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Analysis of Main Factors on Evaluation and Selection of Wet Waste Disposal Modes: A Case Study of Universities in Shanghai, China

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Abstract: This paper explores greenhouse gas emission intensity and economy of centralized and on-site wet waste disposal mode, while comprehensively evaluating the two modes for decision-making. Based on the fieldwork in Shanghai's 20 campuses of 15 universities, multiple scenarios that can reflect the different levels of technology and management in reality, were set for the following studies. The greenhouse gas emissions generated from centralized and on-site disposal modes of wet waste were calculated in two emission scenarios using Life Cycle Assessment, Life Cycle Inventory, and the IPCC 2006 method. Additionally, the continuous cost input from the universities for the two disposal modes was analyzed in three cost-input scenarios using the Net Present Value method. Furthermore, a comprehensive evaluation of the two modes was also conducted by using Analytic Hierarchy Process and Fuzzy Comprehensive Evaluation under the five main factors of greenhouse gas emission—control, economy, stability, education and innovation, and bargaining power for municipal sanitation departments. The results revealed that the centralized disposal mode is superior to the on-site disposal mode in terms of greenhouse gas emission control and economy. The centralized disposal mode is a more rational choice due to the better comprehensive evaluation performance. It was also emphasized that the construction of the wet waste disposal system is so complicated that the academic community and the policymakers may have to pay more attention to the integration of system design, industrial development, and other aspects of wet waste disposal.

Keywords: wet waste; kitchen waste; food waste; centralized disposal; on-site disposal; greenhouse gas emission; economy; comprehensive evaluation

1. Introduction

First, it is necessary to define and explain three important concepts to help readers clearly understand the following contents of this paper.

Wet waste—Since China has not yet formed a unified definition or category, "wet waste" in this paper refers to "food waste, leftovers, expired food, melon peel and fruit stone, flowers and plants, Chinese medicine residue, and other perishable household waste". The definition is taken from Shanghai Regulations for The Management of Household Waste [1], and the reasons are listed as follows:

- The term "wet waste" and its definition are used in the study region of Shanghai, which is a natural fit for the study;
- This definition has a broad representation, which can effectively satisfy the division of high moisture and high organic components from household waste across China. For example, the municipal definition of "food waste" in Beijing (the capital of China) is as follows: "perishable household waste including vegetable, melon and fruit peel, leftovers and wasted food, as well as residues, processing wastes, and waste edible oils produced by enterprises and public institutions in food processing and catering

services" [2]. It is obvious that the definition adopted by Beijing is highly consistent with that adopted by Shanghai;

- As the first basis for compulsory classification of household waste in China, Shanghai's regulations have demonstrative value and long-term effectiveness.

Centralized disposal refers to wet waste disposal where the wet waste is collected at the source, then transferred, transported, and concentrated to large-scale anaerobic digestion disposal plants by the municipal sanitation department.

On-site disposal refers to wet waste disposal where the wet waste is not transported and concentrated by the municipal sanitation department after its collection at the source, but is directly disposed of by small-scale aerobic composting equipment. Although the technology of the on-site disposal equipment includes aerobic composting, physical crushing-extrusion-dehydration, biological reduction, etc. [3,4], the most widely used technology that conforms to the current concept of green development is aerobic composting. Additionally, according to the investigation, there is almost no pilot project of on-site disposal using the technology of anaerobic digestion in Shanghai.

Carbon Peak and Carbon Neutrality—these are two goals of the greenhouse gas (GHG) emission control for China, which were announced at the general debate of the 75th Session of the United Nations General Assembly. Carbon Peak and Carbon Neutrality refer to reducing the GHG emissions progressively after they peak by 2030 and achieving GHG neutrality by 2060, respectively. The word "Carbon" refers to not only CO_2 but all seven anthropogenic GHGs defined by the United Nations Framework Convention on Climate Change (UNFCCC), including CH_4, N_2O, etc. [5,6].

At present, wet waste disposal in Shanghai plays a critical role in municipal management due to the implementation of compulsory source classification of household waste. In 2021, the amount of the wet waste separated reached 10,311 tons per day, an increase of 89% over 2019, but the city's total disposal capacity of wet waste was only 8030 tons per day [7]. To balance the increasing disposal demand and inadequate disposal capacity, Shanghai is building new large-scale centralized disposal projects while experimenting with small-scale on-site disposal in schools, communities, and other social entities.

However, a series of new policies and new development goals require Shanghai's wet waste disposal system, which is under construction, to be rethought. China introduced the goals of Carbon Peak and Carbon Neutrality, which highlighted the reduction of greenhouse gas (GHG) emissions and the promotion of eco-friendly development. The GHG emissions from wet waste disposal are estimated to account for about 6% of society's total GHG discharge [8], thus the GHG emissions control in the industry of wet waste disposal is important. However, affected by the past idea of "disposal capacity first", the construction of the wet waste disposal system prioritizes disposal capacity, which results in the GHG emission control not being regarded as an important factor. Additionally, many pilot projects of the on-site disposal heavily rely on subsidies from the government. This places a big burden on the municipal public spending impacted by the COVID-19 pandemic and the fiscal-taxation change, while the economy of those on-site projects without the subsidies is not clear. Besides, Shanghai is making an effort to achieve delicacy management. The fieldwork suggested that each social entity's preference for the wet waste disposal mode is affected by other factors such as the availability of land resources, the stability of disposal equipment, the value of environmental education, etc. Hence, there is a need for the evaluation within multiple factors to help the decision-makers select the wet waste disposal mode with the greatest social utility.

On the basis of an analysis of the present situation, this paper aims to provide a scientific basis for further policymaking related to the construction of the wet waste disposal system. Based on the fieldwork, this paper focuses on the overall 20 campuses of 15 universities in Shanghai that participated in the pilot project of on-site wet waste disposal. The hypothetical situation where the universities selected the centralized wet waste disposal mode was added to compare with the on-site one. The GHG emissions (including emissions from energy consumption, CH_4 and N_2O escaping, and GHG emission savings)

from both modes were calculated, and the cumulative cost input for the universities as investors on the two modes was analyzed. By setting multiple scenarios, this paper provides the respective lower limit and upper limit of GHG emissions and cost input, which can better reflect the differences caused by the different levels of technology and management. Besides, combining two methods, a comprehensive evaluation for the two modes was conducted under the consideration of GHG emission control, economy, and other factors.

2. Literature Review

2.1. Accounting of GHG Emissions from the Wet Waste Disposal

Chen et al. established the Life Cycle Assessment (LCA) framework and Life Cycle Inventory (LCI) formation, to investigate the GHG emissions under three wet waste disposal modes in Shanghai pilot communities: mixed collection-incineration, separate collection-centralized aerobic composting, and separate collection-anaerobic digestion-biogas for power generation [9]. Zhan et al. used the accounting method of the IPCC National Greenhouse Gas Inventory Guidelines 2006 and the LCA to study the carbon emission and resource re-utilization of wet waste disposal under the mode of mixed collection-incineration and separate collection-on-site aerobic composting from three pilot communities in Putuo District, Shanghai [10]. Ghosh et al. used the IPCC method, the First-Order Decay (FOD) method, and so forth to estimate CH_4 emissions and energy reuse potentials from the landfill of household waste in Delhi, India [11], and Du et al. used similar methods and ideas to quantify CH_4 emissions from municipal solid waste landfills in China over 10 years from 2003 to 2013 [12]. Taking two different disposal paths of the high organic components of household waste: landfill and anaerobic digestion, Liu et al. performed the LCA and sensitivity analysis for the GHG emissions [13]. Turner et al. investigated the process of household waste recycling after source separation, contributing the data of GHG emission factor as close to ISO 14040 as possible to the industry [14]. Some studies showed that the amount of GHG emissions from the transportation of household waste is too small to have a significant impact on the overall results [9,13,15], and can even be omitted in the study [16] so waste disposal researchers would pay more attention to the optimization of transportation routes other than transportation emission control [17–19]. Some studies also omitted the calculation of GHG emissions for sewage treatment in the wet waste disposal process [16,20].

In summary, first, China's domestic and foreign research on the accounting of GHG emissions from the disposal process of household waste, including wet waste, is mainly based on the LCA method system. In that case, the process of disposal will be disassembled and refined. Therefore, the core of the study is to clarify the input and output of material and energy flow on the LCA system boundary, and the flow's transfer among the subdivisions in the LCA system. Second, for the specific calculation of GHG emissions, almost all the research used the method from IPCC 2006 National Greenhouse Gas Inventory Guidelines (IPCC 2006) [21], or the fine-tuning method based on the IPCC 2006. Third, many studies omitted the accounting of GHG emissions from transportation and secondary sewage treatment, which makes the results less systematic and weakens the effectiveness of LCA and LCI. Finally, for most studies, each calculation parameter was a single value, resulting in a single value for emission amount and re-utilized product amount as well. While high-quality data and rigorous calculations can guarantee that single-value results are representative of reality, they are weak in explaining the uncertainty and volatility of reality, which have difficulty reflecting the difference caused by different technology levels and management skills in actual activities.

2.2. Economy of Wet Waste Disposal Mode

Wang evaluated the whole anaerobic digestion process of the wet waste disposal project under the Build-Operate-Transfer (BOT) operation mode; the aspects of economy, Net Present Value (NPV) and Internal Return Rate (IRR) were used to highlight the time value of all kinds of funds in the life cycle of the project [22]. By investigating the situation

of household waste disposal in a city in Guangdong province, China, Chen et al. analyzed and compared the environmental and economic factors of landfill and incineration under the BOT operation mode. Cost and income accounting were carried out in terms of the three aspects of investment, operation cost, and fund recovery [23]. Focusing on a Chinese city, He analyzed the unit cost and profit of the large-size household waste disposal according to the disposal process, and pointed out the uncertainty risk of the transportation cost and disposal cost [24]. Jia studied the effect of compulsory classification of household waste in Shanghai and calculated the incremental cost and benefit of the full link from the source classification to the end disposal [25]. Xiao et al. summarized the management mode adopted by Shanghai after the implementation of the compulsory classification of household waste and disassembled the cost of waste disposal from the source to the end according to the disposal process. It was pointed out that the large increase of management cost is due to the increase of the propaganda investment and disposal cost [26]. Mayer et al. analyzed and compared the marginal costs of high organic waste under three disposal modes of anaerobic digestion, hydrothermal carbonization, and incineration by calculating Levelized Costs of Exergy (LCOE). The results showed that the anaerobic digestion mode was the most economical [27]. Zheng et al. investigated more than 10 Chinese enterprises that produced equipment for on-site wet waste disposal, then concluded that the land occupation per unit disposal capacity is inversely related to the disposal capacity of equipment, and the energy consumption per unit disposal capacity is negatively related to the capacity of equipment [28].

For the economic problem of waste disposal, studies have shown that cost–benefit is an effective cut-in perspective, which can not only explore the cost and revenue of each node in the full link from collection to disposal with sufficient data, but also make it possible to focus only on the front and rear changes of funds and regard the intermediate specific capital flowing as a "black" box when it is difficult to obtain detailed operational information about the project. Besides, the method that can combine the discount rate, depreciation rate, and other time-related factors, such as NPV, can make the result better reflect the economy of waste disposal as a long-term activity affected by ongoing time. It is also worth noting that with the improvement of equipment's disposal capacity, the marginal incremental cost of land use, power consumption, and other peripheral resources has a decreasing trend.

2.3. Comprehensive Evaluation Method

For things affected by multiple factors, in order to reflect the scientific nature, fairness, and systematicity of their evaluation, it is necessary to adopt a comprehensive evaluation method that can organically combine multiple factors.

Li et al. sorted and summarized the literature related to comprehensive evaluation methods, and introduced the basic principles, advantages, and disadvantages of each method [29]. Zhou established an evaluation model based on the life cycle idea to study the application of waste disposal technology, in which the weight was calculated by the combination of Analytic Hierarchy Process (AHP) and Entropy Weigh (EW), and the ranking of schemes evaluated was carried out with the help of Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [30]. Li used Fuzzy Comprehensive Evaluation (FCE) to evaluate the disposal of household waste, which included four indexes: environmental factor, social factor, economic factor, and technical factor [31]. Based on the theory and method of fuzzy mathematics, Huang et al. made a comprehensive evaluation of the different disposal paths of household waste [32]. Zhang et al. evaluated different disposal modes of household waste by using AHP and FCE [33]. Wang et al. combined AHP, EC and FCE to evaluate the water environment carrying capacity of nine cities in the Guangdong–Hong Kong–Macao Greater Bay Area [34]. Based on AHP and FCE, Yu et al. evaluated the performance of Public–Private Partnership (PPP) projects of urban water environmental management [35].

It can be concluded that these comprehensive methods are suitable for the evaluation of complicated scenarios which are greatly influenced by subjective judgment and many influencing factors. Therefore, the comprehensive evaluation methods are also suitable for this paper studying the evaluation and selection of wet waste disposal modes under multiple main factors. Currently, two or more comprehensive evaluation methods are often used together by academics, because each method has its own advantages and limitations, which means they can be applied to different stages of evaluation. Aiming at the comprehensive evaluation of different environmental management schemes, the AHP is widely used to determine the weight of influencing factors to give full play to its advantage of being good at quantifying the importance of influencing factors, and the FCE is usually used to conduct the final evaluation according to the evaluators' subjective scores.

3. Materials and Methods

3.1. Research Subject

Based on fieldwork, the research subject of this paper is the overall 20 campuses of 15 universities in Shanghai which participated in the pilot projects of on-site wet waste disposal. To compare the centralized and on-site disposal, the hypothetical simulation of the universities selecting the centralized mode was added.

Figure 1 shows the locations of the universities and the centralized disposal plants in Shanghai. There are 307,303 students and faculty in total that generate wet waste of about 125,994.23 kg per day. The innate advantages of launching on-site wet waste disposal at universities include the strong sense of social responsibility, relatively abundant funds, strong environmental education atmosphere, large population density, complicated components of wet waste testing the performance of equipment effectively, and more green lands available for re-utilized fertilizer.

Figure 1. The locations of the universities and the centralized disposal plants in Shanghai. Each red and green mark, respectively, represents a university and a centralized disposal plant. The letter represents the university, and the number presents the campus attributed to the university.

The university population characteristics, lifestyles, and management styles are not fundamentally different from those of other social entities. The composition of wet waste from universities is broadly representative because of its high complexity, and the geographical location across multiple Shanghai administrative districts also fully reflects the situation of wet waste transportation. Thus, the findings and conclusions of the study can

be extended to other social entities such as primary and secondary schools, enterprises, residential communities, etc., as well as other cities.

The information about the universities and the on-site disposal projects is shown in Appendix A (Table A1).

3.2. Data Source

The data and information of equipment parameter, service condition, power consumption, disposal process, operational cost, user's attitude tendency, etc. come from the fieldwork including a field investigation and in-depth interview, which were supported by the universities, Shanghai Municipal Education Commission, Shanghai Landscaping and City Appearance Administrative Bureau, Shanghai Municipal Waste Management Office, and equipment manufacturers. The distance of transportation between the universities and centralized disposal plants is measured manually by Gaode Map. The industry data, such as the emission factor of the electricity grid, comes from the Shanghai official report and standard. Data that cannot be collected in reality come from peer-reviewed scientific studies and the IPCC 2006 default.

To reflect the differences in GHG emissions, which resulted from different levels of technology and management, there are two sets of data for most of the parameters which involve calculation, representing the most advantageous and the most disadvantageous GHG emission control scenario. There are also three sets of economic parameters for on-site disposal, representing the most advantageous, medium, and least advantageous costs, respectively, to illustrate the differences in costs caused by factors such as the different prices for equipment and the maturation of the re-utilization market.

The detailed data and information used in the calculation and the analysis are shown in Appendix A (Tables A2–A6).

3.3. Research Methods

3.3.1. Accounting of GHG Emissions

For a systematic and complete depiction of GHG emissions, the LCA system boundary and LCI for centralized and on-site disposal mode of wet waste were established. And the IPCC 2006 method was used to specifically calculate the emissions of each disposal mode under two scenarios which are most advantageous and most disadvantageous to the GHG emission control (or reduction).

In this paper, there are several categories of GHG emissions. The reasons for the categorization are that, first, according to the instruction from National Development and Reform Commission of China, the main paths to achieving Carbon Peak and Carbon Neutrality include building a clean and low-carbon energy system, promoting energy saving and GHG emission reduction in priority areas, etc. [36]. Thus, the specific calculation of emissions from energy consumption is considered. Second, as mentioned at the beginning, Carbon Peak and Carbon Neutrality include the reduction of non-CO_2 GHGs. And the disposal of wet waste emits non-CO_2 GHGs represented by CH_4 and N_2O during the process. These request this study to include the emission of CH_4 and N_2O [37,38]. Third, both centralized and on-site disposal convert wet waste into re-utilized products such as biogas-electricity, fertilizer, etc. These re-utilized products can replace similar products produced by the drive of fossil energy to reduce the anthropogenic GHG emissions for the whole society [39–41]. Therefore, the GHG emission saving effect from re-utilized products, which is important for Carbon Peak and Carbon Neutrality, is considered in this study as well. For all those reasons, the inventories of GHG emissions are divided into three categories: emissions from energy consumption (CO_2 emissions caused by chemical production, and fossil fuel and power consumption), emissions from CH_4 or N_2O (non-CO_2 emissions), and emission savings (GHG compensation by re-utilized products). This categorization is also widely used in other research [9,16,42].

In IPCC 2006, the general method for calculating anthropogenic GHG emissions is to multiply information about the extent of human activity by a coefficient that quantifies emissions

per unit activity. The former is called Activity Data (*AD*), and the latter is called Emission Factor (*EF*) [43]. Thus, the formula for calculating GHG emissions is generally as follows:

$$Emissions = AD \times EF. \tag{1}$$

According to IPCC 2006, the CO_2 converted from the organic material of wet waste and the microorganism is ignored due to biogenic origin. This idea was applied by many other researchers. In this case, only CO_2 emissions from energy consumption are included.

3.3.2. Economic Analysis

Since wet waste disposal requires long-term continuous investment, based on the universities as the sole funder without any subsidy, the *NPV* method was used to estimate the long-term cumulative cost input of universities for each disposal mode. Especially, there are three scenarios for on-site disposal which are most advantageous, medium, and most disadvantageous to cost input control, respectively.

The formula for calculating the cumulative *NPV* is as follows:

$$NPV = \sum_{t=1}^{T} \frac{C_{in,t}}{(1+r)^t} - C_{out}, \tag{2}$$

where $C_{in,\,t}$ is the net cash flow in *t* period, C_{out} is the initial investment, *T* is the project life, *r* is the discount rate.

If the initial investment is regarded as the net cash flow in year zero, the Formula (2) can be rewritten as follows:

$$NPV = \sum_{t=0}^{T} \frac{C_{in,t}}{(1+r)^t}. \tag{3}$$

3.3.3. Comprehensive Evaluation within Multiple Factors

According to the fieldwork, GHG emission control, economy, stability, education and innovation, and bargaining power for municipal sanitation departments are designated as the five main factors influencing the evaluation for wet waste disposal modes. The interpretations of stability, education and innovation, and bargaining power for municipal sanitation departments are as follows:

Stability indicates the ability of the wet waste disposal mode to consistently meet disposal demand. It depends on the failure rate of disposal equipment and supporting facilities, tolerance to the purity of wet waste, aging speed, and redundancy disposal ability to deal with risks.

The pilot universities believe that on-site disposal has the value of environmental education and the value of innovative construction of ecological civilization. The facility of on-site disposal at those universities has not only become the teaching and scientific research bases for teachers and students of Environment, Biology, etc., but also as a relatively novel mode of household waste disposal, has played an important role in promoting waste classification, reduction of leftovers, separation of tableware and waste, etc.

The pilot on-site disposal can also be used as a reason, based on the depth interviews of the universities, to limit price increase when negotiating with the municipal sanitation department for wet waste disposal charge, since there is still a large amount of wet waste generated in campus beyond the capacity of pilot on-site disposal and other household waste needing to be taken away by the municipal sanitation department.

Due to the subjectivity and fuzziness of decision-making when social entities are selecting the disposal mode, the AHP was used to determine the weight of each factor, and FCE was used to evaluate and compare the modes.

The steps in the AHP to determine the weight of factors are as follows:

First, a pairwise comparison matrix is constructed based on the importance of each factor to the decision-making objective. The quantification of importance is based on the scale of 1–9 (Table 1) proposed by Saaty [44,45].

Table 1. The AHP scale for pairwise factors.

Scale	Signification
1	The two factors are of equal importance.
3	The former is slightly more important than the latter.
5	The former is significantly more important than the latter.
7	The former is very important in comparison with the latter.
9	The former is extremely important in comparison with the latter.
2, 4, 6, 8	The median value of the importance comparison.

Assuming that there are n factors, according to the scale above to quantify the importance, the constructed pairwise comparison matrix A is as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \tag{4}$$

where a_{ij} is the quantified importance of i-th factor relative to the j-th factor. a_{ij} and a_{ji} are reciprocal.

Second, based on the pairwise comparison matrix, the weight of factors can be derived by the formula as follows:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}, \tag{5}$$

where w_i is the weight of the i-th factor.

The weight vector W for n factors with fuzziness can be expressed as follows:

$$W = (w_1, w_2, \ldots, w_n). \tag{6}$$

Finally, it is necessary to check the consistency rate (CR) of the pairwise comparison matrix for the reliability of the weights. The check formula is as follows:

$$CR = \frac{\lambda_{max} - n}{(n-1) \times RI}, \tag{7}$$

where λ_{max} is the largest eigenvalue of pairwise comparison matrix A, RI is the consistency index shown in Table 2. When $CR < 0.1$, the outcome of weights is reliable.

Table 2. The number of factors n and RI.

n	2	3	4	5	6	7	8
RI	0	0.58	0.90	1.12	1.24	1.32	1.14

Following the weight determination, the steps to evaluate a scheme within multiple factors by FCE are as follows:

First, the factor vector U and evaluation-result vector V are constructed as follows:

$$U = (u_1, u_2, \ldots, u_m) \tag{8}$$

$$V = (v_1, v_2, \ldots, v_n), \tag{9}$$

where u_m is the m-th factor, v_n is the n-th evaluation-result which can be defined by grades, comments, values, levels, etc.

Second, if the membership (0~1) of the m-th factor in vector U to the 1st evaluation-result in vector V is r_{m1}, then all evaluation-results of the single m-th factor can be represented by a fuzzy vector R_m as follows:

$$R_m = (r_{m1}, r_{m2}, \ldots, r_{mn}). \tag{10}$$

The fuzzy comprehensive evaluation matrix $R_{m \times n}$, which is composed by m fuzzy vectors of single-factor evaluation-results $R_1, R_2, \ldots, R_m$, is as follows:

$$R_{m \times n} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}, \tag{11}$$

where r_{mn} is the membership of the m-th factor to the n-th evaluation result.

Third, considering the differences in the importance of each factor, FCE needs to transform the weight vector W (from AHP) which is related to U into fuzzy vector B which is related to V, that is as follows:

$$B = W_{1 \times m} \blacksquare R_{m \times n} , \tag{12}$$

where $\blacksquare$ is a synthetic operator for the comprehensive evaluation, which is generally the matrix multiplication.

Finally, the final evaluation result of the scheme is the evaluation result corresponding to the maximum membership value in vector B.

In this paper, the evaluation result for disposal modes is defined by "Good" and "Bad". The membership is from 0 to 1, and the sum of all memberships for each main factor is equal to 1. If a disposal mode has a significant advantage for a certain main factor, then the score for the "Good" evaluation result of this disposal mode is 1, and the score for the "Bad" evaluation result of another disposal mode is 1. If no disposal mode has a significant advantage for a certain main factor, the score depends on the situation.

4. Results

4.1. Analysis of GHG Emissions Accounting

The LCA system boundary and LCI of the two wet waste disposal modes are shown in Figures 2 and 3. The material flow begins with the generation and collection of wet garbage on campus, then goes through each functional unit of the disposal process. The labels "Best" and "Worst" in all figures indicate the outcomes of two scenarios which are most advantageous and most disadvantageous to the GHG emission control, respectively. All GHG emissions are measured in CO_2 equivalent.

The summarized inventories of the GHG emissions and re-utilized products are shown in Tables 3 and 4.

Figure 4 shows the net GHG emissions of centralized and on-site wet waste disposal. The net GHG emissions are the algebraic sum of three categories of GHG emissions, where the amount of emission from energy consumption and CH_4 or N_2O is a negative value, and the amount of GHG emission savings is a positive value. The net GHG emissions of the centralized disposal in the most advantageous and most disadvantageous scenarios are $-51,972.18$ kg CO_2eq/d and $-10,443.61$ kg CO_2eq/d, respectively. Correspondingly, for on-site disposal, the net GHG emissions are 381.04 kg CO_2eq/d and 39,561.81 kg CO_2eq/d, respectively.

This result means that for GHG emissions control or reduction, the performance of centralized disposal is much better than that of on-site disposal. Even in the most disadvantageous scenario, the centralized disposal is much superior to the on-site disposal that is in the most advantageous scenario. Besides, on-site disposal always contributes a positive net volume of GHG emissions to the environment no matter which scenario it is in, which means on-site cannot achieve substantial GHG reduction.
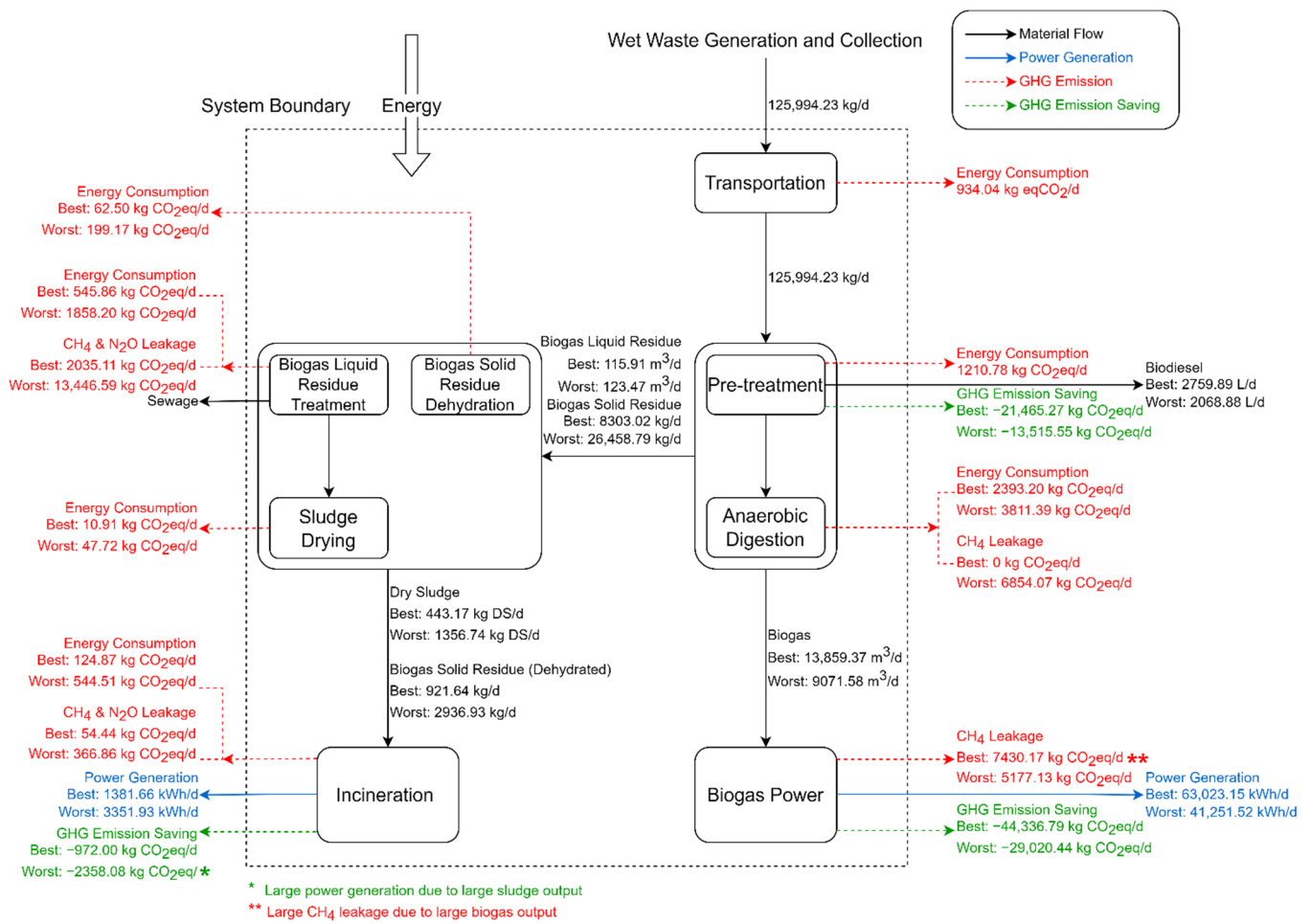
Figure 2. The LCA system boundary and LCI of the centralized wet waste disposal mode.
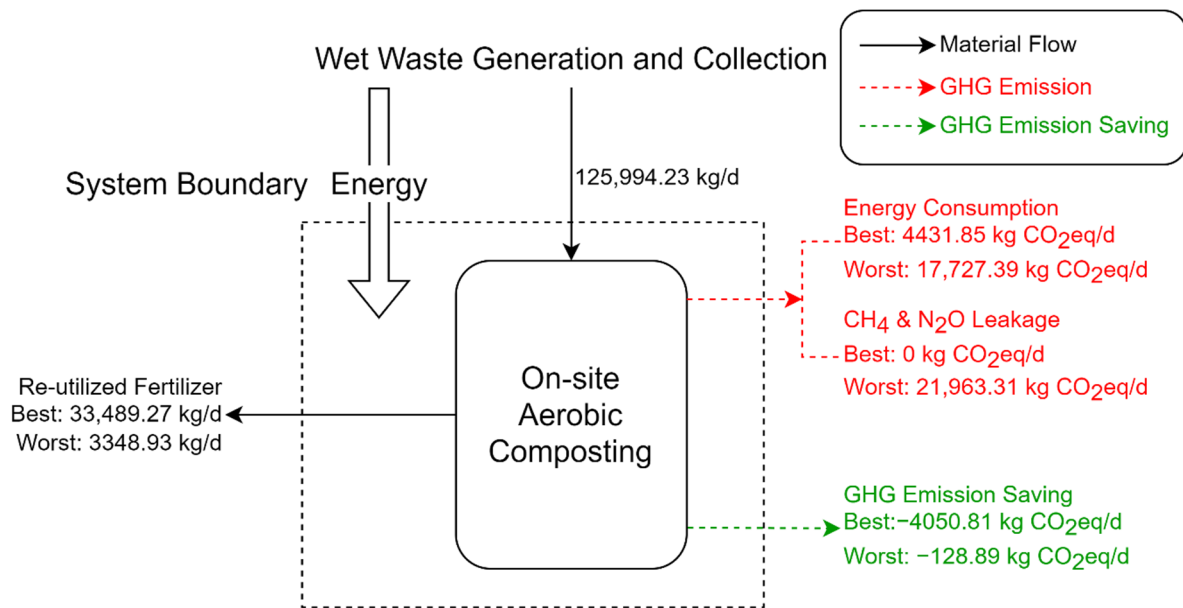

Figure 3. The LCA system boundary and LCI of the on-site wet waste disposal mode.

Table 3. The inventories of the GHG emissions and re-utilized products for centralized wet waste disposal mode.

		TP. [1]	PT. [2]	AD [3]	BSRD [4]	BLRT [5]	SD [6]	I [7]	BP [8]
Emissions from Energy Consumption *	Best	934.04	1210.78	2393.20	62.50	545.86	10.91	124.87	
	Worst			3811.39	199.17	1858.20	47.72	544.51	
Emissions from CH_4 & N_2O *	Best			0		2035.11		54.44	7430.17
	Worst			6854.07		13,446.59		366.86	5177.13
Emission Savings *	Best		−21,465.27					−972.00	−44,336.79
	Worst		−13,515.55					−2358.08	−29,020.44
Re-utilized Products **	Best		Biodiesel 2759.89	Biogas 13,859.37				Electricity 1381.66	Electricity 63,023.15
	Worst		2068.88	9071.58				3351.93	41,251.52

[1] TP.—transportation; [2] PT.—pre-treatment; [3] AD—anaerobic digestion; [4] BSRD—biogas solid residue dehydration; [5] BLRT—biogas liquid residue treatment; [6] SD—sludge drying; [7] I—incineration; [8] BP—biogas power. All abbreviations of heading in this table are derived from Figure 2. * The unit refers to the amount of GHG emission is kg CO_2/d. ** The unit refers to the amount of re-utilized production is L/d for the biodiesel, m^3/d for the biogas, and kWh/d for the electricity.

Table 4. The inventories of the GHG emissions and re-utilized products for on-site wet waste disposal mode.

		On-Site Aerobic Composting	
Emissions from Energy Consumption *	Best		4431.85
	Worst		17,727.39
Emissions from CH_4 & N_2O *	Best		0
	Worst		21,963.31
Emission Savings *	Best		−4050.81
	Worst		−128.89
Re-utilized Products **	Best	Re-utilized Fertilizer	33,489.27
	Worst		3348.93

* The unit refers to the amount of GHG emission is kg CO_2/d. ** The unit refers to the amount of re-utilized fertilizer is kg/d.
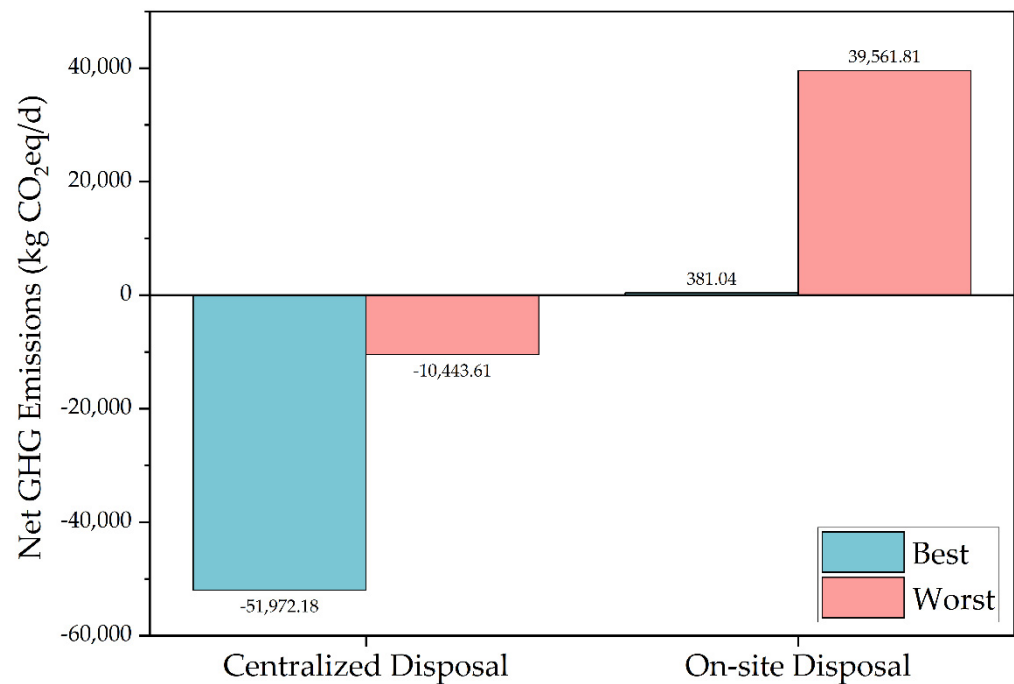
Figure 4. The net GHG emissions of centralized and on-site wet waste disposal.

Figure 5 shows the increase and the reduction contribution of GHG emissions from each functional unit. Biogas solid residue dehydration, biogas liquid residue treatment, and sludge drying in centralized disposal are regarded as one unit, and the replacement of chemical fertilizer by re-utilized fertilizer in on-site disposal is regarded as a separate unit.

The biodiesel and biogas from centralized disposal contribute great value to GHG emission savings: they can be transformed to electricity 30,512.11 kWh/d and 63,023.15 kWh/d, respectively, in the best situation, and 19,211.87 kWh/d and 41,251.52 kWh/d, respectively, in the worst situation. Biogas solid residue dehydration, biogas liquid residue treatment, sludge drying, and anaerobic digestion together contribute the main GHG emissions for centralized disposal, due to the relatively large energy consumption and CH_4 or N_2O escaping.

The aerobic composting may cause immense GHG emissions, which are 4431.85 kg CO_2eq/d in the most advantageous scenario, and 39,690.70 kg CO_2eq/d in the most disadvantageous scenario. The latter is nearly nine times larger than the former. In that case, the GHG emissions saving from re-utilized fertilizer is offset. In the best situation, re-utilized fertilizer contributes 4050.81 kg CO_2eq/d to GHG emission savings, which means that on-site disposal hardly reaches a balance between the GHGs' output and input for the environment. The results suggest that on-site disposal equipment needs high-level management to prevent CH_4 and N_2O from escaping, or on-site disposal projects may become an intensive GHG emission source.

4.2. Analysis of Economy

The cumulative NPVs of cost input on centralized and on-site wet waste disposal are shown in Figure 6. The "Best", "Medium", and "Worst" in the legend indicate the outcomes of three scenarios which are most advantageous, medium, and most disadvantageous to cost control of on-site disposal, respectively. Since the design life of on-site disposal equipment is about ten years, the cumulative NPV of the first ten years is the main concern. For on-site disposal, the area between the best and worst NPV curves is the "possible domain", which means all possible situations of the universities' cost input of selecting on-site disposal under the influence of different equipment prices, market maturity, etc.
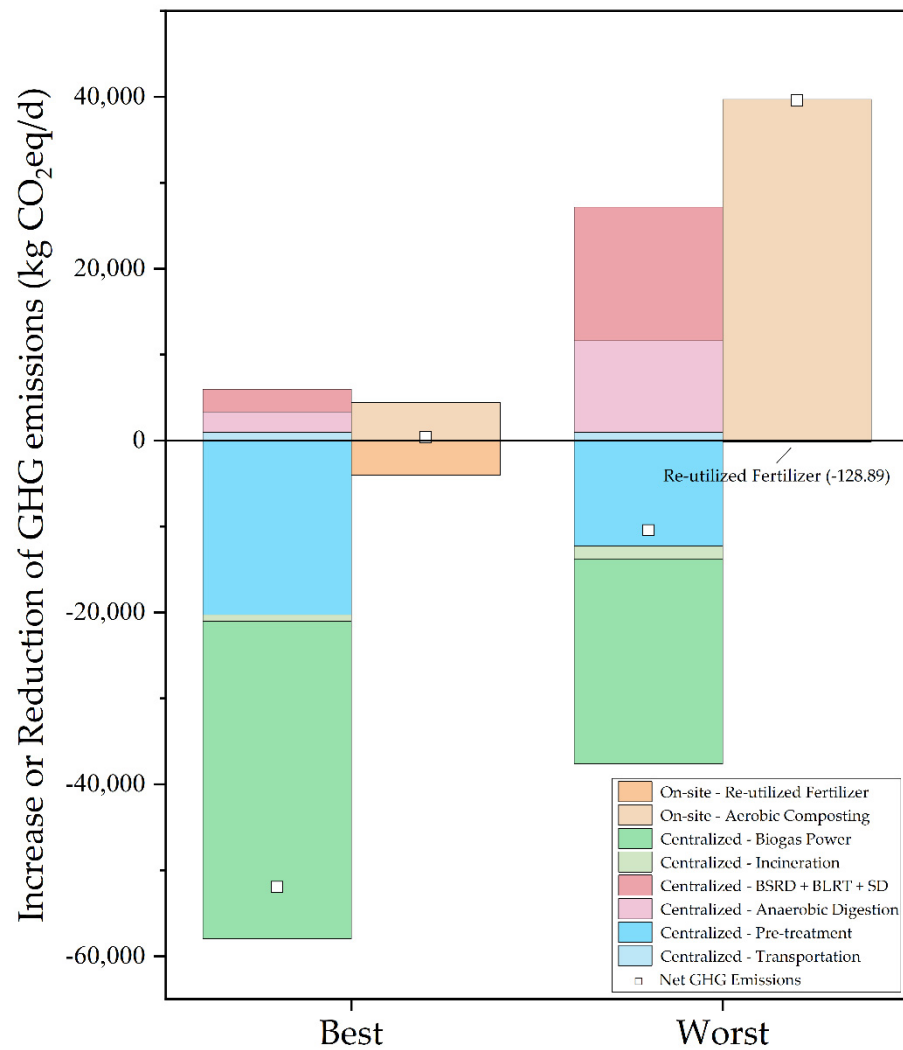
Figure 5. The increase or reduction of the GHG emissions from each functional unit.

In the most advantageous scenario, if the universities all select the on-site disposal, the cost input in the first two years is not as ideal as the centralized disposal, but from the third year, the on-site disposal will be more economical than the centralized disposal. By the eighth year, it is possible to "recoup" from the benefits of re-utilized fertilizer, and this time point is at the end of the life of most on-site disposal equipment.

The cumulative NPV of on-site disposal in the medium scenario tends not to change greatly over time, which means that the benefits from the re-utilized fertilizer can offset a large part of the continuous operational costs. Under the circumstances, on-site disposal is equal to centralized disposal in cumulative NPV after sixteen years, but this length of time is well beyond the working life of most on-site disposal equipment.

It is obvious that, for the universities as a whole, over a ten-year evaluation period, whether the on-site disposal is superior to the centralized disposal in terms of cost input depends on whether the overall operation situation is in the upper part of the "possible domain". If the universities cannot achieve excellent cost control in the phase of fixed assets increase and continuous operation, it would be a safer option to select the centralized disposal mode.
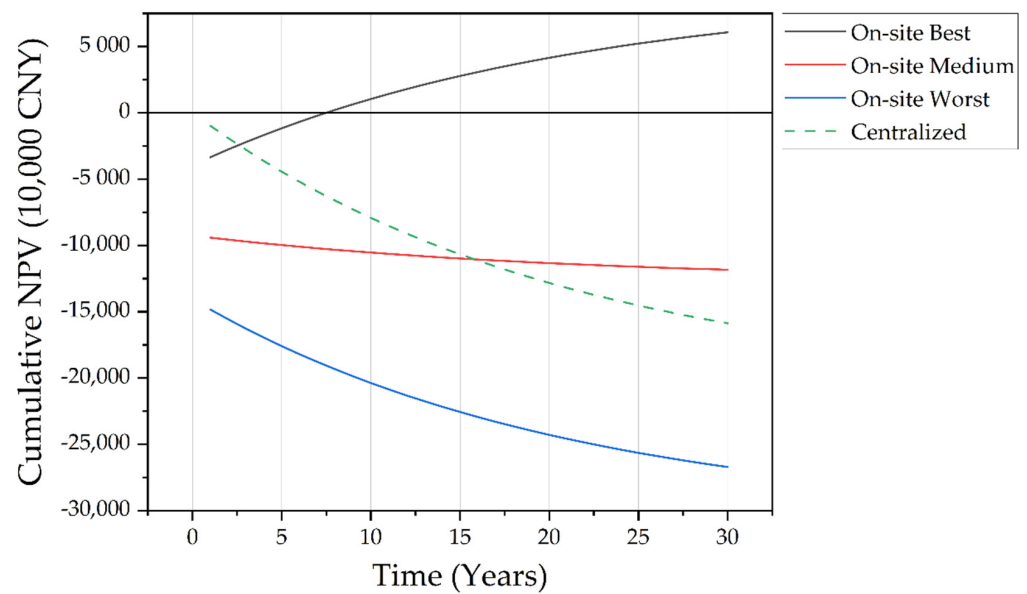
Figure 6. The cumulative NPVs of cost input on centralized and on-site wet waste disposal. The discount rate used in the calculation is 4.9%, which is an interest rate for loans of more than five years from the People's Bank of China. According to the fieldwork, the charge of centralized disposal paid by the universities is usually 54 CNY per bucket (240 L) which is about 0.225 CNY per kilogram wet waste, the charge is assumed to be constant in the calculation.

4.3. Comprehensive Evaluation of Centralized and On-Site Disposal Mode

Based on the fieldwork and subjective judgment, the pairwise comparison matrix of the five main factors including GHG emissions control (GHGEC), economy, stability, education and innovation (EI), and bargaining power for municipal sanitation departments (BPMSD) is shown in Figure 7. The importance of each factor compared to another factor can be introduced by the AHP scale, for example, GHGEC is as important as EI, while GHGEC is slightly more important than BPMSD.

The consistency of the pairwise comparison matrix is checked, *CR* = 0.0539 < 0.1, thus the results of factor importance are reliable.

Table 5 shows the weight of each main factor and the corresponding priority sorted by the weight. The weights of the factors of GHGEC, economy, stability, EI, and BPMSD are 0.6005, 0.0871, 0.1860, 0.0393, and 0.0871, respectively. The priority sorting indicates that, for the universities, the overall importance of the five main factors influencing the selection of waste wet disposal mode in descending order is: GHGEC > stability > economy = BPMSD > EI.

Table 5. The weight and priority of each main factor.

	GHGEC	Economy	Stability	EI	BPMSD
Weight	0.6005	0.0871	0.1860	0.0393	0.0871
Priority	1	3	2	5	3

The fuzzy comprehensive evaluation matrixes of the two disposal modes are shown in Figure 8. The membership for each factor in FCE is based on the following:

1. For GHGEC, according to the previous accounting and analysis, centralized disposal has significant advantages over on-site disposal. Therefore, the memberships of centralized mode to "Good" and "Bad" are 1 and 0, respectively. The memberships of on-site disposal to "Good" and "Bad" are 0 and 1, respectively;

2. For economy, according to the previous cumulative NPV results, with a ten-year operational period, the score is determined by the ratio of the area between the centralized disposal curve and the best on-site disposal curve in "possible domain" to the area of

the whole "possible domain". Based on the calculation, the memberships of centralized mode to "Good" and "Bad" are 0.77 and 0.23, respectively. The memberships of on-site disposal to "Good" and "Bad" are 0.23 and 0.77, respectively;

3. For stability, according to the fieldwork, a large amount of the on-site disposal equipment was not available due to failure, which accounted for 37.5% of all equipment. In this case, the universities have no choice but to call the municipal sanitation department for transferring disposal. However, centralized disposal relies on large-scale disposal plants which hardly fail to operate for some reason. Hence, centralized disposal has significant advantages over on-site disposal. The memberships of centralized mode to "Good" and "Bad" are 1 and 0, respectively. The memberships of on-site disposal to "Good" and "Bad" are 0 and 1, respectively;

4. For the EI, according to the fieldwork, universities believe that on-site disposal has a good value of environmental education and innovative construction of an environmentally friendly society. Besides, although on-site disposal shows a high potential for GHG emissions and the high possibility of cost input, it can continue to play an educational role as a negative example. Compared with on-site disposal, centralized disposal has no obvious function of education and innovation. Therefore, the memberships of centralized mode to "Good" and "Bad" are 0 and 1, respectively. The memberships of on-site disposal to "Good" and "Bad" are given 0.60 and 0.40, respectively;

5. For BPMSD, only by selecting on-site disposal can universities have additional bargaining power for municipal sanitation department, so on-site disposal has significant advantages over centralized disposal. Therefore, the memberships of centralized mode to "Good" and "Bad" are 1 and 0, respectively. The memberships of on-site disposal to "Good" and "Bad" are 0 and 1, respectively.

	GHGEC	Economy	Stability	EI	BPMSD
GHGEC	1	1/3	1/7	1	3
Economy	3	1	1/7	3	5
Stability	7	7	1	7	9
EI	1	1/3	1/7	1	3
BPMSD	1/3	1/5	1/9	1/3	1

Figure 7. The pairwise comparison matrix of the five main factors.

	Good	Bad
GHGEC	1	0
Economy	0.77	0.23
Stability	1	0
EI	0	1
BPMSD	0	1

(**a**)

	Good	Bad
GHGEC	0	1
Economy	0.23	0.77
Stability	0	1
EI	0.60	0.40
BPMSD	1	0

(**b**)

Figure 8. The fuzzy comprehensive evaluation matrix of (**a**) centralized disposal mode and (**b**) on-site disposal mod.

Figure 9 shows the final evaluation results (final memberships) after the combination of the fuzzy comprehensive evaluation matrix and the weight of each main factor. The final memberships of centralized disposal mode to "Good" and "Bad" are 0.8615 and 0.1385, respectively. The final memberships of on-site disposal mode to "Good" and "Bad" are 0.1307 and 0.8693, respectively. Therefore, the final evaluation result of centralized disposal belongs to "Good" and the final evaluation result of on-site disposal belongs to "Bad". This indicates that the centralized disposal mode of wet waste is a more rational choice.
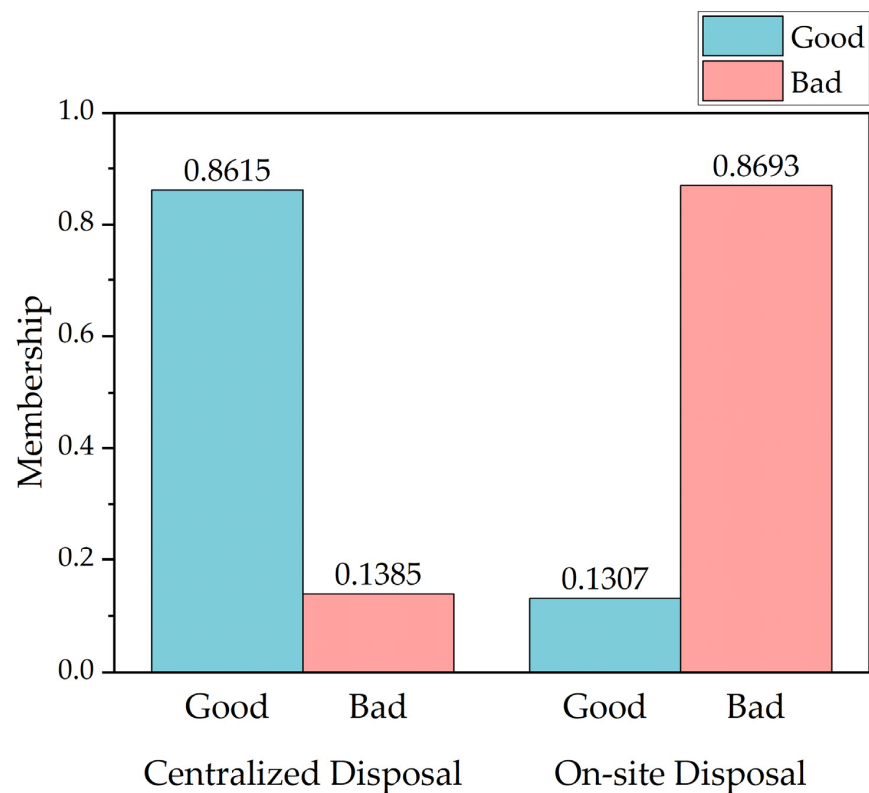

Figure 9. The final membership to the evaluation-result of the centralized disposal and on-site disposal of wet waste.

5. Discussion and Conclusions

The GHG emission intensity and economy of centralized and on-site wet waste disposal modes are examined in this paper. Furthermore, a comprehensive evaluation for the two-modes selection was conducted. The discussions and conclusions are as follows:

The centralized waste wet disposal mode is much better than the on-site one in terms of GHG emission reduction. This can be interpreted in two ways. First, the centralized disposal mode is supported by mature technology and sound management, which maintains not only a high upper limit for the ability to control GHG emissions, but also a high lower limit for that. This inference is supported by other research [20,42,46]. Second, the aerobic composting used by the on-site disposal mode is a technology with naturally high GHG emission potential, since even the on-site disposal in the best scenario cannot achieve a positive net GHG emission value. Furthermore, the CH_4 and N_2O emissions of the on-site disposal in the worst situation are nearly nine times larger than that in the best situation. This may be caused by the different levels of anti-GHG-escaping measures, which have been observed in the fieldwork, and by the negligence of staff in GHG escaping control such as piling up the compost at will, which has also been observed. Thus, it is necessary for the existing on-site disposal projects to strengthen the control of GHG escape to prevent the aerobic composting facilities from becoming the "lighthouse of GHG emission".

From the perspective of cost control, it is a more secure way for social entities to select the centralized disposal operated and supported by the municipal sanitation department. Within a ten-year time span, although the centralized disposal cannot return the capital, its total cost input is less than that of on-site disposal in most cases. However, once the municipal sanitation department raises the disposal charge, the outcome may be changed a lot. This is possible since municipal finance has been impacted by the COVID-19 pandemic and the fiscal-taxation change, while recently the proposal of a universal charging system for household waste disposal has been widely discussed. Additionally, for on-site disposal without subsidies, equipment and re-utilized product price accounts for a significant influence on the total cost input. The combination of a low equipment price and a high re-utilized fertilizer price may make the wet waste disposal profitable. However, to meet the two conditions is a big challenge for the social entities since it depends on not only the inherent elements such as the bargaining power, but also on external opportunities such as the maturity of the re-utilized product market. Moreover, according to Shanghai's administration, when wet waste is disposed of by the centralized mode, most of the incineration ash or residues are landfilled for an economic reason. Although researchers are always trying to develop technologies for re-utilizing incineration residues such as making building materials, for now landfill is still the most economical and efficient option for the administration. Thus, it is necessary to acknowledge that re-ultized fertilizer from on-site disposal has more circular-economy value than incineration residues from centralized disposal. It also means that there is a waste of end product for centralized disposal, which could be a potential optimization perspective for revenue in the future.

This study suggests that the centralized disposal is a more rational choice than the on-site disposal when multiple factors are considered. Compared to the on-site disposal, the centralized disposal has higher memberships to all three most important factors including GHG emission control, stability, and economy. These three factors can be regarded as universal factors, then be applied to all kinds of social entities. Thus, even though the study focuses on the universities, the superiority of centralized disposal is widely applicable. Additionally, the weight priority order implies that, on the premise of satisfying the demand of wet waste disposal, the GHG emission intensity and the stable performance of disposal function should be prioritized, while the economic factors such as cost input could be slightly less important. However, the comprehensive evaluation for the two disposal modes was limited by the absence of a systematic survey and more evaluation-results. Further research could be conducted based on a more detailed survey and a multi-evaluation-result set.

The combination of on-site wet waste disposal and anaerobic digestion in Chinese cities may be a topic worth studying, although there is no real case of the combination

in Shanghai. Anaerobic digestion has the advantage of lowering GHG emissions, while on-site disposal has the advantage of being quick to deploy, thus the combination of both may facilitate the wet waste disposal after household waste classification. In China, there was a short-lived trend that small-scale anaerobic digestion projects were deployed in rural areas [47–50], but not in cities. Due to the relatively high technical threshold, the small-scale equipment of anaerobic digestion is mainly imported from abroad, and the local suppliers are few in the market [51]. However, there are many cases of small-scale anaerobic digestion for on-site wet waste disposal in the cities of developed countries [52–54]; these suggest that the combination of on-site wet waste disposal and anaerobic digestion may be possible in Chinese cities. Therefore, further research could focus on the technology development of small-scale anaerobic digestion for wet waste disposal, while dealing with the potential coordination problem with municipal management, for the better disposal of wet waste in Chinese cities. There is another key finding of this paper, that is, the synergy of wet waste disposal policies should be strengthened. A good environmental management policy usually has strong synergy, which deals with two or more issues. However, although the on-site disposal is an efficient way to re-utilize resources, it will likely exacerbate the GHG emissions. The adoption of centralized disposal is beneficial to the goals of Carbon Peak and Carbon Neutrality, it neither meets the disposal demand in a short time due to the long construction period, nor promotes innovation and public participation in the construction of ecological civilization. Therefore, considering there are still several years before the time limit to Carbon Peak, a disposal system, where the centralized projects are completed as quickly as possible and the on-site projects are deployed as half-way solutions, might be advisable. Due to the complexity of the wet waste disposal issue, the academic community and policy-making departments are suggested to pay more attention to the integration of system design, industrial development, and other aspects related to wet waste disposal.

Appendix A

Table A1. The overview of wet waste on-site disposal in Shanghai pilot universities.

University	Campus	Number of Equipment	Number of Equipment in Service	Disposal Capacity (t/d)	One-Time Acquisition Cost (10,000 CNY)	Acquisition Costs of Unit Disposal Capacity [10,000 CNY/(t/d)]	Start Year of Use
A	A1	3 (Type I) 1 (Type II)	0 —	3 2	120	— 60	2015
B	B1	1	1	0.2	6.8	—	2020
C	C1	1	1	0.3	33	110	2014
D	D1	1	1	1.5	—	—	2019
E	E1	1	1	0.5	73	146	2015
F	F1	1	—	0.5	In 2020, the market price of a same-brand and same-type equipment with the capacity of 2 t/d is 685,000 CNY.		Not be investigated
G	G1	1	1	0.5	38	76	2018
H	H1	1	1	0.6	58	96.7	2020
I	I1	2	1	0.8	38	—	2012
J	J1 J2	1 1	0 1	1 0.3	— —	— —	Under construction 2020
K	K1 K2	1 1	1 0	0.5 0.5	— —	— —	2020 Under construction
L	L1	2	2	0.6	60	50	2018
M	M1	1	0	0.2	4.8	—	2020
N	N1 N2	2 2	1 2	0.84 0.65	— —	— —	2012 —
O	O1 O2 O3	1 1 1	1 0 0	1.5 2 3	100+ (estimated) 46 —	66.7 23 —	2020

Table A2. The parameters and data used in the calculation of GHG emission (Part 1). The labels "Best" and "Worst" in the table indicate the value corresponding to two emission scenarios which are most advantageous and most disadvantageous to the GHG emission control, respectively (the same below).

Parameter		Value		Unit	Source
Total wet waste yield		125,994.23		kg waste/d	Fieldwork & Calculation
Fuel consumption of transportation vehicle		0.000125		L/kg·km	[9,39,55,56]
Average transportation distance		21.49		km	Measurement on Gaode Map
Density of diesel fuel		0.86		kg/L	[57]
Emission Factor of Diesel		3.209		kg CO_2/kg diesel	[57]
Factor of crude oil extraction	Best		0.023	kg/kg waste	[58]
	Worst		0.017		[59]
Conversion efficiency of crude oil to biodiesel		0.85			[60]
Density of biodiesel		0.88		kg/L	[61]
Heat value of biodiesel	Best		39,800	kJ/L	[62]
	Worst		33,430		[61]
Electricity consumption of pre-treatment		0.01366		kWh/kg waste	[58]
Emission factor of electricity		0.7035		kg CO_2/kWh	[57]
Electricity consumption of anaerobic digestion equipment	Best		0.027	kWh/kg waste	[63]
	Worst		0.043		
CH_4 emission factor of anaerobic digestion	Best		0	kg CH_4/kg waste	[21]
	Worst		0.002		
Non-fossil-source CH_4 GWP-100		27.2			[21]
Factor of biogas solid residue generation (undehydrated)	Best		0.0659	kg/kg waste	[58]
	Worst		0.21		[42]
Water content of undehydrated biogas solid residue		90%			[42,58,64]
Water content of dehydrated biogas solid residue		10%			
Electricity consumption of dehydration equipment		0.0107		kWh/kg wet biogas residue	[64]
Heat value of dehydrated biogas solid residue		15,000		kJ/kg	[65]
Conversion efficiency of heat to electricity	Best		25%		[9,10]
	Worst		20%		

Table A3. The parameters and data used in the calculation of GHG emission (Part 2).

Parameter		Value	Unit	Source
Factor of biogas liquid residue (BLR) generation	Best Worst	0.00092 0.00098	m^3/kg waste	[42] [9]
BOD concentration of BLR	Best Worst	- 8.2	kg/m^3	[9]
COD concentration of BLR	Best Worst	7.08 -	kg/m^3	[66]
General ratio of BOD/COD concentration		0.45		Industry experience
Ratio of Maximum CH_4 production in BLR treatment		0.6	kg CH_4/kg	[21]
Correction factor of CH_4		0.165		[67]
Total nitrogen concentration of BLR	Best Worst	1.99 4.78	kg/m^3	[9] [68]
Emission factor of N_2O in nitrogen removal process	Best Worst	0.005 0.035	kg/kg TN	[67] [10]
N_2O GWP-100		273		[21]
Electricity consumption of BLR treatment equipment	Best Worst	0.13 0.3	kWh/m^3	[69] [70]
Factor of dry sludge generation	Best Worst	1.2 1.34	kg/kg BOD	[70] [9]
Factor of chemical PAC addition		0.05	kg/kg dry sludge	[9]
Emission factor of chemical PAC		22.7	kg CO_2/kg PAC	[70]
Factor of chemical PAM addition	Best Worst	0.003 0.007	kg/kg dry sludge	[9]
Emission factor of chemical PAM		1.5	kg CO_2/kg PAM	[70]
Factor of chemical lime addition	Best Worst	0.1 0.3	kg/kg dry sludge	[71] [9]
Emission factor of lime		0.683	kg CO_2/kg lime	[67]

Table A4. The parameters and data used in the calculation of GHG emission (Part 3).

Parameter	Value		Unit	Source
Electricity consumption of sludge drying	Best Worst	0.035 0.05	kWh/kg	[72] [71]
Electricity consumption of dry sludge incineration	Best Worst	0.275 0.4	kWh/kg	[73] [71]
Natural gas consumption of dry sludge incineration	Best Worst	0.027 0.04	Nm^3/kg	[74]
Emission factor of natural gas		2.184	kg CO_2/Nm^3	[57]
NaOH consumption of dry sludge incineration	Best Worst	0.018 0.02	kg/kg dry sludge	[71] [73]
Emission factor of NaOH	Best Worst	1.12 1.17	kg CO_2/kg	[75] [76]
$Ca(OH)_2$ consumption of dry sludge incineration		0.00941	kg/kg dry sludge	[71]
Emission factor of $Ca(OH)_2$		0.975	kg CO_2/kg	[76]
Heat value of dry sludge	Best Worst	13,700 12,000	kJ/kg	[76] [77]
CH_4 emission factor of dry sludge incineration	Best Worst	0 0.00000485	kg/kg dry sludge	[21]
N_2O emission factor of dry sludge incineration	Best Worst	0.00045 0.00099	kg/kg dry sludge	[21]
Factor of biogas generation	Best Worst	0.11 0.072	m^3/kg waste	[42] [39]
Rate of biogas leakage		5%		Industry experience
Percentage of CH_4 in biogas		60%		Industry experience
Density of CH_4 (normal temperature and pressure)		1.9763	kg/m^3	[78]
Heat value of CH_4		35,900	kJ/m^3	[79]
Conversion efficiency of CH_4 to electricity		80%		[16]

Table A5. The parameters and data used in the calculation of GHG emission (Part 4).

Parameter	Value		Unit	Source
Electricity consumption of aerobic composting equipment	Best Worst	0.05 0.2	kWh/kg waste	Fieldwork
CH_4 Emission factor of aerobic composting	Best Worst	0 0.004	kg/kg waste	[21]
N_2O Emission factor of aerobic composting	Best Worst	0 0.00024	kg/kg waste	[21]
Percentage of organic component in wet waste	88.60%			[10]
Factor of re-utilized fertilizer generation	Best Worst	0.3 0.03		Fieldwork
Mass ratio of nitrogen in re-utilized fertilizer	Best Worst	0.0308 0.014		[10] [80]
Mass ratio of urea to nitrogen	4.29			General Standard
Efficiency of re-utilized fertilizer	Best Worst	100% 70%		Fieldwork

Table A6. The parameters and data used in the calculation of NPV. The labels "Best", "Middle", and "Worst" in this table indicate the value corresponding to three cost-input scenarios which are most advantageous, medium, and most disadvantageous to cost control of on-site disposal, respectively.

Parameter	Value		Unit	Source
Average price of equipment unit disposal capacity	Best Middle Worst	230 620 970	CNY/kg waste	Fieldwork
Construction expense of site and support facilities	Best Middle Worst	100 150 200	CNY/kg	Fieldwork
Comprehensive electricity consumption of disposal capacity per ton	Best Middle Worst	20,000 25,000 30,000	kWh/a	Fieldwork
Price of electricity	0.641		CNY/kWh	Shanghai official

Table A6. *Cont.*

Parameter	Value		Unit	Source
Strain and maintenance expense of disposal capacity per ton	Best Middle Worst	10,000 20,000 30,000	CNY/a	Fieldwork
Additional labor salary of disposal capacity per ton	Best Middle Worst	0 1000 2000	CNY/m	Fieldwork & Estimation
Re-utilized fertilizer yield	Best Middle Worst	33,489.27 18,419.10 3348.93	kg fertilizer/d	This study
Average market price of re-utilized fertilizer in operation period	Best Middle Worst	0.8 0.65 0.57	CNY/kg fertilizer	Fieldwork & Estimation
Wet waste charge for municipal sanitation	0.225		CNY/kg waste	Fieldwork
Discount rate	4.9%		People's Bank of China-Interest rates for loans over five years	

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