Spatial-temporal Analysis for PPP Waste-to-energy Projects in China

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ABSTRACT: The accelerating urbanization and improvement of living standards have greatly increased the municipal solid waste (MSW) generation in China. Public private partnership (PPP) widely used in the field of waste-to-energy (WTE) industry can decrease the volume of MSW, generate power and address the serious environmental problems caused by MSW. The advantage of PPP model can be expressed in its inherent incentive, expanding product quality, improving capacity utilization, saving transaction costs, improving efficiency of WTE industry. We collect data of municipal solid waste disposal fee from 69 PPP WTE projects of 231 operating projects, covering 30% of all PPP WTE operating projects in 29 provinces from 1999–2016, the spatial-temporal model is built to analyze the waste-to-energy environmental efficiency in PPP waste-to-energy industry.

INTRODUCTION

With rapid economic growth and massive urbanization, China faces the problem of municipal solid waste (MSW) disposal and the pressing need for development of alternative energy. Increasingly growing populations have accelerated the generation rate of Municipal Solid Waste (MSW) in cities, causing this issue to become more and more crucial both for the daily management and long term sustainability of cities. In 1980, the generation of Municipal Solid Waste Removal (MSWR) is 31 million tons in China, meanwhile urbanization rate is 19.4%, thirty-five years later, MSWR increasing to 192 million tons in China, and urbanization rate becomes 56.1%, nearly three times than in 1980 [data from China Statistical Yearbook, (1980–2015)].

The hierarchy of methodologies for dealing with MSW consists of three main treatment methods: (1) Landfilling, (2) Incineration, (3) Composting. Waste-to-Energy (WTE) technologies seem to be an better option to tackle the growing waste management problems in many developing countries. Waste-to-energy (WTE) incineration which recovers energy from discarded MSW and produces electricity and/or steam for heating, is recognized as a renewable source of energy. At present, MSW generation in Asia surpasses 1 million tons/day, and it is estimated that in 2025, this figure will increase to 1.8 million tons/day [1]. In 2014, only approximately 13% of MSW generated in China is disposed in WTE facilities [2]. With the significant benefits of environmental quality, the reduction of greenhouse gas (GHG) emissions, and government policies and financial incentives as a renewable energy source, WTE incineration industry is expected to experience significant growth in the coming decade, make greater contribution to supplying renewable energy in China.

A number of WTE incineration plants have been developed in China through PPP;BOT;BOO arrangement, which is regarded as an effective means to attract funds from the private sector to provide public works and services and to improve efficiency in the delivery of such works and services [4]. Public private partnership (PPP) play an important role in bringing private sector competition to public monopolies in infrastructure development, it received increasing attention from academia and policy-makers [5]. With encouragement from Chinese Ministry of Finance, it becomes widely accepted from central government to local government. Public private partnership (PPP) has been widely used as an infrastructure delivery model by many governments, including toll highway, freeway, bridge,
culvert and WTE plants [6], it was often the proposed response to reduce the cost of waste management and improve service quality [7]. One of the reasons for the popularity of PPP is that governments can simultaneously attract private firms and claim that they are not privatizing. Independently of these political reasons, PPP have the potential to increase efficiency and improve resource allocation [8].

Private partner have more experience for constructing and maintenance, for example, shorter construction time, lower construction cost, and lower operation and maintenance cost. PPP projects are quite common in many developed and developing countries, and China has accelerated PPP WTE plants during recent 10 years. China is now the world’s largest MSW generator surpassed the United States since 2008 [9]. Until 2014, the city’s municipal solid waste treatment rate reached 96.4%, harmless treatment rate reached 91.8%, 653 cities manufacture 179 million tons of municipal solid waste, 188 WTE incineration plants provide the capacity of 533,000 tons/day [10].

This poses enormous challenges for environmental protection and sustainable development. The state’s 18th five-year plan (20013–2018) has allocated approximately 200 billion RMB to be invested in environmental protection. All aspects of China’s waste management systems must undergo great changes in order to meet this challenge. China’s waste-to-energy (WTE) power generation industry has been ushering in the golden period of development, the main driving factors include: China's cities waste treatment demand continued to flourish; waste-to-energy (WTE) accounts for a relatively low proportion, continue to benefit from the government industry support policies; large-scale WTE plants trend; WTE equipment localization. The distribution of WTE incineration plants has great spatial and temporal variability. China’s vast territory, unbalanced economic development, people’s living standards are very different, so the composition of urban life is not the same, the MSW disposal methods are also different. The western region is sparsely populated, mainly in landfill, the eastern region of the shortage of land resources, mainly to incineration.

As of February 2016, the number of garbage power plants in the country ranked the first three provinces of Zhejiang, Jiangsu and Guangdong, respectively, reached 40,25,19, while Gansu, Xinjiang, Ningxia only one, Qinghai, Tibet are zero. Waste incineration in the harmless, reduction, resource-saving treatment for the community to provide a full range of services, at the same time, its damage for environmental pollution can not be ignored, it is necessary to attach importance to short-term interests of long-term interests, not only attach importance to economic efficiency but also pay attention to ecological benefits. Waste incineration in turning can make waste into treasure, reducing land resource consumption, but also carry undesirable output such as emissions of waste gas, waste water, fly ash. It is necessary to introduce the concept of efficiency into the WTE incineration power generation industry. Through the spatial distribution and time series growth of the waste incineration power plant, the environmental efficiency in different time and different regions can be calculated. In this paper, with DEA (Data Envelopment Analysis) evaluation and decision-making method, the models is built for evaluation indicators, collecting data of municipal solid waste disposal fee from 69 PPP WTE projects of 231 operating projects, covering 30% of all PPP WTE operating projects in 29 provinces from 1999~2016. The results of the incineration industry layout and industry management to provide the basis for decision-making. Methodology

### DEA (Data Envelopment Analysis) Model

DEA is a common used nonparametric mathematical programming technique, to evaluate the relative efficiencies of a set of peer DMUs involving mul-

<table>
<thead>
<tr>
<th>Methods</th>
<th>Landfilling</th>
<th>Incineration</th>
<th>Composting</th>
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<tbody>
<tr>
<td>Investment (yuan/tons)</td>
<td>60,000~100,000</td>
<td>350,000~650,000</td>
<td>50,000~200,000</td>
</tr>
<tr>
<td>Maintenance (yuan/tons)</td>
<td>50~80</td>
<td>50~150</td>
<td>50~100</td>
</tr>
<tr>
<td>Volume reducing (yuan/tons)</td>
<td>5%~10%</td>
<td>80~90%</td>
<td>10~20%</td>
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### Table 1. Comparing with Three MSW Treatments.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Landfilling</th>
<th>Incineration</th>
<th>Composting</th>
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<tbody>
<tr>
<td>pros</td>
<td>simple process, low cost in construction, retaining and recycling</td>
<td>save land, reduction, resource-saving, generate electricity</td>
<td>micro-organisms, harmless, low fee</td>
</tr>
<tr>
<td>cons</td>
<td>occupy land</td>
<td>large investment, expensive operation fee, PCDDs</td>
<td>slow decomposition, accumulation of heavy metals, location limited</td>
</tr>
</tbody>
</table>

Data resource [3].
On the contrary, if \((y, b) \in P(x)\) and \(b' \in b\), we can deduce \((y, b') \in P(x)\), then \(P(x)\) satisfies the strong disposability of undesired outputs. When the environmental technology satisfies the strong disposable characteristic, its corresponding possible output set is:

\[
p'(x) = \{(y, b) | \sum_{j=1}^{n} z_j x_j \leq x, \sum_{j=1}^{n} z_j y_j \geq y, \sum_{j=1}^{n} z_j b_j \geq b, z_j \geq 0\}
\]

The existing directional distance function and Malmquist-Luenberger index are improved by \(P'(x)\) as shown in Equation (2) to establish the measurement model of WTE.

Directional distance function is a generalization of the Shephard output distance function. In order to achieve maximum expected output and minimum undesired output, this paper uses the output-based directional distance function basic form:

\[
D(x, y, b; y) = \sup \{\beta : (y, b) + \beta g \in p'(x)\}
\]

Where \(\beta\) is the maximum possible quantity of WTE output growth and contaminant reduction, and \(g^+(y, b)\) is the direction vector of output expansion, \(g^+(y, -b)\), that is, with the increase in the proportion of expected output.

According to Equation (3), the solution model of directional distance function is constructed, as shown in Equation (4).

\[
\rightarrow D_0'(x)(x^{i,k'}, y^{i,k'}, b^{i,k'}, y^{i,k'}, -b^{i,k'}) = \max \beta \\
\forall i, \sum_{k=1}^{N} z_{k,i} y_{k,m} \geq (1+\beta) y_{k,i}, m = 1, 2, \cdots, S \\
\sum_{k=1}^{N} z_{k,b_{ki}} b_{ki} \geq (1-\beta) b_{ki}, i = 1, 2, \cdots, K \\
\sum_{k=1}^{N} z_{k,x_{kn}} \leq x_{k,n}, n = 1, 2, \cdots, M \\
z_{k} \geq 0, k = 1, 2, \cdots, N
\]

\((x^{i,k'}, y^{i,k'}, b^{i,k'})\) is the input, expected output and the expected decision-making unit output at the time \(i\), and the production possibility set for other decision-making units in the same period. Therefore, we can solve the planning problem shown in Equation (4), and calculate the distance of the \((DMU_j)\) to the environmental frontier producer in a certain period.
The existing efficiency measure models like that of joint weakly disposable distance function and SBM model mainly based on the thoughts of environmental efficiency. However, Waste-to-energy environmental efficiency (WTEEE) at present China could not meet the demand of either model as the null combination of pollution output (unexpected output) and joint weakly disposability are two necessities for two models respectively. Therefore, another way must be found to measure the WTEEE. The strong disposability thought provides a solution for measuring China’s MSW environmental efficiency [15].

\[
\text{WTEEE} = \frac{1}{1 + D(x, y, b; g)}
\]

Notes: “x” is input variable; “y” is the expected output variable; “b” is the unexpected output variable;

\[
D(x, y, b; g) = \sup \{ \beta : (y, b) + \beta g \in p^*(x) \}, \quad p^*(x) = \left\{ (y, b) \mid \sum_{j=1}^{n} z_j x_j \leq x, \sum_{j=1}^{n} z_j x_j \geq y, \sum_{j=1}^{n} z_j b_j \leq y, z_j \geq 0 \right\}
\]

**Variable Definition and Data Analysis**

After comprehensive consideration of the existing research achievements and the characteristics of WTEEE, the indexes in this paper are selected as follows (Table 2).

It is easy to find out from the map that northeast and northwest of China WTE incineration plants are pink blocks, (below to 5 in every province, such as Heilongjiang, Neimengu, Xinjiang Province) and in South-east there are two largest WTE Incineration plants(red & blue block, including Zhejiang, Guangdong, Shandong Province). In the center of map?there are yellow and green blocks, and WTE Incineration plants from 6~20, ranks middle in all provinces. MSW is obviously connected with social and economic developments.

Almost all of WTE power plants have been developed in China through public private partnership (PPP) arrangement, which is regarded as an effective means to attract funds from the private sector to provide public works and services and to improve efficiency (example, shorter construction time, lower construction cost, and lower operation and maintenance cost) in the delivery of such works and services [4]. PPP WTE incineration plants which cover build, operate and transfer arrangements for merely 20–30 years. Unlike other types of PPP projects, a PPP WTE incineration project has two main sources of income: MSW treatment subsidy and power generation income. In practice, the income from MSW treatment generally depends on the per-unit subsidy and the adjusted quantity of the treated MSW [4]. Subsidy for each PPP WTE incineration projects should be adjust every 3~5 years, and it differs a lot by social, economic and environment factors. Since 1999~2015, MSW disposal fee has decreased more than 50%, Shanghai Jiangqiao waste incineration project was built in 1999, MSW disposal fee was 213 yuan/ton before 2008, a decade later in 2009 that is below to 100, and 90 in 2012, in 2015 Bengbu and Gaoyou WTE incineration projects are below 30 yuan through open tender, respectively 26.8 yuan/ton and 26.5 yuan/ton, compared with the Shanghai Jiangqiao project nearly 5times lower [16].

Figure 3 are the MSW disposal fee in 1999~2016,most of these datas are collected from Financial statements, listing announcement and IPO Papers of waste Incineration listed Company (including China Everbright

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<th>Table 2. Measure index of WTEEE.</th>
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<td><strong>First-grade indexes</strong></td>
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<td>Input</td>
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<td>Output</td>
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There are 69 samples of PPP WTE Incineration projects from 26 provinces including northeast, north-west, southeast, southwest and center part of China, from the first PPP WTE projects in Shanghai, and the blooming development in 2016, more than 30 projects are announced and planning.

1. The trends of MSW disposal fee is a decreasing curve. It means WTE environmental efficiency has improved directly. On the one hand, the trend that WTE power generation has substituted landfill treatment. In addition, the use of mechanical furnace, fluidized bed waste incineration furnace mature technology, revenue stability, with the construction of WTE power plants, China-made equipment, complete, standardized, management and other aspects have made great progress, the

Figure 1. 1980–2015 Urbanization rate and MSWR in China.

Figure 2. Incineration plant covering in China.
construction period can be shortened to less than two years, more than half of the developed countries. This also makes the cost of construction of domestic WTE plant, operation and maintenance costs continued to significantly lower.

2. At the same time, the consumption level of residents will increase, the calorific value of MSW will continue to increase, the coverage of urban and rural environmental health services continues to expand, the amount of household waste to be burned will be increased accordingly, the future which is expected to WTE power plant revenue is growing. Therefore, large-scale solid waste power plant project will become a popular project, more and more private sectors influx into WTE industry, Market capacity and management capacity growing simultaneously.

3. PPP model have great advantage to use private
sectors in the capital, technology, management experience and benefit, to choose the private sectors by tender from open market.

4. MSW disposal fee has the spatial effect, especially in 2015 and 2016. In Xinjiang Province, the MSW disposal fee is 238 yuan/ton, and average price in Shandong and Jiangsu Province are lower than 50 yuan/ton. The curve trends to decrease, but in 2008~2009, some fluctuations moved up and down in the curve, and then the financial crisis broke out, many projects put off or canceled, unpredictable risks bring about a lack of competition.

Based on all these factors, the WTE environment management can perform better to describe the efficiency and effectivity of PPP WTE industry amendments. Measurement model can be built to study its spatial heterogeneity, as well as by temporal differences. Many scholars have probed into the path of agricultural water environmental improvement from the perspective of environmental efficiency [15,17,18], but seldom references can be found to study the environmental efficiency in WTE field. In fact, waste-to-energy environmental efficiency (WTEEE) can be better improved with the coordinated development of economy and environment.

CONCLUSIONS AND SUGGESTION

The result of China’s Waste-to-energy environmental efficiency (WTEEE) measurement in 2013 can be obtained through Equation (1) and Figure 4 is the bitmap. The bitmap clearly shows that the spatial distribution characteristics of Waste-to-energy environmental efficiency in China is unbalanced and the distribution pattern can be described to be gradually decreased from east to west, north to south. There are 5 main gathering area: Eastern coastal developed regions; Central regions; Bohai Sea and the Northeast regions; southwest regions; Northwest and Mongolia regions. The average efficiency values of these regions are 0.918, 0.861, 0.719, 0.637, 0.482 in 2005~2015 (Hong Kong, Macao and Taiwan regions not include).

1. The disposable direction distance function was applied to measure the efficiency of waste-to-energy environmental efficiency (WTEEE) during 2005~2015 in China, and the spatial econometric model was further used to analyze the space effect of WTEEE as well as its influencing factors. As a result, two main conclusions were drawn from the research. Firstly, environment efficiency in 29 provinces of China (Hong Kong, Macao and Taiwan regions not include) is spatially related. The two spatial distribution features are unbalanced spatial distribution which presents gradually decreased distribution pattern from east to west and spatial aggregation where eastern coastal areas are mostly high while the majority of Northwest and Mongolia regions stay in the low part.

2. Secondly, regional structural differences among neighboring provinces also influence the WTEEE apart from the mutual impact factor. Regional structural differences behave in many aspects such as economic development level of rural area, industrialization in rural region, MSW input and treatments, environmental infrastructure, environmental regulation, etc. These spatial influence factors perform their influences to WTEEE in their own way of which the coordination of the above elements can be benefit to the improvement.

3. Public Private Partnership (PPP) is a form of institutional arrangements involving infrastructure. According to the understanding of institutional economics, effective institutional arrangement is the key to promote economic growth, improve the efficiency changes. First of all, the system should have the inherent incentive, and thus the formation of power to expand the production of the product quality and quality can be sustained; Second, the system should have inherent savings in transaction costs tendencies, especially in the “external” in the ubiquitous modern economy, reducing the transaction costs of society as a whole is of particular significance [19]. The blooming PPP WTE plants and decreasing subsidy price promote in order to reach the maximum the total social welfare with the public sector, the private sector and urban residents.

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