

## MUNICIPAL SOLID WASTE MANAGEMENT IN HANGZHOU, CHINA

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## 1. Introduction

Hangzhou city is the capital city of Zhejiang province and it is located in East coast of China approximately 180 km South West from Shanghai. There are approximately 7 million inhabitants in the city (Hangzhou government statistics 2014). The city is well known in China for its green nature and many tourist travel to Hangzhou to stroll along the west lake, which can be seen as main attraction of the city. Hangzhou is also more widely known for its high quality tea.

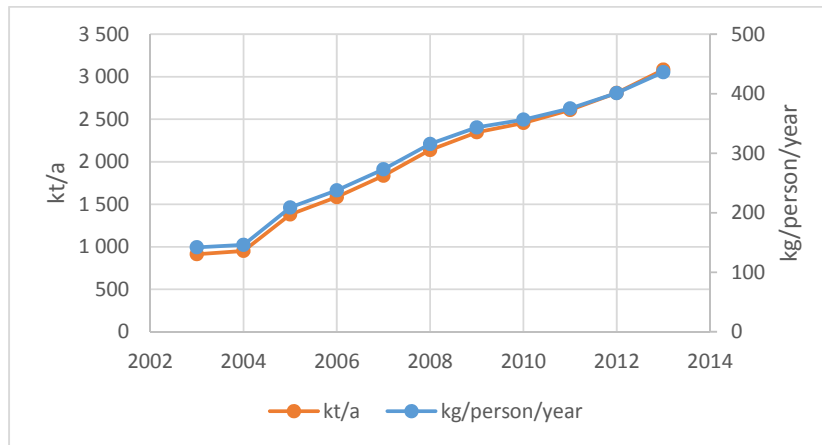
The economic development of China has seen a rapid increase in the recent years and China has become the largest producer of Municipal solid waste, producing MSW 155 million metric tons in 2014 (National Bureau of Statistic of China 2005) and 172 million metric tons in 2013 (National Bureau of Statistic of China 2014). This mass does not include the MSW fractions collected by waste pickers, which is estimated to be 8-10% of the total MSW (Chen et al. 2010). MSW management in China is still heavily relying on disposing MSW into landfills and in 2010 the share of MSW disposed into landfills was 80% (Dong et al. 2014). Meanwhile in Hangzhou, which is seen as one of the most developed area in China the share of MSW disposed in landfills was 50% in 2010 (Chi et al. 2014).

The Chinese MSW is characterized by high share of food waste which results to high moisture content of MSW (Chen et al. 2010). The high content of food waste means that when MSW is disposed into landfills high amount of landfill gas released causing global warming. Since most of the MSW is disposed into landfills in China there is a great potential to decrease emissions caused by MSW management.

This paper describes the MSW management in Hangzhou to date and future trends.

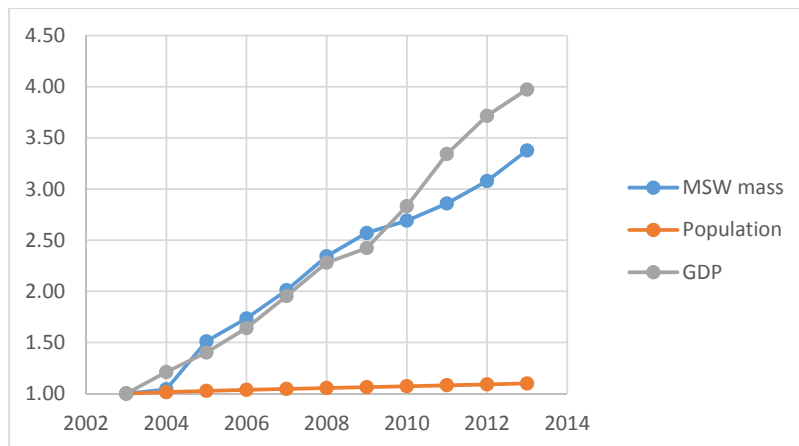
## 2. MSW amount

According to the statistics, the MSW amount in Hangzhou city has been increasing very rapidly during the recent years (Hangzhou Municipal Solid Waste Disposal Supervision Center 2014). The annual increase rate has been on average 10% and the MSW mass has increased by 240% in ten years, **Figure 1**. The total amount of MSW in 2013 was 3 100 kt. The MSW generation rate per person per year has also followed similar trend.



**Figure 1.** Development of total MSW mass amount and generated MSW per person and year. (Hangzhou Municipal Solid Waste Disposal Supervision Center 2014, Hangzhou government statistics 2014).

The MSW generation in Hangzhou has followed the rapid development of gross domestic product (GDP) rather than population growth, **Figure 2**. For example, Chen et al. (2010) have also recognized similar relation in MSW development in China.



**Figure 2.** Development of MSW generation, population and total gross domestic product (GDP) in Hangzhou showing relative values to the value in year 2003 (Hangzhou Municipal Solid Waste Disposal Supervision Center 2014, Hangzhou government statistics 2014).

### 3. MSW properties

Hangzhou MSW composition is characterized by high amount of food waste. It has fluctuated a lot but the food waste still composes clearly the largest waste fraction. Other two main fractions of waste are paper and plastics which might be mainly coming from packaging material. Together these three waste fractions have comprised 70-90% of the MSW in Hangzhou. However, it is unclear whether this waste compositions include the MSW collected and recycled by waste pickers. Most likely the composition of waste has been done for waste going to landfill or incineration. Then the waste collected and recycled by waste pickers is not included in the composition studies.

**Table 1.** Composition of Hangzhou MSW during 2005-2011.

	2005	2006	2007	2008	2009	2010	2011	Average
Food waste	64	60	47	60	51	57	56	57
Paper	10	11	8	11	11	9	16	11
Plastic	14	18	18	18	27	19	17	19
Textile	2	2	5	2	4	3	2	3
Wood and bamboo	1	1	2	1	1	2	2	1
Dirt / dust	6	4	4	6	3	4	2	4
Ceramics	1	1	0	1	1	0	1	1
Glass	2	2	1	1	2	1	2	2
Metal	1	1	0	0	1	0	1	1
Other	0	0	0	0	0	0	0	0
Mixed	0	0	14	0	0	4	1	3
Total	100	100	100	100	100	100	100	100

**Table 2** presents the composition and moisture content of separately collected food waste and other waste in area of the Hangzhou main districts where there is separate collection for food waste as well as the properties of mixed waste from area of the main districts where there is no separate collection of food waste and all waste is collected as mixed. The source separated food waste still contains almost 30% impurities mainly paper and plastic waste. The source separated other waste has lower organic matter than the mixed waste (including all the waste fractions). The moisture content of other waste is 25% lower than mixed waste due to separate collection of food waste.

**Table 2.** Properties of mixed waste, food waste and other waste from Hangzhou main district (Hangzhou Municipal Solid Waste Disposal Supervision Center 2014)

	Organic matter	Inorganic		Recyclables						Moisture
	Meat and plants	Clay	Ceramic	Paper	Plastic	Textile	Glass	Metal	Wood	
2012	%	%	%	%	%	%	%	%	%	%
Mixed waste	56	5	3	11	15	4	3	2	1	58
Food waste	76	0	0	8	11	1	3	1	0	71
Other waste	49	2	2	16	19	6	1	3	1	44
2013	%	%	%	%	%	%	%	%	%	%
Mixed waste	54	4	2	12	16	5	3	3	2	60
Food waste	73	0	0	10	10	2	3	1	0	66
Other waste	50	3	1	16	17	6	3	2	1	44
Average	%	%	%	%	%	%	%	%	%	%
Mixed waste	55	5	2	11	16	4	3	2	2	
Food waste	75	0	0	9	10	2	3	1	0	
Other waste	50	2	1	16	18	6	2	3	1	

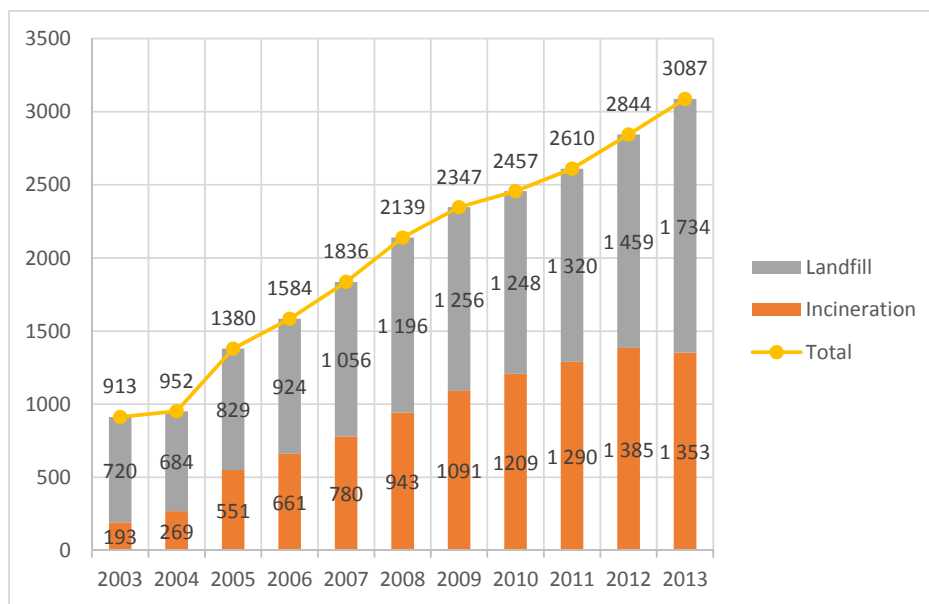
Moisture content, lower heating value as received ( $LHV_{ar}$ ) and ash content are important factors considering waste incineration. These properties are summarized to **Table 3**. As in **Table 2** the moisture content of mixed MSW is high which results to low  $LHV_{ar}$ . This makes it difficult to incinerate this MSW without auxiliary fuel.

**Table 3.** Moisture content, ash content and LHV<sub>ar</sub> of Hangzhou MSW (Hangzhou Municipal Solid Waste Disposal Supervision Center 2014).

	Moisture %	ASH % TS	LHV <sub>ar</sub> MJ/kg
2008	54	25	4.0
2009	52	31	5.3
2010	55	13	5.8
2011	63	17	4.5
2012	58		
2014	60	12	

#### 4. MSW management

Despite the low LHV<sub>ar</sub> of MSW, the MSW incineration has gained popularity in MSW management in Hangzhou during the recent years. The share of incinerated MSW was 20 % in 2003 and reached 50% during 2010-2012. The share dropped to 40% in 2013 because incineration capacity did not increase while MSW generation continued to increase. Disposing MSW into landfill is still a major treatment method in Hangzhou.



**Figure 3.** Development of MSW management in Hangzhou.

#### 4.1. Source separation

The source separation is mainly done by unofficial waste pickers who collect recyclables straight from households and sometimes also from small businesses. For official collection of MSW there is a four bin system in place. There are separate bins for food waste, hazardous waste, recyclables and other waste, **Figure 4**. However, in practice most of these bins contain similar mixed MSW. The valuable recyclables are partially also collected from bins by waste pickers who deliver them to collection points to receive money from them. This is another reason why the recyclable waste collected by the official system is not really good quality.



**Figure 4.** MSW bins in Hangzhou from left to right: hazardous waste, kitchen waste, other waste and recyclables.

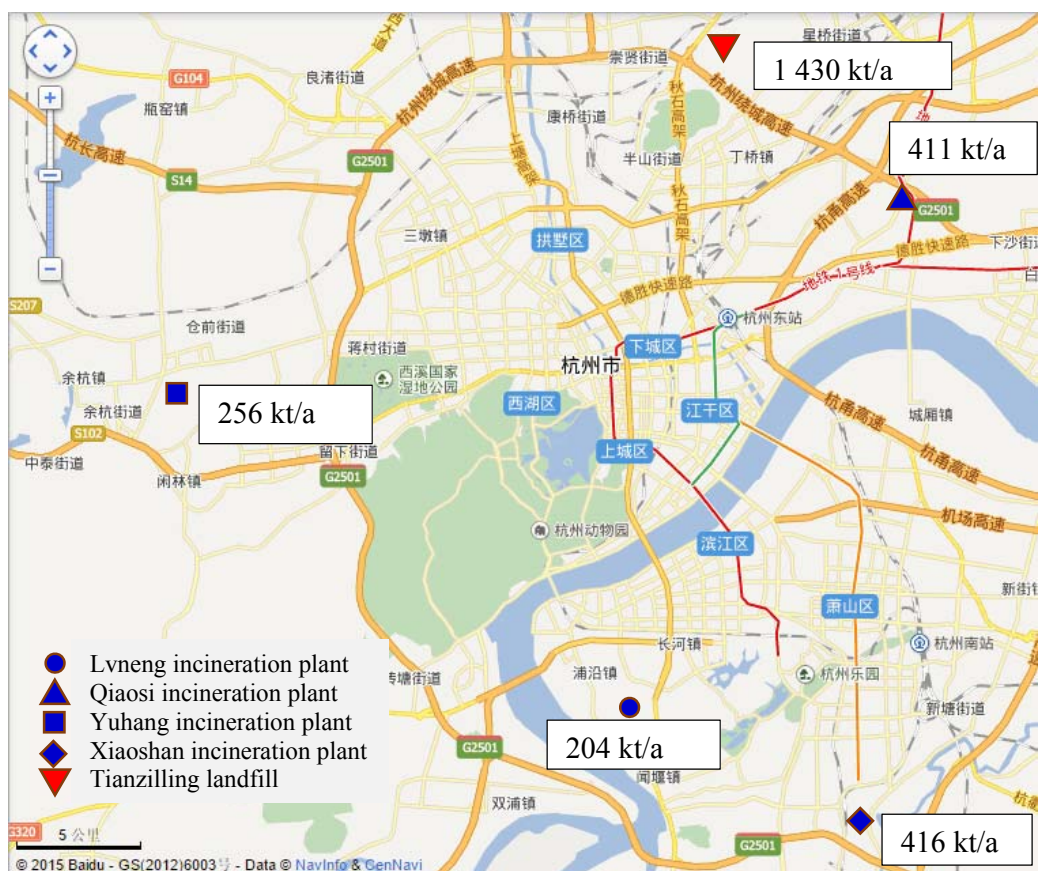
The only information about the source separated food waste and other waste is from the main districts of Hangzhou, where they comprised 15% of the total generated MSW in 2013.

**Table 4.** The amount of source separated food waste and other waste and total amount of MSW from main districts in Hangzhou in 2013 (Hangzhou Municipal Solid Waste Disposal Supervision Center 2014).

Waste	Mass		Share %
	t/a	t/d	
Food waste	109 243	299	6 %
Other waste	145 394	398	9 %
Total source	254 636	698	15 %
Total MSW in main district	1 684 175		

#### 4.2. MSW treatment to date

There were two landfills operating in Hangzhou (Tianziling and Liugongduan) and four incineration plants in 2013. In 2015 the Liugongduan landfill was not operating anymore and waste was directed into landfill only in Tianziling landfill site. The locations of operating landfill and four incineration plants are shown in **Figure 5**. The mass amounts for treatment locations and shares of treatment in 2013 are summarized to **Table 5**.



**Figure 5.** Locations of four operating waste incineration plants and landfill and MSW treated in 2013.

**Table 5.** Hangzhou MSW treatment in 2013 (Hangzhou Municipal Solid Waste Disposal Supervision Center 2014).

	Incineration				Landfills		Total	
	Lvneng	Qiaosi	Yuhang	Xiaoshan	Liugongduan	Tianziling		
Mass	560	1127	702	1139	1004	3923	8455	t/d
Mass	204	411	256	416	366	1432	3086	kt/a
Share	7	13	8	13	12	46	100	%

#### 4.2.1. Landfilling

In 2013 there were still two landfills operating in Hangzhou namely Liugongduan and Tianziling landfills. Liugongduan landfill has been closed since then and only Tianziling landfill remains.

During the visit to Tianziling landfill site on 22.4.2015, one manager of Hangzhou Environmental Group (HEG) presented the operations on the landfill site. HEG is responsible for operating the landfill site. HEG is also responsible for collecting the MSW in Hangzhou city. The Clean & Direct waste transport which is part of HEG is responsible of collecting the waste and transporting it to landfill or incineration.

The first part to Hangzhou Tianziling waste disposal center was built in 1991 and closed in 2006. It was the first landfill in China to have landfill gas collection in place. The second part



is now being filled up with waste. Initially it was estimated to be enough for MSW collected in 22 years but because the MSW generation has increased rapidly it is expected to be full already in 5-6 years. The landfill gas collection has been 6000 m<sup>3</sup>/h and the methane content is estimated to be 50-60%. The manager also estimated that in China the maximum share of generated landfill gas that could be collected is roughly 30%.

In addition there is also anaerobic digestion plant located in the disposal center which utilizes 200 t/d source separated food waste. Even though the food waste is source separated it contains 30% impurities which are mechanically and manually removed before anaerobic digestion. There are 8 turbines, each 1 MW, which are used to produce electricity from landfill gas and biogas from anaerobic digestion. They run well almost every day.

#### 4.2.2. Incineration

The four existing incineration plants utilized 40% of the total amount of MSW generated in 2013. There is one plant with grate furnace and three with fluidized bed furnace. Except for Xiaoshan plant, all the plants are receiving higher daily mass of MSW than what their design capacities are. This becomes evident when comparing **Table 5** and **Table 6**. The plants only produce electricity and no heat is recovered because there isn't need for district heating in Hangzhou. More information about the operation of the plants is presented in Appendix 1. The waste incineration gets largest share of income from the produced electricity since they can sell it with a guaranteed prize of 0.65 CNY/kWh to Power Supply Bureau. The coal incineration plants can sell electricity with 0.45 CNY/kWh and the average electricity market prize in Hangzhou is 0.54 CNY/kWh. The monetary flows of Xiaoshan and Lveneng incineration plants are presented in Appendix 2 and 3.

**Table 6.** Waste incineration plants in Hangzhou city. (Hangzhou Municipal Solid Waste Disposal Supervision Center 2014).

Name	Lvneng	Qiaosi	Yuhang Jinjiang	Xiaoshan Jinjiang
Technology	grate	fluidized bed	fluidized bed	fluidized bed
Capacity (t/d)	450	800	600	1200
Fly ash disposal	solidification and landfill	solidification and landfill	solidification and landfill	solidification and landfill
Starting operation	2004	2002	1998	2007

#### 4.3. MSW management developments

According to that manager from HEG, the future trend in Hangzhou MSW management is that waste recycling and incineration would be increased and landfilling would be phased out completely. According to him, there isn't even available place for a new landfill. The Tianziling waste treatment center is being developed and more actions toward recycling of MSW are taken. There is existing plans to build a new anaerobic digestion plant to Tianziling waste treatment center which would start to utilize food waste from restaurants. It would have the same capacity as the current anaerobic digestion plant. The manager also mentioned that they are open for foreign experts to provide knowhow to improve the Tianziling waste treatment center to develop more in the direction of recycling park. In the Tianziling waste

treatment center there is already a place for educating general public about the reasons and benefits for increasing recycling.

The share MSW incineration is aimed to increase by building new incineration plants. At the moment there is one incineration plant being built with a capacity of 1600 t/d. In addition to this plant there are plans for building incineration plant with staggering capacity of 3000 t/d. These plans have received fierce opposition from the public and in the demonstrations some have even lost their lives. These demonstrations have lead the Hangzhou government to realize that, when moving forward with MSW incineration, it has to more carefully take into considerations the concerns of the general public.

There are also plans to improve MSW refining by producing RDF from MSW. This way the quality of waste going to incineration would improve and it is expected that higher amounts of electricity could be produced. It also might increase the recycling of metals from MSW. The separated organic fraction could then be composted or directed to anaerobic digestion.

## **5. Conclusions**

At present in Hangzhou city, approximately half of MSW is disposed into landfills and the other half is incinerated. This is the MSW which remains after the unofficial MSW collection. The aim is that after the Tianziling landfill phase 2 is full there should be enough incineration capacity to replace the landfilling of MSW. This might be a challenging task due to the relatively short time period before Tianziling landfill is full. It was estimated that Tianziling landfill could be full already in five years (approximately 2020). Therefore there is not much time to increase the MSW incineration capacity. In 2013, 5000 t/d was disposed into landfill.

One incineration plant is being built (1 600 t/d) and another is planned (3000 t/d). These two have approximately enough capacity to incinerate similar MSW mass which was landfilled in 2013. However, the MSW generation has been increasing during the recent years and there is a possibility that it will continue to increase. The plans to build more waste incineration capacity have also raised high public opposition. This has led the local government to acknowledge that the public opinion should be more taken into account in decision making. However, the aim in Hangzhou is to increase recycling and incineration of MSW. One practical reason for this is that there does not seem to be suitable locations available for building new landfills close to Hangzhou city.

One of the most important things right now is the education of general public about the benefits of source separation. At present the source separation is not really working but the four bin system is in place. The unofficial pickers ensures that some waste for example bottles and cardboard are recycled to some extent. When the food waste would be more widely separated it could be utilized in anaerobic digestion plants and less incineration capacity would be needed. HEG is continuing to educate people about the benefits of recycling but like any change it will require some time before majority of people adopt MSW source separation.

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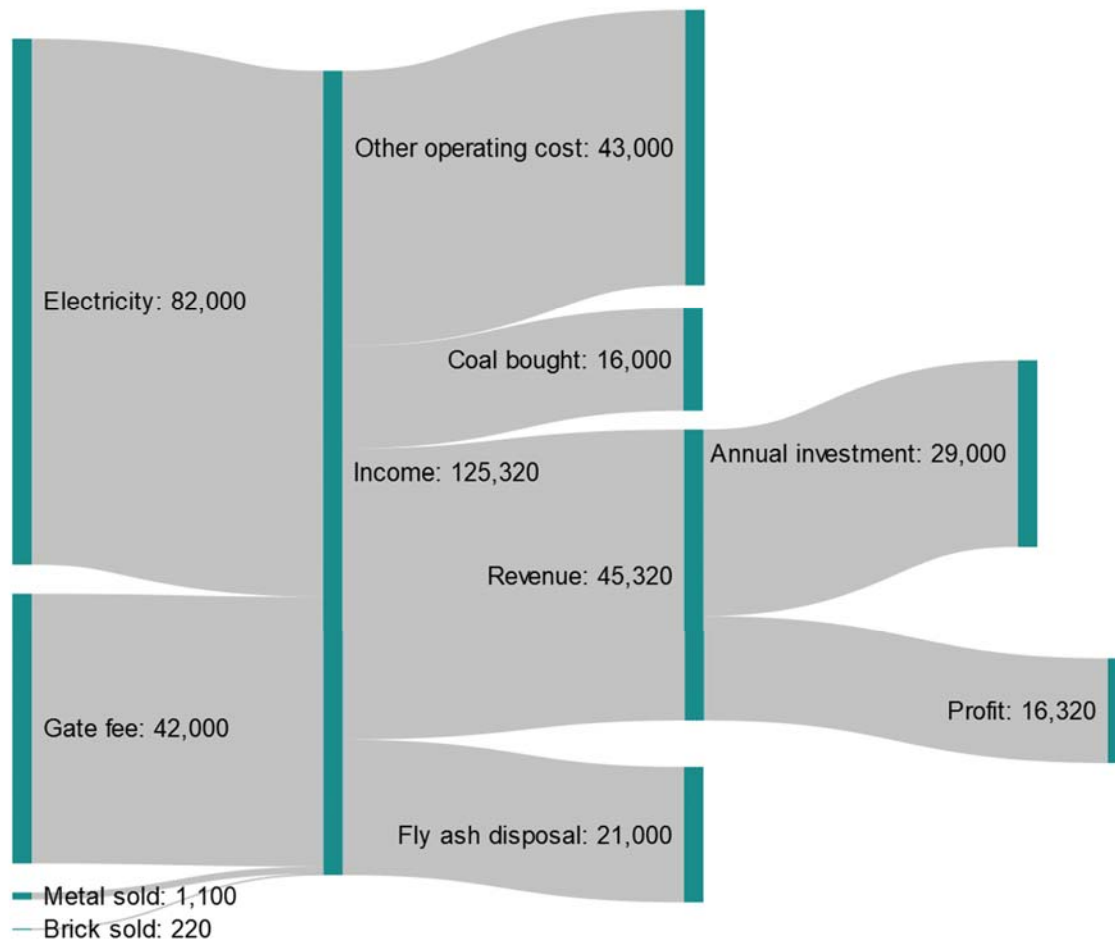
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**Appendix 1.** Operation data of the four MSW incineration plants in Hangzhou.

Operation data			Lvngeng		Qiaosi		Yahang		Xiasohan	
			2 013	2014	2 013	2014	2013	2014	2013	2014
MSW	Mass	t/a	200 000	210 000	410 000	350 000	260 000	260 000	520 000	
	LHV <sub>ar</sub>	MJ/kg	3.9	3.9	4.2	4.2	4.2	4.2	4.6	
Coal	Mass	t/a	2 670	779	2 340	2 630	8 100	9 360	28 600	
		% of MSW	1 %	0.4 %	1 %	1 %	3 %	3 %	5 %	
	LHV <sub>ar</sub>	MJ/kg	21	21	21	21	21	21	21	
Fuel energy	MSW	MWh/a	240 000	230 000	490 000	420 000	340 000	360 000	840 000	
	Coal	MWh/a	16 000	4 500	14 000	15 000	46 000	55 000	170 000	
		% of total	7 %	2 %	3 %	4 %	14 %	15 %	20 %	
	Total	MWh/a	240 000	230 000	490 000	420 000	340 000	360 000	840 000	
Electricity production		MWh/a	56 000	60 000	95 000	92 000	54 000	58 000	160 000	
Electricity use by the plant		MWh/a	11 000	11 000	28 000	28 000	14 000	15 000	34 000	
Electric efficiency		%	24 %	26 %	20 %	22 %	16 %	16 %	19 %	
Own use		% of produced	19 %	18 %	29 %	31 %	25 %	26 %	21 %	
Leachate	Mass	t/a	37 000	38 000					23 000	
		kg leachate/kg MSW	0.18	0.18					0.044	
Ash	bottom ash	t/a	35 000	36 000	41 000	35 000	25 000	25 000	63 000	
		% of MSW	17 %	17 %	10 %	10 %			12 %	
	fly ash	t/a	6 100	6 300	25 000	21 000	20 000	20 000	52 000	
		% of MSW	3 %	3 %	6 %	6 %			10 %	
	total	t/a	41 000	42 000	66 000	57 000	45 000	45 000	120 000	
		% of MSW	20 %	20 %	16 %	16 %	18 %	17 %	22 %	

**Appendix 2.** The incomes and expenses as well as yearly profit for Xiaoshan plant (2014 data), all flows (CNY/a)



Investment of the plant (CNY)	320 000 000
Operating cost of plant (CNY/a)	80 000 000
Electricity when sold (CNY/kWh)	0.65
Coal prize (CNY/t)	570
Gate fee for MSW (CNY/t)	80
Bottom ash bricks sold (CNY/t)	5
Fly ash disposal (CNY/t)	360
Recovered metal sold (CNY/t)	400

Assuming:

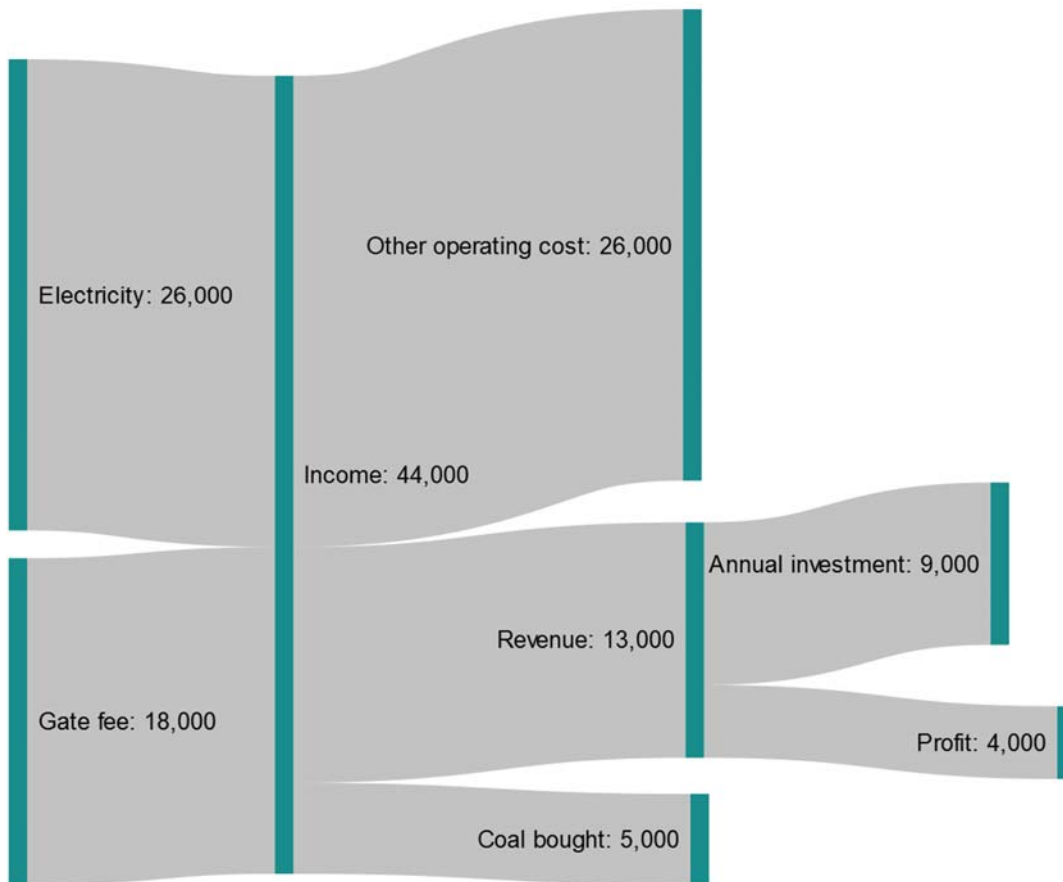
Operating time of the plant 20 a and interest 6.5 %

Calculated

Payback (without interest): 7.1 year

Internal rate of return IRR: 13 %

**Appendix 3.** The incomes and expenses as well as yearly profit for Yuhang plant (2014 data), all flows (CNY/a)



Investment of the plant (CNY)	99 000 000
Operating cost of plant (CNY/a)	37 750 000
Electricity when sold (CNY/kWh)	0.65
Coal prize (CNY/t)	600
Gate fee for MSW (CNY/t)	69

Assuming:

Operating time of the plant 20 a and interest 6.5 %

Calculated

Payback (without interest): 7.9 year

Internal rate of return IRR: 13 %