Carbon Emission of Municipal Solid Waste in Shanghai

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Abstract. In recent years, the issue of global warming caused by carbon emissions has attracted the attention of scholars from all walks of life. The amount of carbon emissions caused by urban activities has also been increasing. Especially, the contribution of urban household waste to carbon emissions is very high. It is the second largest global greenhouse gas. Adults are sources of emissions. The research object of this article is Shanghai Municipal Solid Waste, which simplifies the life cycle of domestic waste into two parts: transportation part and treatment part. It uses the provincial GHG inventory production method recommended by IPCC (2006) for the life of Shanghai from 2005 to 2015. Rubbish carries out carbon emission accounting and observes the changing trend of carbon emissions year by year. The results show that the production of domestic garbage in Shanghai has basically stabilized, and the proportion of household garbage disposed by sanitary landfills accounts for the most. The main carbon emissions in the transportation process are automobile vehicle tail gas emissions. The main carbon emissions in the waste treatment process are carbon emissions from sanitary landfills. The carbon emissions from landfill disposal are at a minimum, and the generation of household waste when incinerated and generated can be reduced. For Shanghai, the optimization of transportation routes and the reduction of sanitary landfill disposal of the amount of domestic waste is the most important emission reduction measure.

1. Introduction
Nowadays, global warming has become an environmental problem concerned by the world. The increase of greenhouse gas (GHG) in the atmosphere is an important cause of climate change. MSW treatment is one of the important sources of greenhouse gas emission.

With Shanghai as the research object, this study use the recommended method to estimate the waste carbon emissions in 2005-2015 in Shanghai, and based on whole life cycle assessment (LCA) [1], determined by clear objectives and scope, inventory analysis, impact assessment, improving the evaluation process, clear present situation of living garbage in Shanghai, the future development trend, the quantitative evaluation of Shanghai living garbage generation, transportation and processing of carbon emissions characteristics and its impact on the environment.

2. Materials and Methods
According to the guide of the provincial greenhouse gas emissions list preparation and city construction in Shanghai statistical yearbook data (2005-2015), carbon emissions of Municipal Solid Waste in Shanghai were estimated by the IPCC (intergovernmental panel on climate change) recommended model [2]. Based on the LCA model, the characteristics and influencing factors of
greenhouse gas emission of domestic garbage were discussed, and the main influencing factors were determined.

2.1. The Carbon Emission of Transportation
Transport is the main cause of carbon emissions. At present, there is no direct monitoring data of carbon emissions in the process of garbage transportation, so this study calculated carbon emissions through energy consumption in the process of collection and transportation. The IPCC recommends that greenhouse gas emissions from energy use are determined by the amount of energy used and its emission factors. According to the IPCC [2], Carbon dioxide emissions are calculated as follows:

\[ D_t = \sum_{i=1}^{n} \varepsilon_i D_i \]  

where: \( D_t \) is Total carbon dioxide emissions; \( i \) is type i energy; \( \varepsilon_i \) is Carbon dioxide emission coefficient of energy i (table 1); \( D_i \) is the consumption of energy i; \( n \) is the number of energy.

| Type                | Gasoline | Diesel | Electric power | Biomass energy |
|---------------------|----------|--------|----------------|----------------|
| Emission factor     | 2.26 kg/L | 3.16 kg/L | 0.997 kg/kWh  | 1.97 kg/L      |

2.2. Carbon Emissions from Sanitary Landfill
The sanitary landfill method adopts the method of low layer anti-seepage, garbage layered landfill, and the top layer covered with soil after compaction, so that the garbage can be fermented under anaerobic conditions to achieve harmless treatment [3]. Compared with other treatment methods, sanitary landfill has the characteristics of large treatment capacity, low construction investment, simple operation process and low operating cost. The main problem brought by sanitary landfill method is that site selection is difficult, but not all urban suburbs can find suitable sanitary landfill sites [4]. According to the 2006 IPCC carbon emission guidelines, the calculation of carbon emissions is as follows:

Without methane collection, the emission equivalents of methane and carbon dioxide are as follows:

\[ E_{CH_4} = W \cdot DOC \cdot DOC_f \cdot MCF \cdot F \times (16/12) \]  
\[ E_{CO_2} = W \cdot DOC \cdot DOC_f \cdot (1-MCF^F) \times (44/12) \]

where \( W \) is the weight of Municipal Solid Waste; \( DOC \) is Biodegradable organic carbon (IPCC recommended default value is 14%); \( DOC_f \) is the actual decomposable organic carbon ratio, (IPCC recommended default value is 50%); \( MCF \) is Methane oxidation factor; \( F \) is Proportion of CH\(_4\) volume in landfill gas.

2.3. Carbon Emissions from Incineration
The carbon emission equivalent generated by domestic waste combustion is [5]:

\[ E_{CO_2} = W \cdot CF \cdot OF \times (44/12) = 0.561W \]  

where \( CF \) is Combustible carbon content of domestic waste; \( OF \) is an oxidation factor.

Burning 1 kg of waste is equivalent to reducing 0.24 kg of carbon dioxide, therefore, the emission reduction effect of household waste incineration instead of coal burning is [6]:

\[ E_r = 0.24W \]

2.4. Carbon Emissions from Compost
The main greenhouse gases in the composting process are CH\(_4\) and N\(_2\)O [7].
$E_{CH_4} = W \times EF \times 10^{-3}$  \hspace{1cm} (6)

$E_{N_2O} = W \times EF \times 10^{-3}$  \hspace{1cm} (7)

where: $W$ is the total amount of household waste treated by composting ($10^4$ t); $EF$ is CH$_4$/N$_2$O emission factor for composting treatment (g/kg).

3. Result and Discussion

3.1. Characteristics of Municipal Solid Waste in Shanghai

The total amount of domestic garbage collected and transported in Shanghai from 2005 to 2015 is shown in figure 1. During the six years from 2005 to 2010, the total amount of domestic garbage collected and transported has been on a steady rise. However, with the restriction of Shanghai’s urban population, the total amount of municipal solid waste tends to be stable after 2010. Especially after 2014, due to the strict restrictions of Shanghai on urban population, the total amount of domestic garbage collected in the past two years dropped to about 6.1 million tons and remained stable.

![Figure 1. Shanghai municipal solid waste removal/ 104 tons 2005-2015.](image)

Different processing methods from 2005 to 2015 are shown in table 2. According to the analysis of relevant data of Shanghai municipal solid waste treatment from 2005 to 2015, Shanghai solid waste treatment basically presents the trend of sanitary landfill treatment volume > incineration treatment volume > composting treatment volume. In 2015, the harmless disposal capacity of domestic garbage in Shanghai was 6.132 million tons, of which the sanitary landfill capacity was 3.93 million tons, the incineration capacity was 2.05 million tons, and the composting capacity was only about 340 thousand tons. However, in recent years, the proportion of sanitary landfill treatment has decreased, and the amount of incineration treatment has been increasing gradually [8]. The proportion of incineration treatment for power generation has been increasing, and the amount of composting treatment has also been decreasing.

3.2. Carbon Emission from Transportation

Daily output of domestic garbage per capital in Pudong new area is 0.71 kg/day, while that in Shanghai is 0.77 kg/day. Basically, the carbon emission of the whole process of collection and transportation in Pudong new area can be used to calculate the carbon emission of the whole process of collection and transportation in Shanghai. The daily garbage collection volume of Pudong new area
is 2,535.46 tons, and the carbon emission of the collection and transportation is 40,368.2 kg, so the daily garbage collection volume of Shanghai is 16,800 tons, and the carbon emission of the collection and transportation is 267,480.36 kg, that is, the carbon emission of the domestic garbage collection and transportation in Shanghai in 2015 is about 97,600 tons.

### Table 2. Domestic waste disposal capacity in Shanghai in 2005-2015.

| Year | Sanitary landfill | Burning | Compost |
|------|-------------------|---------|---------|
| 2005 | 69.7              | 102.4   | 50.2    |
| 2006 | 208.8             | 114.5   | 57.9    |
| 2007 | 314.5             | 103.6   | 41.8    |
| 2008 | 367.1             | 117.8   | 20.7    |
| 2009 | 380.7             | 106.1   | 15.2    |
| 2010 | 416.5             | 108.2   | 25.2    |
| 2012 | 377.5             | 103.6   | 117.4   |
| 2013 | 419.0             | 170.0   | 76.7    |
| 2014 | 328.8             | 238.5   | 41.2    |
| 2015 | 329.2             | 250.0   | 34.0    |

3.3. Carbon Emission from Treatment

The total carbon emissions from the treatment process from 2005 to 2015 are shown in figure 2. Generally speaking, the carbon emission of domestic waste has been on the rise, which has been stable in the past two years, especially after 2014. The change of total carbon emission is most affected by the total amount of domestic garbage treatment, and the change trend is basically the same as that of the total amount of domestic garbage treatment in Shanghai.

![Figure 2. Total carbon emissions from domestic garbage in Shanghai, 2005-2015.](image)

Carbon emissions from sanitary landfill, incineration and composting are as shown in table 3. As shown in the table, Shanghai’s domestic waste carbon emissions totalled 4.6028 million tons in 2015. The annual carbon emission of sanitary landfill treatment is the largest, mainly because the carbon dioxide equivalent of sanitary landfill treatment is the largest, and the proportion of sanitary landfill treatment in the total treatment volume is also the largest.
Table 3. Carbon emissions from Shanghai sanitary landfills during 2005-2015 (104t).

| Year | Sanitary Landfill | Burning | Compost |
|------|-------------------|---------|---------|
| 2005 | 77.23             | 34.48   | 16.77   |
| 2006 | 230.69            | 38.55   | 19.34   |
| 2007 | 348.47            | 34.88   | 13.96   |
| 2008 | 406.75            | 39.67   | 6.91    |
| 2009 | 421.82            | 35.72   | 5.08    |
| 2010 | 461.48            | 34.84   | 8.42    |
| 2011 | 401.87            | 19.93   | 2.61    |
| 2012 | 418.27            | 34.88   | 39.21   |
| 2013 | 464.25            | 57.24   | 25.62   |
| 2014 | 364.31            | 80.31   | 13.76   |
| 2015 | 364.75            | 84.18   | 11.36   |

4. Conclusion
The harmlessness of household garbage in Shanghai has reached 100%, and almost all municipal household garbage adopts harmlessness treatment technology. In the harmless treatment, sanitary landfill accounts for the largest proportion, followed by incineration treatment, but in recent years the amount of domestic garbage incineration treatment has increased.

The total carbon emission of household waste in Shanghai was 4.7 million tons in 2015; the process of collection and transportation accounted for 2.2%, and the carbon emission in the transportation phase accounted for 95% of the emissions in the whole process. The treatment process accounts for 97.8% and is the main source of carbon emissions from domestic waste. Among them, sanitary landfill is the main source of carbon emissions from domestic waste treatment in Shanghai, accounting for about 79%.

We suggested using clean energy and optimizing the collection and transportation routes to reduce carbon emissions in the transportation process; we will increase the proportion of electricity generated by incineration and make rational use of landfill methane to reduce carbon emissions from the treatment process.

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