern China under the current situation.

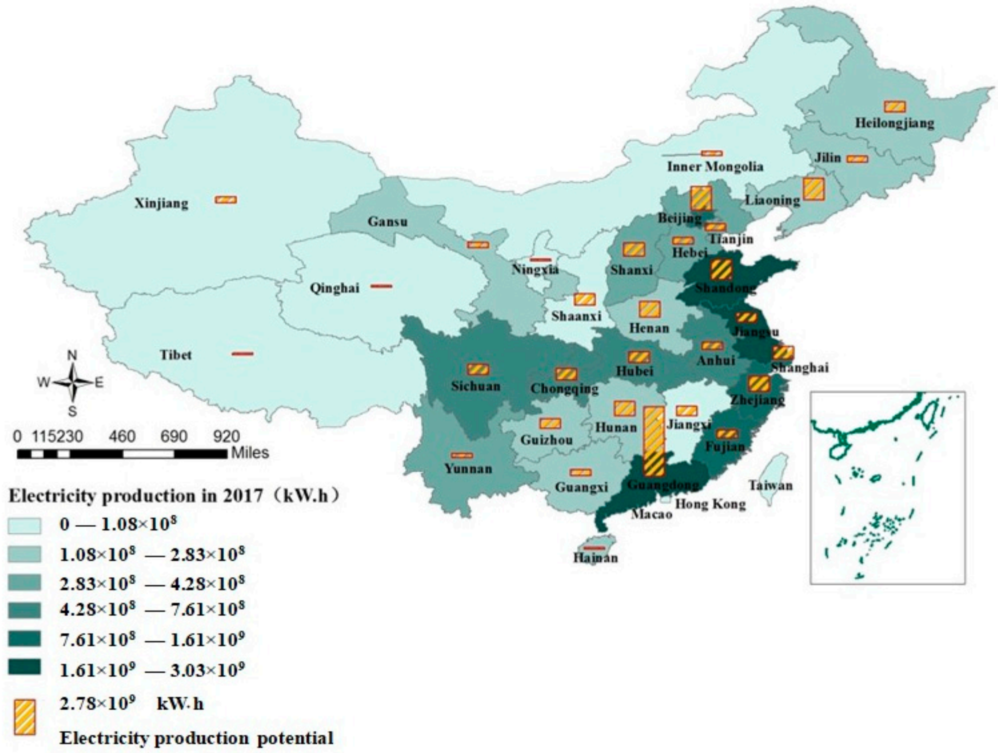

Figure 4. Current situation and potential of annual incineration power generation.

3.3. Life Cycle Environmental Impact Analysis of 31 Chinese Provinces

According to the actual treatment of MSW in different regions, six environmental impacts were calculated from Gabi 8.0. As can be seen in Figure 5, the environmental impacts of Human Toxicity Potential (HTP), Ozone Layer Depletion Potential (ODP) and Terrestric Ecotoxicity Potential (TETP) in the Jiangsu Province were much higher than other areas, about 474 million kg DCB eq., 0.19 kg R11 eq. and 277 million kg DCB eq., respectively. This has occurred because the quantity of MSW incineration in the Jiangsu Province ranked the first, and the contribution of incineration to these three environmental assessment indicators was greater than landfill. While for Global Warming Potential (GWP) and Eutrophication Potential (EP), the Guangdong Province had a dominant contribution because of its higher amount of MSW and relatively lower incineration rate. Besides, its Acidification Potential (AP) was the lowest, only −1.33 million kg SO_2 eq. Results also showed that for other areas with high existing incineration, such as the Shandong Province, Zhejiang Province, Fujian Province and Sichuan Province, the influence of HTP, ODP and TETP was also large, indicating that the treatment of MSW in these areas caused more serious damage to human health, the ozone layer and ecosystem. Moreover, the Acidification Potential (AP) results presented were prominently different, which was significantly related to the power generation structures in different areas. Particularly, the higher the proportion of thermal power generation, the better the reduction of the acidification effect of incineration. In China, AP effects of MSW disposal in four municipalities, the Shanxi Province, Liaoning Province, Anhui Province and Shandong Province were much lower. Finally, due to the low amount of MSW, incineration and landfill in the northwestern region, the MSW treatment had less impact of all the six indicators on the environment.

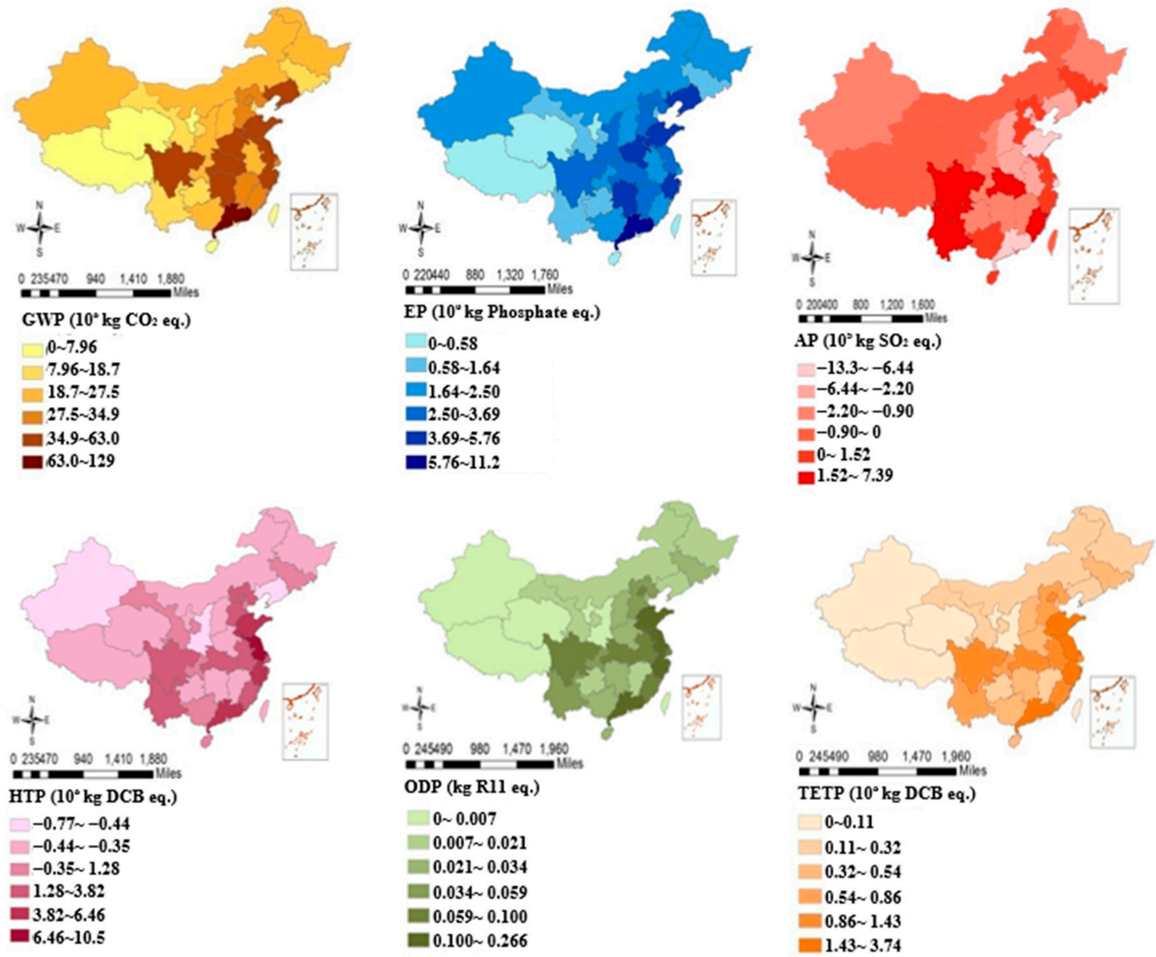

Figure 5. LCA environmental impact of 31 Chinese provinces in 2017.

3.4. Life Cycle Unit Cost of MSW Incineration

Due to the heterogeneous amount of MSW incineration power generation and the price of coal-fired power generation, the economic benefit from MSW incineration power generation in various provinces was of great difference, resulting in different life cycle unit costs of MSW incineration. For unit electricity generation by incinerating one ton of MSW, 23 provinces and cities such as Hebei, Liaoning and Heilongjiang, was less than 280 kWh. However, only a few regions, such as Beijing and Shanghai, surpassed this value. As is shown in Figure 6, the area with the highest MSW incineration unit cost was Inner Mongolia, about 197.30 RMB/t, followed by Xinjiang and Hebei being 185.00 RMB/t and 180.71 RMB/t, respectively. The reason was that the calorific value of MSW in these provinces was relatively low. Additionally, due to the relatively higher calorific value, the regions that had lower unit incineration costs were Guangdong, Beijing, Tianjin, Guizhou and Tibet, with values of 60.93 RMB/t, 70.94 RMB/t, 74.14 RMB/t, 75.20 RMB/t and 77.41 RMB/t, respectively. Furthermore, because MSW landfill has no revenue, the unit costs of landfill for 31 Chinese provinces were the same in this study, with a value of about 338.44 RMB/t. This reveals that the incineration cost is lower than landfill, and the incineration cost of some provinces is even only 1/5 of its landfill cost.

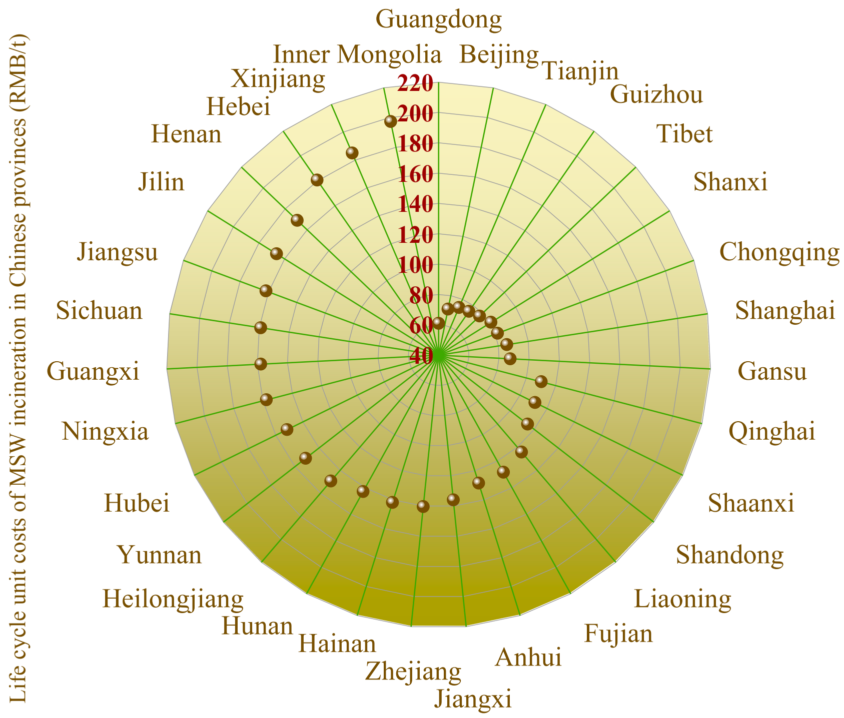

Figure 6. Life cycle unit costs of MSW incineration for 31 Chinese regions.

3.5. Cost-Benefit Analysis of Incineration

To investigate the potential environmental impact and economic cost for implementing 100% incineration in 31 Chinese provinces, Figure 7 further shows the life cycle environmental impacts and cost under scenarios S1 and S2. Deviation in Figure 7 means the difference of results between scenarios S1 and S2, namely, S1 minus S2.

It can be found that the environmental impact factors of Global Warming Potential (GWP) and Eutrophication Potential (EP) decreased for all 31 provinces after implementing 100% incineration, indicating that MSW incineration had greater emission reduction benefits for these two indicators. For GWP, the impact in Beijing, Tianjin, Shanghai, Shaanxi and Shanxi dropped the most, about 90.0%, 89.6%, 86.5%, 82.7% and 81.9%, respectively. Moreover, the decline rate of EP for 14 regions exceeded 100%, and the region with the largest decline was Tianjin, plummeting to 110.1%. On the contrary, with the increase of the MSW incineration rate, the influence of Human Toxicity Potential (HTP), Ozone Layer Depletion Potential (ODP) and Terrestric Ecotoxicity Potential (TETP) also enhanced, demonstrating that MSW incineration might cause great damage to human health, terrestrial and the ozone layer. Guangdong, Jiangsu, Zhejiang and Shandong were provinces with the largest increase regarding the three environmental impact indicators with their higher incineration potential. For example, the increase of environmental impacts HTP, ODP and TETP for Guangdong were about 1.77 Mt DCB-*eq.* (373%), 0.36kg R11-*eq.* (190%) and 0.48Mt DCB-*eq.* (174%), respectively. As for Acidification Potential (AP), because of the disparity of power generation structure in different provinces, it increased in several developed provinces such as Beijing, Shanghai, Shandong and Guangdong, while it decreased in southern provinces like Fujian, Hubei, Sichuan and Yunnan. Besides, AP was the only impact factor that had both positive and negative values for 31 Chinese provinces.

As for the life cycle cost, it is indisputable evidence that incineration will no doubt reduce MSW management cost for all provinces, which is different from traditional findings that incineration will increase the cost. Mainly, Guangdong Province had the highest LCA cost reduction of about 6.06 billion RMB under 100% incineration, because of its high incineration potential. Vice versa, Tibet exhibited the lowest LCA cost of about 3.6 million RMB. When all MSW is incinerated, the cost of MSW treatment will be significantly reduced, because the MSW incineration power generation can generate some revenue. Among the 31 Chinese provinces, Guangdong had the highest rate of cost reduction, about 73.4%. Following is Guizhou, Shanxi, Shaanxi and Qinghai, with reduced rates of about 71.26%, 68.26%, 66.84% and 65.30%, respectively. Because of the lower unit of MSW incineration power generation and incineration potential, the cost reduction rate of Jilin Province was the smallest, only 10.95%, indicating that the MSW was less affected by the incineration treatment.

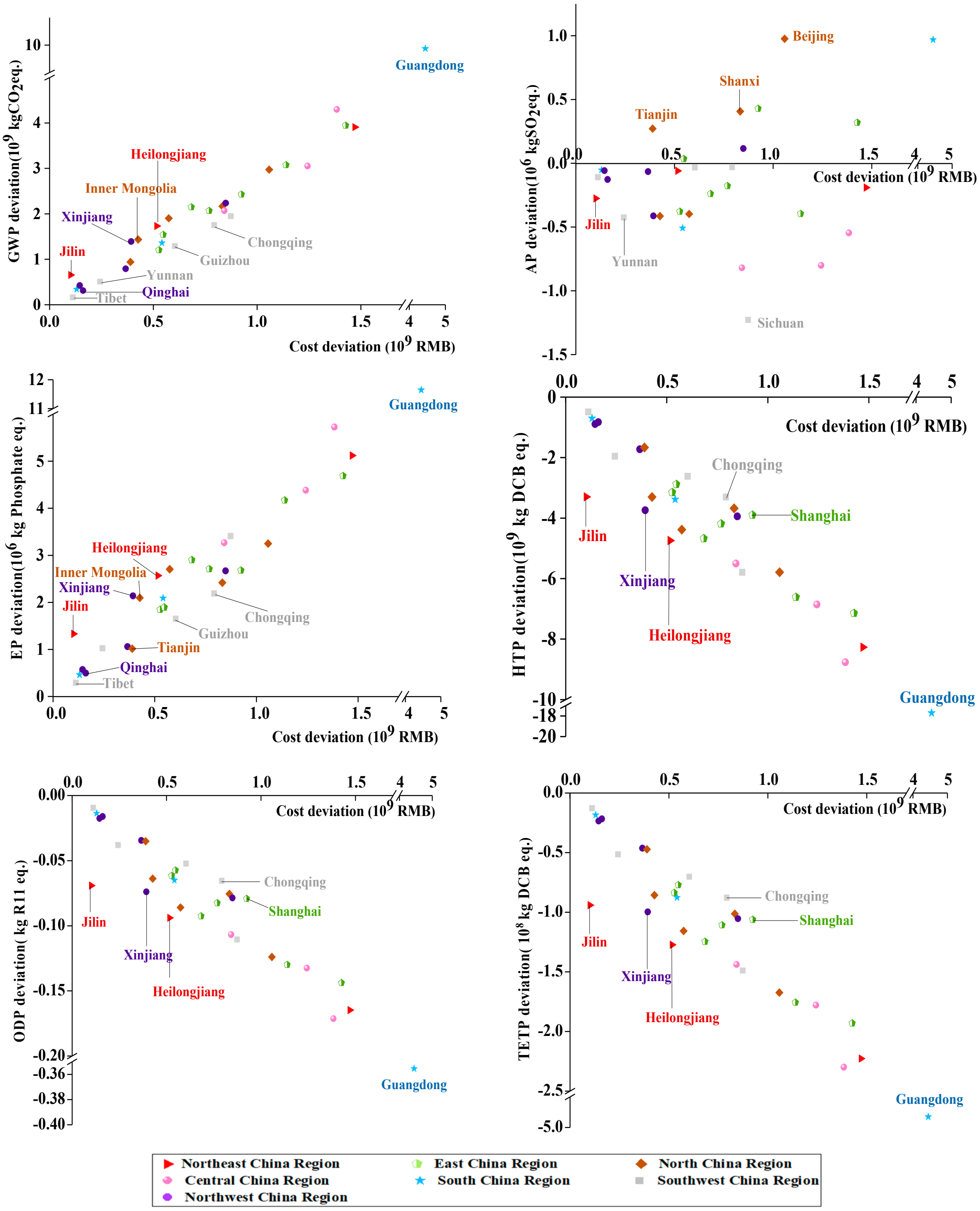

Figure 7. Cost-benefit analysis results.

Cost-benefit analysis is a comprehensive assessment of municipal solid waste management by combining both the environmental impact and cost. The slope in Figure 7 reflects the cost-benefit value, with a substantial positive value or a small negative value being more cost-efficient. It was found that for Global Warming Potential (GWP), the cost-benefit values were within a specific range, from 1.46 kg CO_2 eq./RMB for Tibet to 6.46 kg CO_2 eq./RMB for Jilin, the values were all positive, indicating that for GWP, the changes in environmental benefits and economic costs were consistent. Moreover, the data in northern provinces such as Xinjiang, Inner Mongolia and Heilongjiang was a little higher than other regions, reaching 3.54 kg CO_2 eq./RMB, 3.36 kg CO_2 eq./RMB and 3.36 kg CO_2 eq./RMB, respectively, indicating that the carbon emission reduction of MSW incineration was more efficient in these three provinces. Meanwhile, regions with lower cost-benefit values were Qinghai and Yunnan, at 1.94 kg CO_2 eq./RMB and 2.09 kg CO_2 eq./RMB, and the consequence of most provinces was between 2.00 kg CO_2 eq./RMB to 3.00 kg CO_2 eq./RMB, indicating that there was a significant regional disparity in carbon emission reduction of MSW incineration in China. In addition, for Acidification Potential (AP), it has both positive and negative environmental impact due to diversity power generation structures. Therefore, the cost-benefit results were between -1.41×10^{-3} kg SO_2 eq./RMB for Sichuan and 9.22×10^{-4} kg SO_2 eq./RMB for Beijing. Eight of them were favourable with their higher proportion of thermal power generation, such as Tianjin and Anhui, and 23 were negative. Northern regions were more cost-efficient in reducing AP, which is similar to features of GWP. Eutrophication Potential (EP) also has similar regional disparity with GWP. As for the cost-benefit analysis of Ozone Layer Depletion Potential (ODP), Terrestric Ecotoxicity Potential (TETP) and Human Toxicity Potential (HTP), they presented similar trends but being opposite to GWP and EP. Cost-benefit values of northern provinces such as Jilin, Heilongjiang and Xinjiang were relatively small, while the cost-benefit efficiency was more exceptional in economically developed regions like Guangdong, Chongqing, Shanghai and Tianjin.

3.6. Sensitivity Analysis

Sensitivity analysis for environmental performance has been done in another forthcoming paper by us, which focuses on the life cycle environmental performance of incineration. The results showed that indicator GWP was more sensitive to carbon dioxide emissions, while AP was more sensitive to sulfur dioxide, nitrogen oxides and hydrogen chloride. In addition, dioxins emissions had a more significant impact on toxicity indicator HTP. The economic cost sensitivity results are further shown in Table 2, with the change rate for all types of costs being 5%. A negative value means that the changing trend of total economic costs was opposite to the benefits. It can be found that cost was the most sensitive to the benefits from selling electricity or heat. When benefit decrease by 5%, the LCC will increase by 10.65%. Following parameters are investment costs, energy costs and depreciation costs, with vales being 3.86%, 3.76% and 3.48%, respectively. Therefore, to reduce the total costs of MSW incineration, the focus should be paid on investment costs, energy costs, depreciation costs and power generation revenue.

Table 2. Results of cost sensitivity analysis.

Types	$C_{inv.}$	$C_{mat.}$	$C_{mai.}$	$C_{lab.}$	$C_{ene.}$	$C_{dep.}$	$C_{dis.}$	B
Rate	+3.86%	+0.69%	+0.93%	+0.87%	+3.76%	+3.48%	+2.07%	−10.65%

4. Discussions and Policy Implications

4.1. Discussion and Policy Implications

As an effective measure to reduce MSW volume temporally, MSW incineration has been developed rapidly in recent years, and the proportion has also increased a lot. Many studies have also been conducted to investigate the life cycle impact of MSW incineration, with a few studies being done using LCA software Gabi. For example, one study that calculated the annual environmental performance of MSW incineration and landfill in Hangzhou city showed that GWP, AP and EP were 360 kg CO_2 eq./t, −0.86 kg SO_2 eq./t and −0.072 kg phosphate eq./t, respectively [62], which are similar to our results except that GWP is higher than our results. Another study on life cycle environmental impacts of the Lvzhou MSW incineration plant in China presented that the values of GWP, AP, EP and HTP per ton of MSW incineration were −110 kg CO_2 eq., −0.204 kg SO_2 eq., 0.00862 kg phosphate eq. and −127 kg DCB eq., respectively, lower than that in our study. The reason is that the heat from incineration was used for cogeneration [63]. In addition, for the life cycle environmental impact of MSW incineration in foreign countries, a study on the UK showed that the carbon footprint of MSW incineration was −179 kg CO_2 eq./t [64], a little lower than our results. In our study, the value of GWP in 2017 for Chinese provinces varied a lot, ranging from zero to 367.5 kg CO_2 eq./t. Moreover, because of differences in economic development and ecological environment, the progress of MSW incineration in China has large regional disparity. This paper therefore comprehensively analyzed the environmental impact and economic cost efficiency of MSW incineration policy for 31 Chinese provinces.

Following policy implications are discussed to guide the future implementation of MSW incineration in Chinese provinces.

First, policymakers should have the right understanding that incineration does not increase the MSW treatment cost, but instead can get an economic benefit from a life cycle perspective. Therefore, incineration can be a better option compared to existing landfill treatment if only the economic benefit is considered. This is different from most of the existing findings that landfill is low cost and a better financial option [65]. Thus, it is important for both the government and incineration companies to recognize this point and change incineration cost from a barrier to an incentive scheme. However, the profit from incineration is low due to the high operation cost, although it can generate revenue. Most existing incineration companies in China need to turn to government subsidy for help. Therefore, the government subsidy system for incineration still needs to be reinforced to promote further incineration. One problem is that incineration companies may maliciously force down the bid price of incineration projects to cheat for the subsidy. In such a situation, the environmental risk from incineration will further deteriorate, because they will tend not to comply with the waste emission control standards to reduce operation cost.

Second, high incineration potential provinces may not be the most effective from a cost-benefit analysis, and priority provinces for incineration could be different if the control target is different. Results showed that eastern coastal provinces with a high economic level and population usually exhibited features of both high incineration volume and incineration potential, such as Guangdong, Jiangsu, Zhejiang, Shandong and Liaoning. However, the cost-benefit efficiency of most of these provinces is not the best. Further, take the five northern provinces such as Jilin, Xinjiang, Inner Mongolia, Heilongjiang and Hebei for example, they had the best cost-benefit values regarding GWP and EP, but they had the lowest cost-benefit in HTP, ODP and TETP. Besides, they also had the highest unit cost. Therefore, if these provinces pay much attention to responding to GWP and EP, they can give priority to incineration. If these provinces pay much attention to toxic impact, they should not give priority to incineration policy. By comprehensively considering the incineration potential, unit cost and cost-benefit efficiency, Guangdong, Shanghai, Beijing, Shandong and Tianjin should be prioritized as provinces for the incineration mechanism compared to other provinces. The government should first promote incineration policies to increase incineration in these provinces.

Third, the combination of MSW sorting and recycling and incineration could eliminate the cost-benefit regional disparity and promote the MSW management problem for all Chinese provinces. As mentioned by He and Lin [5], sorting & recycling is one of the main obstacles in the waste incineration industry. The difference in MSW component is an essential factor to affect the electricity generation efficiency, thus causing provincial disparity in cost-benefit aspect. If MSW sorting and recycling was done before incineration, the incineration components for all provinces will be similar, and the regional disparity will be much smaller. For example, after the sorting of MSW, recyclable wastes such as metals, plastics, and glasses can be recycled. This can reduce emissions of toxins and heavy metals, which are primary sources to cause environmental impacts. Besides, kitchen waste can also be separated and recycled for biogas or fermentation through sorting and recycling. Kitchen waste is usually the dominant component in Chinese MSW, accounting for about 60%. Once it can be separated, the MSW component will become more stable and the low heat value will also be much improved. The good phenomenon is that source separation and recycling system has been put into the agenda in China presently. Shanghai, the largest megacity in China, just passed the first local regulation on MSW management on 1 July 2019. Four classification system, namely, hazardous waste, recyclable wastes, wet/kitchen wastes and dry/other wastes, have been put into force. Such urban recycling system needs to be further strengthened and promoted to other cities immediately. This will help conquer the existing obstacles for incineration and greatly facilitate MSW management for all provinces.

4.2. Limitations

There are three limitations in this study. First, this study selected the waste components data of a large city in a province to represent the components of this province if provincial data is not available, because it is difficult to obtain data about the composition of municipal solid waste for all 31 provinces. Second, the provincial difference between incinerators and flue gas purification technologies were not considered in this study because it is impossible to get the process data for all the incineration plants of 31 provinces. Although more accurate results can be obtained by considering the provincial difference in MSW components and incineration technology, it is a great challenge to get such information. Therefore, the above assumptions were made to realize the cost-benefit analysis of 31 Chinese provinces under such situations. Further improvements in both methods and data availability are expected to be done to increase the accuracy of the results. Finally, not all the environmental impact indicators of CML-2001 are selected in this study, so the comprehensiveness of the results may be affected by a certain degree. Moreover, if other environmental impact assessment methods such as EDIP97 and Eco-Indicator 99 are used, the results may also be a little different. Therefore, in future study, other researchers can follow these limitations to find more reliable and comprehensive results.

5. Conclusions

As an effective measure to reduce MSW volume temporally, MSW incineration has been developed rapidly in recent years, and its proportion has also increased a lot. However, barriers of cost and environmental issues impede the implementation of incineration. The environmental benefits and economic costs of MSW disposal in different provinces of China are investigated using life cycle assessment and life cycle costing methods. The following main findings can be drawn. First, the developed and populated provinces of Guangdong, Shandong, Jiangsu and Zhejiang ranked the top in incineration power generation, while less developed and not populated western provinces ranked the least. Second, Jiangsu, Guangdong, Shandong, Zhejiang and Fujian had higher MSW incineration quantities and incineration rate and showed more significant toxic impacts in Human Toxicity Potential, Ozone Layer Depletion Potential and Terrestric Ecotoxicity Potential. Third, incineration does not increase the MSW treatment cost but instead is an economic benefit from a life cycle perspective because of the consideration of electricity sale. Finally, cost-benefit analysis exhibits an enormous difference regarding different environmental impacts. The northern provinces of Jilin, Xinjiang, Inner Mongolia, Heilongjiang and Hebei, had the best cost-benefit values regarding GWP and EP, but the lowest cost-benefit in HTP, ODP and TETP. In contrary, the developed provinces of Guangdong, Chongqing, Shanghai, and Tianjin exhibited the highest cost-benefit efficiency in toxic impacts in HTP, ODP and TETP. These findings can provide academic support for Chinese provinces to understand their incineration potential and situation, and eventually, to make a decision about whether to choose incineration policy or not.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/2/697/s1, Table S1: Annual amount of MSW incineration in 31 Chinese provinces. Table S2: MSW composition in 31 Chinese provinces. Table S3: Power generation structure of 31 Chinese provinces. Table S4: Life cycle inventory of MSW incineration. Table S5: LCC of MSW incineration and landfill.

Author Contributions: Conceptualization, H.D.; methodology, S.Y. and H.D.; software, S.Y.; validation, H.D. and S.Y.; formal analysis, S.Y. and H.D.; investigation, S.Y. and H.D.; resources, H.D.; data curation, H.D.; writing—original draft preparation, S.Y.; writing—review and editing, H.D.; visualization, S.Y.; supervision, H.D.; project administration, H.D.; funding acquisition, H.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the National Natural Science Foundation of China (Grant No. 71974126, 71603165, 71690241).

Acknowledgments: We would like to thank Ade Brian Mustafa for his help in language editing, and the support of Shanghai Environmental Key Lab of Environmental Data and Intelligence.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. National Bureau of Statistics. *China Energy Statistics Yearbook*; China Statistics Press: Beijing, China, 2018. Available online: http://www.stats.gov.cn/tjsj/ndsj/2018/indexch.htm (accessed on 8 July 2019).
2. National Development and Reform Commission. *13th Five-Year Plan for the Construction of Harmless Treatment Facilities for Urban Domestic Wastes*; National Development and Reform Commission: Beijing, China, 2016. Available online: http://www.ouhai.gov.cn/art/2018/10/18/art_1531074_21988609.html (accessed on 2 January 2019).
3. Lin, P.-Y.; Lai, S.-P.; Wang, M.-C.; Liang, J.-J.; Chiang, C.-F.; Kuo, H.-W. Environmental health risks perception, attitude, and avoidance behaviour toward municipal solid waste incinerator. *Int. J. Environ. Health Res.* **2018**, *28*, 159–166. [CrossRef] [PubMed]
4. Vongdala, N.; Tran, H.-D.; Xuan, T.; Teschke, R.; Khanh, T. Heavy metal accumulation in water, soil, and plants of municipal solid waste landfill in Vientiane, Laos. *Int. J. Environ. Health Res. Public Health* **2019**, *16*, 22. [CrossRef] [PubMed]
5. He, J.; Lin, B. Assessment of waste incineration power with considerations of subsidies and emissions in China. *Energy Policy* **2019**, *126*, 190–199. [CrossRef]
6. Aracil, C.; Haro, P.; Fuentes-Cano, D.; Gomez-Barea, A. Implementation of waste-to-energy options in landfill-dominated countries: Economic evaluation and GHG impact. *Waste Manag.* **2018**, *76*, 443–456. [CrossRef]
7. Khandelwal, H.; Dhar, H.; Thalla, A.K.; Kumar, S. Application of life cycle assessment in municipal solid waste management: A worldwide critical review. *J. Clean. Prod.* **2018**, *209*, 630–654. [CrossRef]
8. Cherubini, F.; Bargigli, S.; Ulgiati, S. Life cycle assessment (LCA) of waste management strategies: Landfilling, sorting plant and incineration. *Energy* **2009**, *34*, 2116–2123. [CrossRef]
9. Arena, U.; Mastellone, M.L.; Perugini, F. The environmental performance of alternative solid waste management options: A life cycle assessment study. *Chem. Eng. J.* **2003**, *96*, 207–222. [CrossRef]
10. Maria, F.D.; Fantozzi, F. Life cycle assessment of waste to energy micro-pyrolysis system: More significantCase study for an Italian town. *Int. J. Energy Res.* **2004**, *28*, 449–461. [CrossRef]
11. Turconi, R.; Butera, S.; Boldrin, A.; Grosso, M.; Rigamonti, L.; Astrup, T. Life cycle assessment of waste incineration in Denmark and Italy using two LCA models. *Waste Manag. Res.* **2011**, *29*, S78–S90. [CrossRef]
12. Eriksson, O.; Finnveden, G.; Ekvall, T.; Björklund, A. Life cycle assessment of fuels for district heating: A comparison of waste incineration, biomass-and natural gas combustion. *Energy Policy* **2007**, *35*, 1346–1362. [CrossRef]
13. Finnveden, G.; Johansson, J.; Lind, P.; Moberg, Å. Life cycle assessment of energy from solid waste—Part 1: General methodology and results. *J. Clean. Prod.* **2005**, *13*, 213–229. [CrossRef]
14. Zaman, A.U. Comparative study of municipal solid waste treatment technologies using life cycle assessment method. *Int. J. Environ. Sci. Technol.* **2010**, *7*, 225–234. [CrossRef]
15. Mølgaard, C. Environmental impacts by disposal of plastic from municipal solid waste. *Resour. Conserv. Recycl.* **1995**, *15*, 51–63. [CrossRef]
16. Riber, C.; Bhander, G.S.; Christensen, T.H. Environmental assessment of waste incineration in a life-cycle-perspective (EASEWASTE). *Waste Manag. Res.* **2008**, *26*, 96–103. [CrossRef] [PubMed]
17. Beylot, A.; Muller, S.; Descat, M.; Ménard, Y.; Villeneuve, J. Life cycle assessment of the French municipal solid waste incineration sector. *Waste Manag.* **2018**, *80*, 144–153. [CrossRef]

18. Chen, D.; Christensen, T.H. Life-cycle assessment (EASEWASTE) of two municipal solid waste incineration technologies in China. *Waste Manag. Res.* **2010**, *28*, 508–519. [CrossRef]
19. Dong, J.; Chi, Y.; Zou, D.; Fu, C.; Huang, Q.; Ni, M. Comparison of municipal solid waste treatment technologies from a life cycle perspective in China. *Waste Manag. Res.* **2014**, *32*, 13–23. [CrossRef]
20. Hong, R.; Wang, G.; Guo, R.; Cheng, X.; Liu, Q.; Zhang, P.; Qian, G. Life cycle assessment of BMT-based integrated municipal solid waste management: Case study in Pudong, China. *Resour. Conserv. Recycl.* **2006**, *49*, 129–146. [CrossRef]
21. Zhao, W.; Van Der Voet, E.; Zhang, Y.; Huppes, G. Life cycle assessment of municipal solid waste management with regard to greenhouse gas emissions: Case study of Tianjin, China. *Sci. Total Environ.* **2009**, *407*, 1517–1526. [CrossRef]
22. Norris, G.A. Integrating life cycle cost analysis and LCA. *Int. J. Life Cycle Assess.* **2001**, *6*, 118–120.
23. Massarutto, A.; de Carli, A.; Graffi, M. Material and energy recovery in integrated waste management systems: A life-cycle costing approach. *Waste Manag.* **2011**, *31*, 2102–2111. [CrossRef] [PubMed]
24. Martinez-Sanchez, V.; Kromann, M.A.; Astrup, T.F. Life cycle costing of waste management systems: Overview, calculation principles and case studies. *Waste Manag.* **2015**, *36*, 343–355. [CrossRef] [PubMed]
25. Dong, J.; Chi, Y.; Zou, D.; Fu, C.; Huang, Q.; Ni, M. Energy–Environment–Economy assessment of waste management systems from a life cycle perspective: Model development and case study. *Appl. Energy* **2014**, *114*, 400–408. [CrossRef]
26. Emery, A.; Davies, A.; Griffiths, A.; Williams, K. Environmental and economic modelling: A case study of municipal solid waste management scenarios in Wales. *Resour. Conserv. Recycl.* **2007**, *49*, 244–263. [CrossRef]
27. Martinez-Sanchez, V.; Tonini, D.; Møller, F.; Astrup, T.F. Life-cycle costing of food waste management in Denmark: Importance of indirect effects. *Environ. Sci. Technol.* **2016**, *50*, 4513–4523. [CrossRef] [PubMed]
28. Komilis, D.; Evangelou, A.; Giannakis, G.; Lymperis, C. Revisiting the elemental composition and the calorific value of the organic fraction of municipal solid wastes. *Waste Manag.* **2012**, *32*, 372–381. [CrossRef]
29. Finnveden, G.; Hauschild, M.Z.; Ekvall, T.; Guinée, J.; Heijungs, R.; Hellweg, S.; Koehler, A.; Pennington, D.; Suh, S. Recent developments in life cycle assessment. *J. Environ. Manag.* **2009**, *91*, 1–21. [CrossRef]
30. Consoli, F. Guidelines for Life-Cycle Assessment. *Environ. Sci. Pollut. Res.* **1994**, *1*, 55.
31. ISO. *ISO 14040-2006: Environmental Management–Life Cycle Assessment–Principles and Framework*; International Organization for Standardization (ISO): Geneva, Switzerland, 2006.
32. ISO. *ISO 14044-2006: Environmental Management–Life Cycle Assessment–Requirements and Guidelines*; International Organization for Standardization (ISO): Geneva, Switzerland, 2006.
33. Cheng, J.; Dong, X. Analysis on Physical and Chemical Characteristics of Domestic Waste in Shanghai. *Environ. Sanit. Eng.* **2017**, *4*, 36–40.
34. Ding, K. Optimize Domestic Waste Incineration System by Using Life Cycle Assessment Method. Master's Thesis, Tongji University, Shanghai, China, 2008.
35. Huber, F.; Laner, D.; Fellner, J. Comparative life cycle assessment of MSWI fly ash treatment and disposal. *Waste Manag.* **2018**, *73*, 392–403. [CrossRef]
36. Damgaard, A.; Riber, C.; Fruergaard, T.; Hulgaard, T.; Christensen, T.H. Life-cycle-assessment of the historical development of air pollution control and energy recovery in waste incineration. *Waste Manag.* **2010**, *30*, 1244–1250. [CrossRef] [PubMed]
37. Sundqvist, J.-O. *Life Cycles Assessments and Solid Waste: Guidelines for Solid Waste Treatment and Disposal in LCA*; AFR, Naturvårdsverket: Stockholm, Sweden, 1999.
38. Tang, Z. Study on Greenhouse Gas Emission and Its Emission Reduction Strategy of Urban Domestic Waste Management System in Changsha City. Master's Thesis, Hunan University, Changsha, China, 2014.
39. Stanisavljevic, N. Temporal and spatial characteristics of urban domestic waste generation and treatment from 1979 to 2016. *Chin. Environ. Sci.* **2018**, *38*, 235–245.
40. Chen, A.; Chen, C.; Tao, X.; WAng, G. Life Cycle Assessment of domestic waste sanitary landfill in Changsha city. *Environ. Sci. Technol.* **2013**, *S2*, 390–395.
41. Chen, J.; Liu, D. Analysis of thermal value monitoring of domestic waste in Xiamen city and its Influencing factors. *Environ. Sanit. Eng.* **2010**, *18*, 14–15.
42. Duan, L.; Sheng, L.; Wang, Z. Analysis on current situation of domestic waste treatment in Changchun city and countermeasures. *Environ. Sanit. Eng.* **2004**, *12*, 168–170.

43. Gao, Y.; Qi, C. The Status Quo of urban domestic waste in Zhengzhou city and countermeasures. *Environ. Sanit. Eng.* **2008**, *16*, 25–27.
44. Guo, B.; Zhou, B.; Su, Y.; Yu, L. Present situation and countermeasures of Manag. and disposal of domestic waste in Shijiazhuang city. In Proceedings of the China Environmental Science Society Solid Waste Professional Committee Annual Meeting and Solid Waste Recycling and Circular Economy Conference, Beijing, China, 20–22 October 2006; pp. 141–143.
45. Guo, G.; Wei, W.; He, X. Analysis on the change trend of domestic garbage characters and diversification of treatment technology in Nanning city. *Guangxi Town Constr.* **2013**, *9*, 124–127.
46. Guo, H.; Zhang, C.; Li, D.; Guo, J. Application of modern management technology in the optimization of domestic waste treatment scheme in Haikou city. *Environ. Sanit. Eng.* **2007**, *15*, 7–9.
47. Kang, X.; Wang, S. Household garbage survey and reduction analysis in Nanjing. *Environ. Sci. Manag.* **2009**, *34*, 46.
48. Li, Y.; Wang, F.; Chen, J.; Zheng, J. Study on the treatment and utilization effect of urban domestic waste in Yinchuan city. *J. Agric. Environ. Sci.* **2000**, *19*, 145–147.
49. Lu, X.; Yang, D.; Yao, J. Study on the factors affecting the thermal value of domestic waste in Taiyuan city. *Environ. Sanit. Eng.* **2018**, *26*, 29–32.
50. Wang, G.; Zhang, H.; Wang, D.; Zhang, L.; Sun, W. Analysis of composition and characteristics of domestic garbage in urban areas of Beijing. *Environ. Eng.* **2018**, *36*, 132–136.
51. Wu, X. Analysis and Treatment of the Status Quo of Domestic Waste in Chengdu. Master's Thesis, Southwest Jiao Tong University, Chengdu, China, 2007.
52. Xu, Y.; Yang, X.; Zhou, J.; Chen, L.; Dong, S.; Li, M.; Song, H. Analysis and treatment of spring domestic garbage in Kunming. *Renew. Energy* **2008**, *26*, 93–96.
53. Yang, N.; Shao, L.; He, P. Analysis of moisture content and characteristics of municipal solid waste components in China. *Chin. Environ. Sci.* **2018**, *38*, 1033–1038.
54. Zhao, J.; Sun, W.; Yang, J.; Jiang, Q. Analysis of composition and characteristics of urban domestic waste in Hohhot city. *J. Inn. Mong. Univ.* **2005**, *36*, 100–103.
55. Astrup, T.; Møller, J.; Fruergaard, T. Incineration and co-combustion of waste: Accounting of greenhouse gases and global warming contributions. *Waste Manag. Res.* **2009**, *27*, 789–799. [CrossRef]
56. Gluch, P.; Baumann, H. The life cycle costing (LCC) approach: A conceptual discussion of its usefulness for environmental decision-making. *Build. Environ.* **2004**, *39*, 571–580. [CrossRef]
57. Shanghai Academy of Environmental Sciences. *Environmental Impact Report of Shanghai Fengxian Municipal Solid Waste Disposal Center Project*; Shanghai Dongshitang Renewable Energy Co, Ltd.: Shanghai, China, 2013.
58. Lin, C. Cost analysis of fly ash treatment in waste incineration plants applicable to GB16889-2008. *Environ. Sanit. Eng.* **2010**, *18*, 50–52.
59. Shi, D.; Zhang, X.; Chen, Y.; Ding, Y.; Lv, Q. Cost analysis and control of domestic waste landfill treatment—Taking Changzhou Municipal Waste Treatment Center as an example. *Environ. Sanit. Eng.* **2012**, *20*, 37–39.
60. Zeng, X. Cost analysis of waste incineration power generation project. *Environ. Sanit. Eng.* **2014**, *22*, 57–60.
61. National Development and Reform Commission. Notice of the National Development and Reform Commission on Improving the Price Policy of Waste Incineration Power Generation. 2012. Available online: http://law391.infoeach.com/view-MzkxfDExMzU1Mg==.html (accessed on 2 June 2019).
62. Havukainen, J.; Zhan, M.; Dong, J.; Liikanen, M.; Deviatkin, I.; Li, X.; Horttanainen, M. Environmental impact assessment of municipal solid waste management incorporating mechanical treatment of waste and incineration in Hangzhou, China. *J. Clean. Prod.* **2017**, *141*, 453–461. [CrossRef]
63. Guo, Y.; Glad, T.; Zhong, Z.; He, R.; Tian, J.; Chen, L. Environmental life-cycle assessment of municipal solid waste incineration stocks in Chinese industrial parks. *Resour. Conserv. Recycl.* **2018**, *139*, 387–395. [CrossRef]
64. Jeswani, H.K.; Smith, R.W.; Azapagic, A. Energy from waste: Carbon footprint of incineration and landfill biogas in the UK. *Int. J. Life Cycle Assess.* **2013**, *18*, 218–229. [CrossRef]
65. Assamoi, B.; Lawryshyn, Y. The environmental comparison of landfilling vs. incineration of MSW accounting for waste diversion. *Waste Manag.* **2012**, *32*, 1019–1030. [CrossRef]