Supplementary material

Temporal evolution of environmental impact from municipal solid waste treatment systems: A case study of Guangzhou, China

Summary information:

Number of pages: 15

Figures: 9 （Figure S1-S9）

Tables：11 （Table S1-S11）

Notes: 1

Supplementary Notes

Calculation formula for low heating value of MSW incineration is shown as S1 [1]

$$Q_L = 81C^Y + 300H^Y - 26(O^Y - S^Y) - 6(W^Y + 9H^Y) \quad \text{(S1)}$$

C^Y, H^Y, S^Y, O^Y, N^Y, W^Y is the weight percent of C, H, S, O, N and water in MSW

The goodness of fit coefficient (R^2) and mean absolute percentage error (MAPE) are used to measure the goodness of fit of the model, calculated using Equations S2 and S3.

$$R^2 = 1 - (\sum_i (x_i - \hat{x}_i)^2 / \sum_i (x_i - \bar{x}_i)^2) \quad \text{(S2)}$$

$$MAPE = \frac{100\%}{n} \sum_{i=1}^{n} \left| \frac{\hat{x}_i - x_i}{x_i} \right| \quad \text{(S3)}$$

Among them, R^2represents the index fitting degree coefficient, the closer to 1, the better the fitting degree, x_i represents the actual value of the index in year i, $x_i\hat{}$ represents the simulated value of the index, and $x_i\bar{}$ represents the average value of the index. A MAPE of 0% indicates a perfect model, and a MAPE greater than 100% indicates an inferior model.

Supplementary Tables

Table S1 Substitution coefficient of MSW recycling

Category	Waste paper	Plastic	Metal		Glass	Textile
Replacement rate	1:0.8（Newsprint）	1:0.9（PET）	1:0.97（Steel）	1:0.95（Aluminum）	1:0.99（Glass）	1:0.85（cotton fiber）

Table S2 Physical composition and elemental analysis of MSW in Guangzhou [2, 3]

Composition	Food wastes	Paper	Wood	Textiles	Plastic and rubber	Other	Moisture content
Proportion .%	53.36	8.3	1.73	9.09	18.6	8.92	55.7
C .%	48	43.5	49.5	55	60.4	27.6	62.7
H .%	6.4	6	6	6.6	7.8	4.1	49.1
O .%	37.6	44	42.7	31.2	17.8	16.7	58.9
N .%	2.6	0.3	0.2	4.6	0.5	1.9	41.6
S .%	0.4	0.2	0.1	0.1	0.1	0.3	49.9
Ash .%	5	6	1.5	2.5	13.4	49.4	46.1

Table S3 Composition of landfill gas

Composition	CH_4	CO_2	H_2S	NH_3	CO	N_2	O_2	H_2	Trace gas
Vol.%	55	40	0.1	1	0.1	3	0.6	0.2	0.1

Table S4 Concentration of pollutants in flue gas from incineration of household garbage [4]

Composition	NO_X	SO_2	HCL	CO	Hg	Cd	Pb	PCDD

	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	mg/m^3	ng TEQ/m^3
Concentration	250	80	20	80	0.05	0.1	1	0.1

Table S5 Physical composition of MSW after classification

Composition	Food wastes	Paper	Wood	Textiles	Plastic and rubber	Other	Moisture content
Proportion	42.88	7.41	2.47	11.36	19.93	15.93	54.00

Table S6 Life cycle inventory of technologies

1t MSW	Unit	Landfill	Incineration without classification	Incineration with classification	Composting
Input					
Diesel	kg	1.41	1.67	1.67	0.78
Electricity	kWh	1.76	73.58	73.58	3.44
HDPE	kg	0.45	--	--	--
Coal	kg	--	50.00	50.00	--
Limestone	kg	--	10.00	10.00	--
NaOH	kg	--	2.40	2.40	--
Output					
Electricity	kWh	143.36	409.09	420.59	--
Fertilizer	kg	--	--	--	280.00
Leachate	kg	--	200.00	200.00	--
Direct emissions to air					
CO_2	kg	216.15	792.67	802.00	59.00
CO	kg	0.0038	0.33	0.33	0.04
SO_2	kg	0.03	0.33	0.33	0.03
NO_X	kg	0.06	1.03	1.04	0.13
CH_4	kg	23.11	--	--	2.95
H_2S	kg	0.29	--	--	0.15
HCl	kg	0.04	0.082	0.083	--
NH_3	kg	0.08	--	--	0.09
VOCs	kg	0.05	--	--	--
Hg	kg	3.41E-08	2.06E-04	2.08E-04	--
Pb	kg	--	4.11E-03	4.15E-03	--
Cd	kg	--	4.11E-04	4.15E-04	--
PCDD/Fs	kg	--	4.11E-10	4.15E-10	--
Direct emissions to water					

COD	kg	0.06	0.019	0.019	--
NH_3-N	kg	0.008	0.0027	0.0027	--
TP	kg	2.38E-03	1.62E-05	1.62E-05	--
Cd	kg	1.00E-05	3.00E-06	3.00E-06	--
Cr	kg	1.00E-04	2.94E-06	2.94E-06	--
Pb	kg	1.00E-04	8.40E-06	8.40E-06	--
Zn	kg	4.50E-05	6.42E-06	6.42E-06	--
Hg	kg	1.75E-07	1.14E-07	1.14E-07	--

Table S7 Environmental impact indicators and related environmental factors

Environmental impact indicators	Abbreviation	Unit	Related environmental factors
Abiotic Depletion	ADP	MJ	Mineral consumption, fossil fuel consumption, etc
Acidification Potential	AP	kg SO_2-eq.	SO_2、NO_X、HCl、HF, etc
Eutrophication Potential	EP	kg PO_4^{3-}-eq.	Ammonia, phosphate, nitrate, etc
Global Warming Potential	GWP	kg CO_2-eq.	CO_2, NO_2, CH_4, CF_6, CH_3Br, etc
Human Toxicity Potential	HTP	kg DCB-eq.	Toxic substances that enter the air, soil and water, including dichlorobenzene, dioxins, As, Cd, Cr, Hg, Ni, Pb, V, Zn etc
Photochemical Ozone Creation Potential	POCP	kg C_2H_4-eq.	Ethylene, NMHC, etc

Table S8 The normalized factors and weighting factors

	Normalized factor	Weighting factors
ADP	3.80E +14	0.143
AP	2.39E+11	0.164
EP	1.58E+11	0.152
GWP	4.22E+13	0.108
HTP	2.58E+12	0.141
POCP	3.68E+10	0.154

Table S9 Main variables, equations and unit of the comprehensive simulation model.

No	Variables and Equations	Unit	Source
	Initial time 2010	Year	
	Final time 2035	Year	
	Stock variable		
1	GDP= INTEG (Growth amounts of GDP,10640.7)	100 million CNY	Guangzhou Statistics Bureau[5]
2	Non-registered population= INTEG (Growth amounts of non-registered population, 464.82)	10 thousand person	Guangzhou Statistics Bureau[5]
3	Registered population= INTEG (Birth population-Death population + Net migration, 806.14)	10 thousand person	Guangzhou Statistics Bureau[5]
4	Accumulated generation of MSW= INTEG (Annual generation of MSW, 0)	Tonne	Research Settings
5	Accumulated incineration amount of classified MSW= INTEG (Annual incineration amount of classified MSW, 0)	Tonne	Research Settings
6	Accumulated recycling MSW= INTEG (Annual recycling MSW, 0)	Tonne	Research Settings
7	Accumulated composting amount= INTEG (Annual composting amount, 0)	Tonne	Research Settings
8	Accumulated recycling MSW= INTEG (Annual recycling MSW,0)	Tonne	Research Settings
9	Accumulated landfill amount of unclassified MSW= INTEG (Annual landfill amount of unclassified MSW, 0)	Tonne	Research Settings
10	Accumulated ADP of MSW treatment system= INTEG (Annual ADP of MSW treatment system,0)	MJ	Research Settings
11	Accumulated AP of MSW treatment system= INTEG (Annual AP of MSW treatment system,0)	kg SO_2-Equiv	Research Settings
12	Accumulated EP of MSW treatment system= INTEG (Annual EP of MSW treatment system,0)	kg Phosphate-Equiv	Research Settings
13	Accumulated GWP of MSW treatment system= INTEG (Annual GWP of MSW treatment system, 0)	kg CO_2-Equiv	Research Settings
14	Accumulated HTP of MSW treatment system= INTEG (Annual HTP of MSW treatment system,0)	kg DCB-Equiv	Research Settings
15	Accumulated POCP of MSW treatment system= INTEG (Annual POCP of MSW treatment system, 0)	kg Ethene-Equiv	Research Settings
16	Accumulated weighted environmental impact of MSW treatment system= INTEG (Annual weighted	Dmnl	Research Settings

	environmental impact of MSW treatment system,0)		
	Flow variable		
17	Growth amounts of GDP= GDP*Growth rate of GDP	100 million CNY	Established based on prior experience
18	Growth amounts of permanent registered population= Growth rate of permanent registered population*Permanent registered population	10 thousand person	Established based on prior experience
19	Birth population=Resident population*Birth rate	10 thousand person	Established based on prior experience
20	Death population=Resident population*Death rate	10 thousand person	Established based on prior experience
21	Net migration of resident population =Resident population*Net migration rate	10 thousand person	Established based on prior experience
22	Annual generation of MSW = Per capita MSW production*Permanent population*10000*365/1000	Tonne	Established based on prior experience
23	Annual incineration amount of classified MSW= Classified MSW amount*Percentage of residual MSW	Tonne	Established based on prior experience
24	Annual landfill amount of unclassified MSW= Unclassified MSW amount*Landfill percentage of unclassified MSW	Tonne	Established based on prior experience
25	Annual incineration amount of unclassified MSW= Unclassified MSW amount*Incineration percentage of unclassified MSW	Tonne	Established based on prior experience
26	Annual recycling MSW= Percentage of recyclable MSW*Classified MSW amount	Tonne	Established based on prior experience
27	Annual composting amount= Classified MSW amount*Percentage of food waste	Tonne	Established based on prior experience
28	Annual POCP of MSW treatment system= Discharged POCP of annual classified MSW composting + Discharged POCP of annual classified MSW incineration +Discharged POCP of annual MSW landfill + Discharged POCP of annual unclassified MSW incineration + Discharged POCP of MSW in transfer station + Discharged POCP of MSW transportation + Discharged POCP of recyclable MSW	kg Ethene-Equiv	Established based on prior experience
29	Annual GWP of MSW treatment system= Discharged GWP of annual classified MSW composting + Discharged	kg CO_2-Equiv	Established based on prior

	GWP of annual MSW landfill + Discharged GWP of annual classified MSW incineration + Discharged GWP of annual unclassified MSW incineration + Discharged GWP of MSW in transfer station + Discharged GWP of MSW transportation + Discharged GWP of recyclable MSW		experience
30	Annual EP of MSW treatment system= Discharged EP of annual classified MSW compositing + Discharged EP of annual classified MSW incineration + Discharged EP of annual MSW landfill + Discharged EP of annual unclassified MSW incineration + Discharged EP of MSW in transfer station + Discharged EP of MSW transportation + Discharged EP of recyclable MSW	kg Phosphate-Equiv	Established based on prior experience
31	Annual weighted environmental impact of MSW treatment system= Weighted environmental impact of annual classified MSW composting + Weighted environmental impact of annual classified MSW incineration + Weighted environmental impact of annual MSW landfill + Weighted environmental impact of annual unclassified MSW incineration + Weighted environmental impact of MSW in transfer station + Weighted environmental impact of MSW transportation + Weighted environmental impact of recyclable MSW	Dmnl	Established based on prior experience
32	Annual AP of MSW treatment system= Discharged AP of annual classifed MSW compositing + Discharged AP of annual classified MSW incineration + Discharged AP of annual MSW landfill + Discharged AP of annual unclassified MSW incineration + Discharged AP of MSW in transfer station + Discharged AP of MSW transportation + Discharged AP of recyclable MSW	kg SO_2-Equiv	Established based on prior experience
33	Annual HTP of MSW treatment system=Discharged HTP of annual classified MSW compositing + Discharged HTP of annual classified MSW incineration + Discharged HTP of annual MSW landfill + Discharged HTP of annual unclassified MSW incineration + Discharged HTP of MSW in transfer station + Discharged HTP of MSW transportation + Discharged HTP of recyclable MSW	kg DCB-Equiv	Established based on prior experience
34	Annual ADP of MSW treatment system=Discharged ADP of annual classified MSW compositing + Discharged ADP of annual classified MSW incineration + Discharged ADP of annual MSW landfill + Discharged ADP of annual unclassified MSW incineration + Discharged ADP of MSW in transfer station + Discharged ADP of MSW transportation + Discharged ADP of recyclable MSW	MJ	Established based on prior experience
	Auxiliary variable		

35	Growth rate of GDP = WITH LOOKUP (Time, ([(2010,0) -(2035,0.2)], (2010,0.11), (2015,0.08), (2020,0.075), (2025,0.06), (2030,0.055), (2035,0.05)))	Dmnl	Guangzhou Statistics Bureau[5], The People's Government of Guangzhou Municipality[6]
36	Birth rate = WITH LOOKUP (Time, ([(2010,0)-(2035,1)], (2010,0)-(2035,1)],(2010,0.0098),(2013,0.014),(2017,0.021),(2021,0.017), (2025,0.004),(2030,0),(2035,0)))	Dmnl	Guangzhou Statistics Bureau[5], The People's Government of Guangzhou Municipality[6]
37	Net migration rate = WITH LOOKUP (Time, ([(2010,0)-(2035,1)], (2010,0.0068), (2015,0.005),(2016,0.008), (2017,0.0016), (2021,0.018), (2025,0.02), (2030,0.015), (2035,0.01)))	Dmnl	Guangzhou Statistics Bureau[5], The People's Government of Guangzhou Municipality[6]
38	Growth rate of permanent registered population = WITH LOOKUP (Time,([(2010,-1)-(2035,1)], ([(2010,0)-(2035,1)], (2010,0.14), (2012,0.08), (2016,0.06), (2019,0), (2025,-0.05), (2030,-0.01), (2035,-0.005)))	Dmnl	Guangzhou Statistics Bureau[5], The People's Government of Guangzhou Municipality[6]
39	Total population=Resident population + Non-registered population	10 thousand person	Established based on prior experience
40	Per capita GDP=GDP*10000/Permanent population	CNY	Established based on prior experience
41	Per Capita Annual Disposable Income= Per capita GDP*0.684-25569.7	CNY	Established based on prior experience
42	Per Capita Annual Living expenditures for consumption= 24716.8*LN(Per Capita Annual Disposable Income)-230156	CNY	Fitting analysis
43	Per capita consumption expenditure impact factor= (Per Capita Annual Living expenditures for consumption-25011.6)/1000*0.005	kg/(person*day)	Fitting analysis
44	Per capita MSW production= (Initial value of per capita	kg/(person*day)	Established

	MSW production + Per capita consumption expenditure impact factor)*Policy impact factor		based on prior experience
45	Harmless disposal rate = WITH LOOKUP (Time, ([(2010,0)-(2035,1.1)], (2010,0.91),(2011,0.81),(2012,0.8),(2013,0.87), (2014,0.87),(2015,0.95),(2016,0.96),(2017,0.965),(2018,1),(2035,1)))	Dmnl	MOHURD[64]
46	Harmless disposal amount of MSW=Volume of MSW*Harmless disposal rate	Tonne	Established based on prior experience
47	Classification rate = WITH LOOKUP (Time,([(2010,0)-(2035,1)], (2010,0), (2018,0), (2019,0.15),(2020,0.25),(2025,0.4),(2030,0.6),(2035,0.8)))	Dmnl	Government G M P [63]
48	Classified MSW amount=Harmless disposal amount of MSW*Classification rate	Tonne	Established based on prior experience
49	Unclassified MSW amount=Harmless disposal amount of MSW*(1-Classification rate)	Tonne	Established based on prior experience
50	Proportion of urban population = ([(2010,0)-(2035,1)], (2010,0.8379), (2015,0.841), (2020,0.89), (2025,0.89), (2030,0.895), (2035,0.9))	Dmnl	Guangzhou Statistics Bureau[5], The People's Government of Guangzhou[6]
	Constant		
51	Death rate=0.00571		Guangzhou Statistics Bureau[5]
52	Initial value of per capita MSW production= 0.9	kg/(person*day)	Guangzhou Statistics Bureau[5]
53	Weighted environmental impact of unit recyclable MSW=-1.82839e-09	Dmnl	LCA calculation
54	Weighted environmental impact of unit transportation distance= 8.43e-14	Dmnl	LCA calculation
55	Weighted environmental impact of unit MSW landfill= 4.54e-11	Dmnl	LCA calculation
56	Weighted environmental impact of unit unclassified MSW incineration= -3.11e-11	Dmnl	LCA calculation
57	Weighted environmental impact of unit classified MSW composting= -5.82e-11	Dmnl	LCA calculation
58	Weighted environmental impact of unit classified MSW	Dmnl	LCA calculation

	incineration= -4.1e-11		
59	Discharged EP of unit MSW landfill=0.00149	kg CO_2-Equiv	LCA calculation
60	Discharged GWP of unit MSW landfill=749	kg Phosphate-Equiv	LCA calculation
61	Discharged AP of unit MSW landfill-0.441	kg SO_2-Equiv	LCA calculation
62	Discharged HTP of unit MSW landfill=-39.1	kg DCB-Equiv	LCA calculation

Table S10 Life cycle inventory of technologies under technology scenario

1t MSW	Unit	Landfill	Incineration without classification	Incineration with classification
Input				
Diesel	kg	1.41	1.67	1.67
Electricity	kWh	1.76	73.58	73.58
HDPE	kg	0.45	--	--
Coal	kg	--	50	50
Limestone	kg	--	10	10
NaOH	kg	--	2.40	2.40
Output				
Electricity	kWh	191.15	572.73	588.83
Fertilizer	kg	--	--	--
Direct emissions to air				
CO_2	kg	248.10	792.67	802
CO	kg	0.0038	0.33	0.33
SO_2	kg	0.03	0.33	0.33
NO_X	kg	0.06	1.03	1.04
CH_4	kg	11.55	--	--
H_2S	kg	0.29	--	--
HCl	kg	0.04	0.082	0.083
NH_3	kg	0.08	--	--
VOCs	kg	0.05	--	--
Hg	kg	3.41E-08	2.06E-04	2.08E-04
Pb	kg	--	4.11E-03	4.15E-03
Cd	kg	--	4.11E-04	4.15E-04
PCDD/Fs	kg	--	4.11E-10	4.15E-10
Direct emissions to water				
COD	kg	0.06	0.019	0.019
NH3-N	kg	0.008	0.0027	0.0027

TP	kg	2.38E-03	1.62E-05	1.62E-05
Cd	kg	1.00E-05	3.00E-06	3.00E-06
Cr	kg	1.00E-04	2.94E-06	2.94E-06
Pb	kg	1.00E-04	8.40E-06	8.40E-06
Zn	kg	4.50E-05	6.42E-06	6.42E-06
Hg	kg	1.75E-07	1.14E-07	1.14E-07

Table S11 Model goodness of fit test results

	Population	GDP	Per Capita Consumption Expenditures	Quantity of MSW
R^2	0.9984	0.9924	0.9910	0.9694
MAPE	1.01%	1.96%	2.57%	3.24%

Supplementary Figures

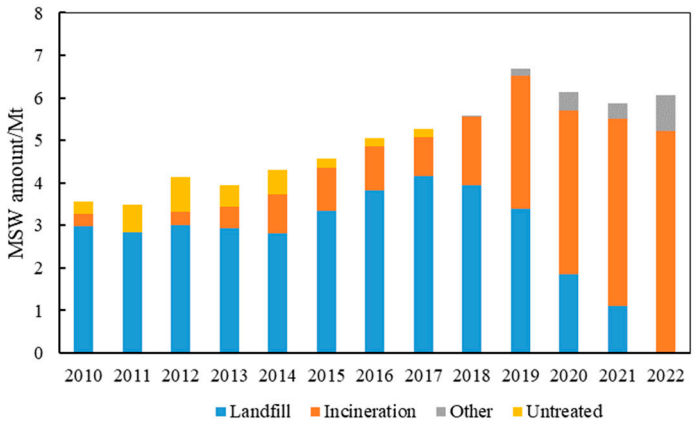


Figure S1 Treatment distribution of MSW in Guangzhou from 2010 to 2022

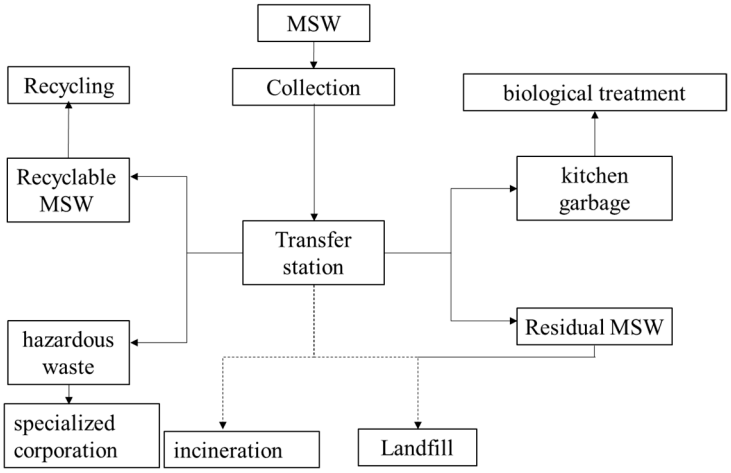


Figure S2 Schematic diagram of MSW classification and treatment in Guangzhou

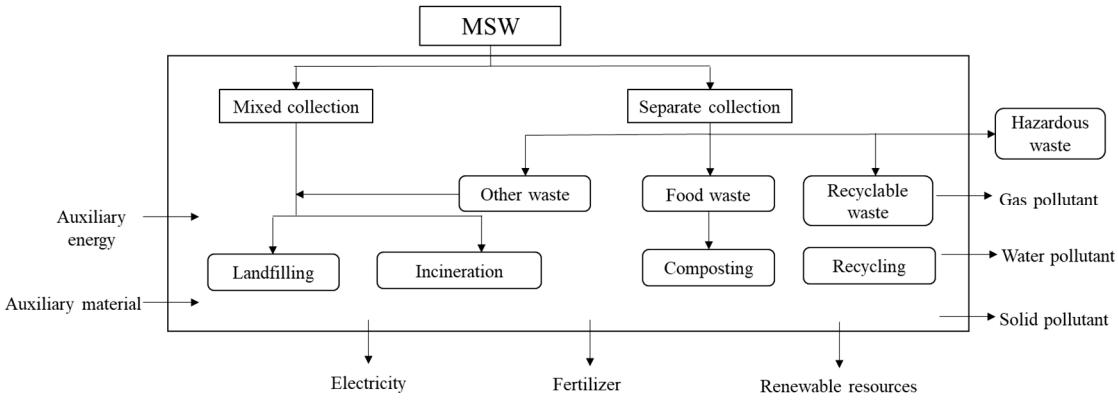


Figure S3 System boundary

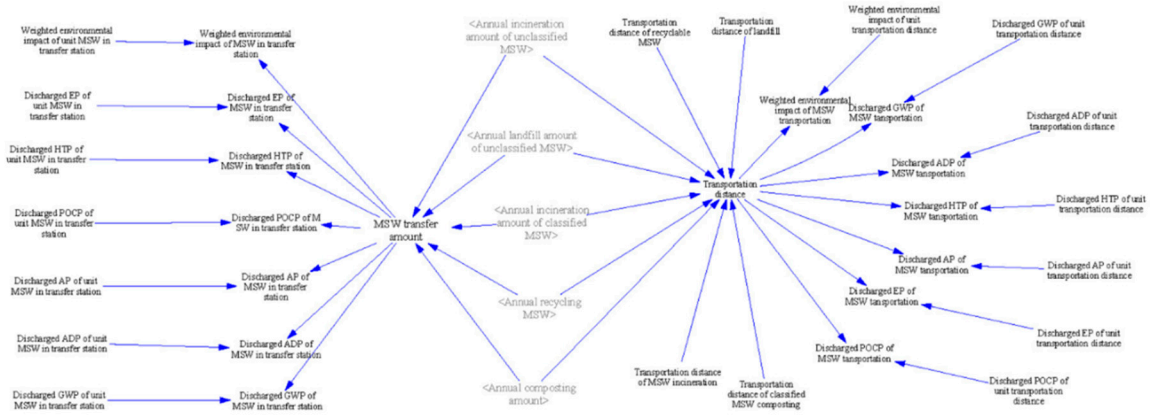


Figure S4 Stock and flow diagram of MSW transfer and transportation subsystem

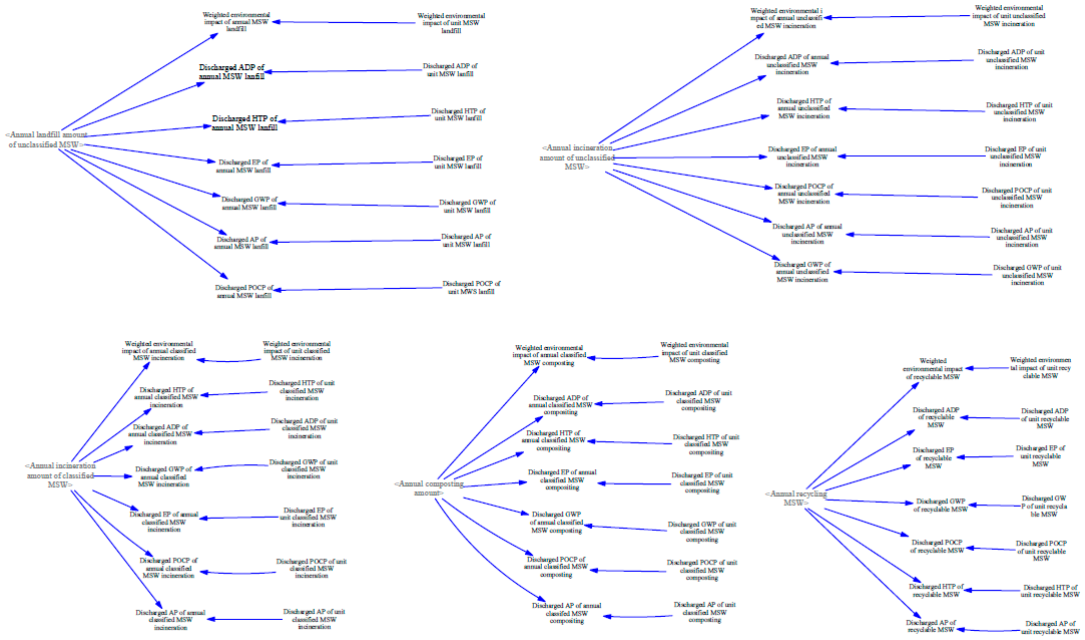


Figure S5 Stock and flow diagram of MSW treatment subsystem

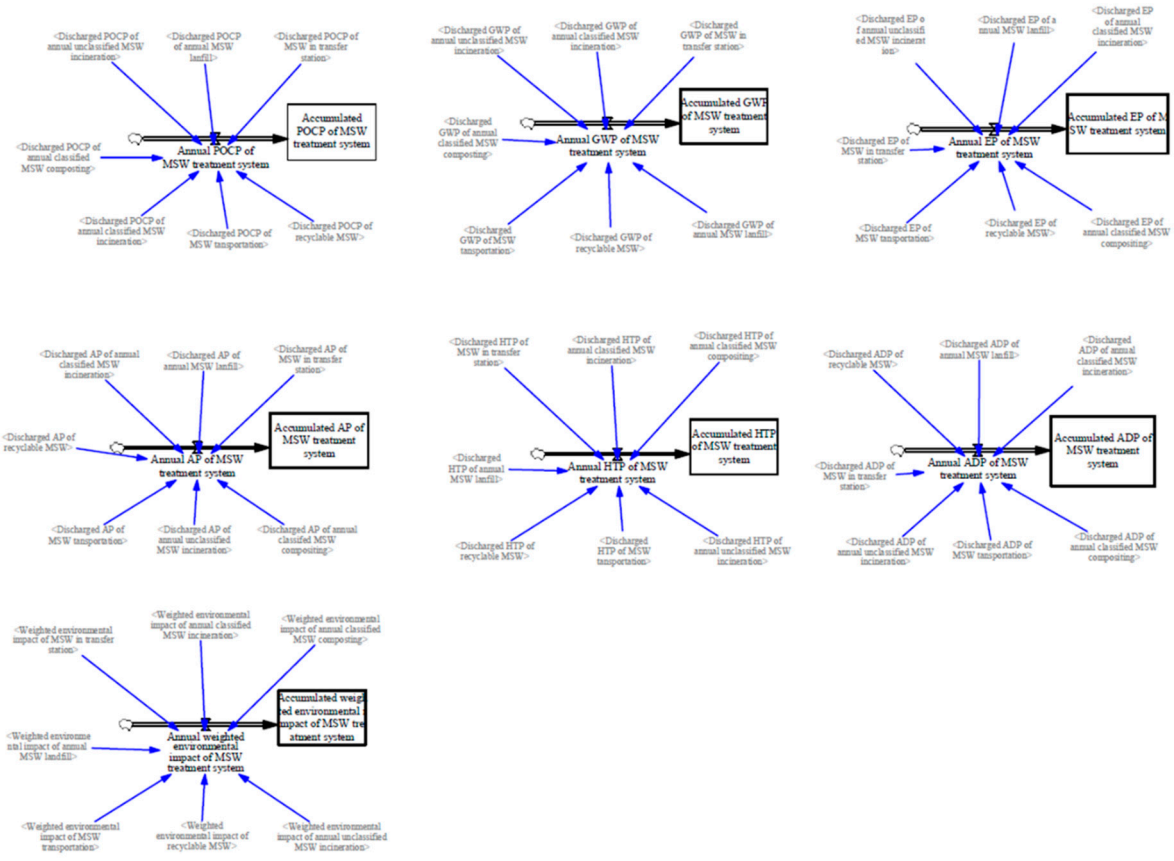


Figure S6 Stock and flow diagram of comprehensive environmental impact subsystem

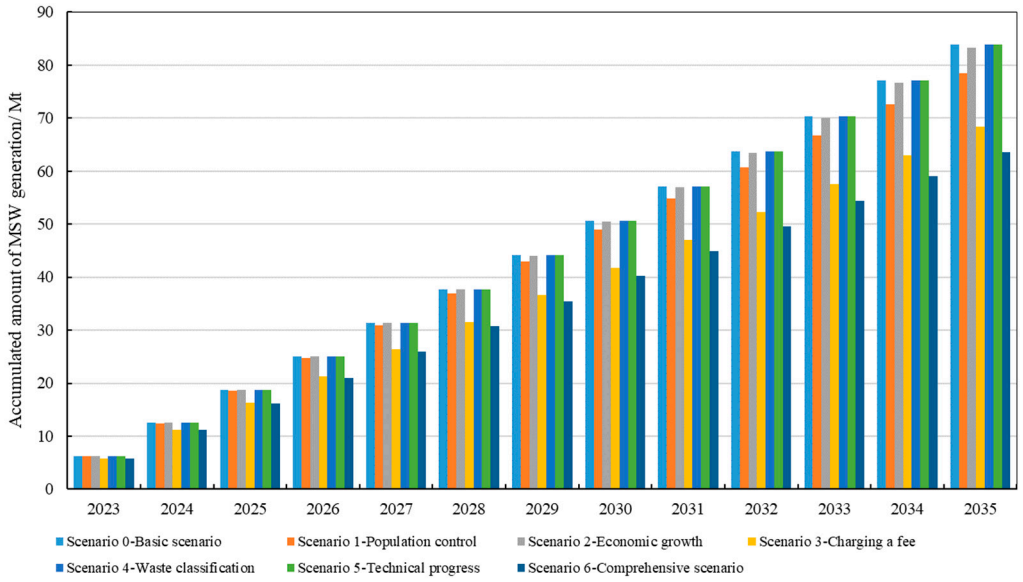


Figure S7 Evolution of accumulated amount of MSW generation under different scenarios from 2023-2025

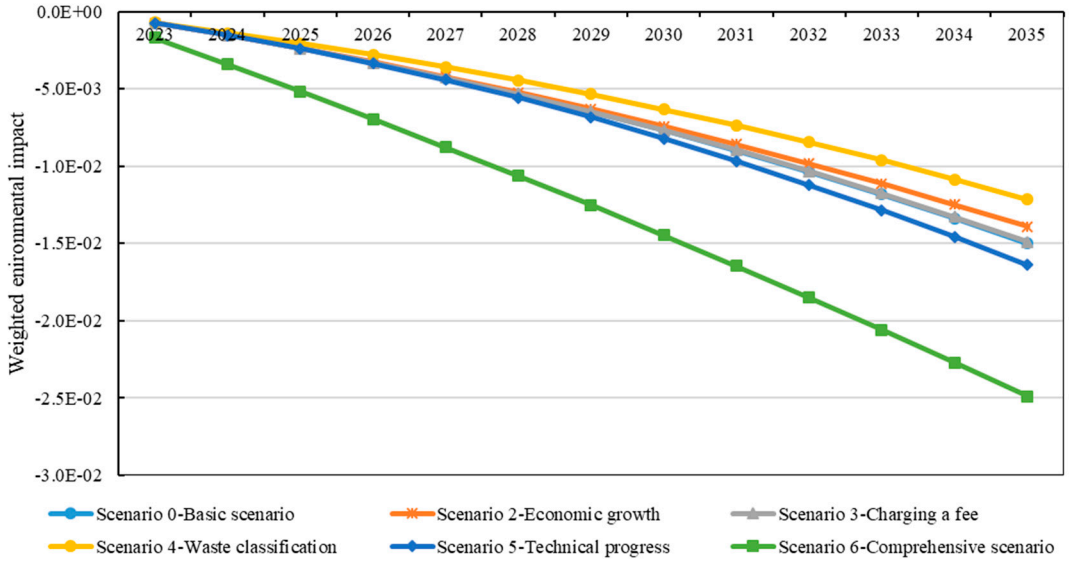


Figure S8 Evolution of accumulated environmental impacts of MSW treatment systems under different scenarios from 2023-2025

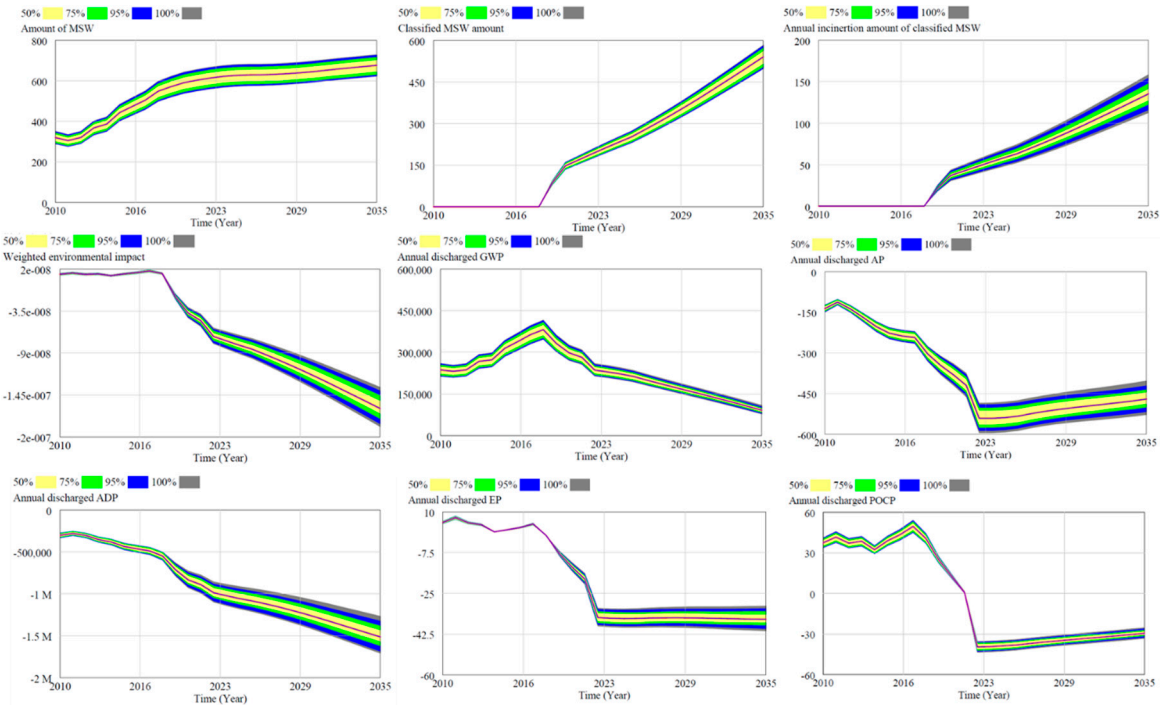


Figure S9 Sensitivity analysis of Guangzhou MSW treatment system

References:

[1] Chen K, Guo C. Treatment and disposal of municipal solid waste. Zhengzhou: Henan Science and Technology Press, 2017.

[2] Chen X. Methane utilization in municipal solid waste landfill (Master's thesis). Jinan University, Guangzhou, 2011.

[3] Ma S, Zhou C, Chi C, et al. Estimating Physical Composition of Municipal Solid Waste in China by Applying Artificial Neural Network Method. ENVIRONMENTAL SCIENCE & TECHNOLOGY, 2020,54(15):9609-9617.

[4] MEE. Standard for pollution control on the municipal solid waste incineration[S]. 2014.

[5] Guangzhou Municipal Bureau of Statistics. Guangzhou statistical yearbook. Guangzhou: China Statistics Press: 2024.

[6] Guangzhou Municipal Government. The 14th Five-Year Plan for National Economic and Social Development of Guangzhou and the outline of the Vision goals for 2035. https://www.gz.gov.cn/zwgk/ghjh/fzgh/ssw/ghgy/content/post_7811746.html.(accessed on 21 January 2024)