Energy Recovery and Waste Reduction Analysis of a Full-scale Anaerobic Digestion Food Waste Plant in Shandong

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Abstract. Methane (CH$_4$) generation via anaerobic digestion is a promising technology for energy recovery and waste reduction. In this study, the techno-economic analysis of a CH$_4$ production from food waste (FW) was carried out. An anaerobic digestion FW plant was capable of treating 100 t/d, which was authorized to operate for 17 years. The pretreatment and anaerobic digestion processes were used to produce CH$_4$ and recovery crude oil. The total investment and annual operational costs of FW treatment plant were 42,786,030 and 2413380 RMB, respectively, while the annual pre-tax annual incomes was 6941293.6 RMB. The return on investment and payback period were 7.79% and 12.84 years, respectively. The daily treatment quantity of FW is 21t, the treatment plant starts to make profits. The assessment results indicated that FW treatment was a comprehensive engineering system, which was strongly associated with society, economy, environment and technology.

Keywords: Anaerobic digestion; Food waste; Methane production; Techno-economic analysis; Sensitivity evaluation.

1. Introduction

With the quickening pace of social-economic growth and urbanization in China, household consumption level has been increasing rapidly, which has the negative influence of the generation of a great amount of food waste (FW). The increase of FW has been a serious and global environmental problem. For example, in 2010, China had produced about 90 million tons FW,[1] which was the main component of municipal solid waste (MSW). It has been generated a large amount MSW in the past decade, being still increasing at 8%/year in China. Specifically, FW mainly generates from the catering industry, which generally consists of carbohydrates, sugars, proteins and lipids.[2] Such waste is mainly characterized by high moisture and salt contents and a large quantity of organic matter. On the other hand, FW is perishable and is easy to breed pathogenic microorganism. These characteristics of FW likely cause great pollution and waste of resources. UK households produce 7 million tons FW per year, it cost the UK £50 monthly to treat them.[3] Besides, in 2017, the subsidy for treating 1 t FW in Beijing was 170 RMB. It has been an urgent problem to deal with FW and recycle resources from FW. Generally speaking, there are three main methods of waste treatment, including incineration, landfill and compost. It is difficult to use landfill to deal with FW, due to the high moisture and salt contents. Landfill waste results in 11% emission of methane that aggravates greenhouse effect.[4] Incineration is difficult to carry out due to high water content and toxic harmful gasses.[5] Moreover, both incineration
and landfill of FW can cause the waste of resources and energy. In terms of technology and environment, anaerobic digestion is more economic and reliable. The digestion technology has been widely used in waste treatment process. It is supposed to as the most suitable way to handle FW. Anaerobic digestion (AD) technique refers to the degradable organic matter that is decomposed into CH₄, carbon dioxide (CO₂) and hydrogen sulfide (H₂S) by facultative and anaerobic bacteria under anaerobic conditions. It is widely applied in the fields of wastewater and organic waste treatments in order to realize economic development, environmental protection, greenhouse gas emission reduction and renewable energy generation. The promising technology is considered as one of the most important methods for biomass energy utilization in 21st century. Such treatment of solid waste converts solid organic matter to soluble organics, and further produces biogas. Furthermore, the biogas generated from bio-wastes is a renewable and environment friendly energy source, which consists of 50-70% CH₄, 20-50% CO₂, 2-7% H₂O, 2-5% N₂, 0-2% O₂ and less than 1% other gas. CH₄ can be used for combustion or power generation to obtain resources and energy utilization. Besides, Franchetti observed that the carbon footprint over 10 years of a scenario where FW was redirected to anaerobic digestion was 16.5% of the baseline profile, where all FW entered into a landfill. Khoo et al. employed a life-cycle assessment (LCA) and found that anaerobic digestion was the most eco-friendly way to treatment of FW in Singapore when compared to the two processes of incineration and composting. In addition, high capital cost of FW anaerobic digestion compared to landfilling and composting, strongly restricted economic incentives. This makes it more challenging for many investors. The challenges can inhibit the generalization and application of anaerobic digestion of FW, especially in China. Although anaerobic digestion has been employed around the world, there are differences in this process. Europe is the leader in anaerobic digestion, and its application has been mainly driven by the strict environmental regulations of waste treatment. Asia has the largest amount of anaerobic digesters, but most of them are household and small-scale systems that are employed in rural communities for lighting and cooking. China is reported to have more than 43 million digesters, serving about 100 million people in rural areas. All these differences in AD implementation around the world are due to socio-economic barriers, policy drivers, and process reliability and availability. Recently, various financial supports like government grants and investment tax credits have been carried out to support anaerobic digestion in China. Although anaerobic digestion has been widely used in China, only 37% of biological FW is actually employed for biological treatment. In 2015, the value of FW in China was about 200 billion RMB, but the current treatment capacity was only 19.5% of FW being hard to meet the treatment requirements. Therefore, there are still great potential and promising prospects for the application of anaerobic digestion of FW. Despite a range of environmental benefits related with anaerobic digestion, some disadvantages should be considered, which include land-use requirement, process complexity, high capital costs, and wastewater effluent that generally requires additional treatment. Developing countries like China and India usually face challenges in operating anaerobic digestion projects in spite of process maturity. Currently, there are less than 100 FW anaerobic digestion plants that maintain normal operation in China, but there is few reports regarding the techno-economic analyses of these FW treatment plants. In addition, techno-economic assessment is an important tool to analyze the economic benefits and costs of different techniques for treating solid wastes. Unfortunately, many existing or new plants are reluctant to provide access to data from the operational performance of FW anaerobic digestion, which limits a comprehensive assessment effort. For current FW anaerobic digestion facilities in China, the digestion effluent is also a challenge that affects system economics. In this work, the existing case used in the FW anaerobic digestion plant in Shandong (China), is presented to investigate the techno-economic feasibility of anaerobic digestion. Therefore, the objective of this study is devoted to exploring whether the process is feasible from the two perspectives of economic benefits and technology reliability and availability while evaluating the return on investment (ROI) and making sensitivity analysis. This work can also support a discussion on deciding to sustainably manage FW.
2. Materials and Methods

2.1. Anaerobic Digestion Process

The FW anaerobic digestion plant with capacity of 100 t/d works 365 days per year is located in Shandong, China. The plant was put into operation in 2016. The feedstock employed was mainly collected from local restaurants. The biogas and crude oil yields are 6634 Nm$^3$/d and 1.96 t/d. Batch and continuous operations were considered for bio-CH$_4$ generation with 365 days per year and 90% working-capacity. The parameters employed in this work were based on the data obtained from the aforementioned plant. The anaerobic digestion system treating FW is described in Figure 1. The main process includes pretreatment and anaerobic digestion. Pretreatment process was employed to remove sand, plastic, chopsticks and other impurities, and obtain crude oil for sale and suitable substrate for biogas production. The anaerobic digestion of FW with capacity of 100 t/d was operated 35°C. Economic analysis depends highly on the detailed process models for the separation process, digestion technology, and on a large number of references with different capital investment.

2.2. Economic Analysis Method

Although anaerobic digestion of FW focuses on environmental benefits, its economic investment and benefits also have to be considered. The economic feasibility is associated with the process profitability, total capital investment, total operational costs, and the return on investment (ROI).

2.2.1. Total investment. Total investment $C_1$ (RMB) refers to the sum of fixed-asset $C_2$ (RMB) and current asset $C_3$ (RMB) in a certain period of time. Fixed assets refers to the total investment of fixed assets in all sectors of the national economy. The FW treatment engineering mainly includes equipment procurement $C_4$ (RMB) and direct and indirect costs of construction plants $C_5$ (RMB). The investment in current assets refers to the increase in raw materials, in-process products, finished goods and commodity stocks, and the inventory of materials. In this work, the current asset investment cost is 5% of the fixed investment.[13] The quotation and cost of equipment are provided by the FW treatment plant. Thus, the relationship among these parameters ($C_1$-$C_5$) are described in Eqs.(1-2):

$$C_1 = C_2 + C_3 \quad (1)$$

$$C_2 = C_4 + C_5 \quad (2)$$

2.2.2. Annual operating cost. The annual operational cost mainly consists of raw material, water-electricity, repairing, transportation costs, and laboratory and office expenses. The maintenance and repair costs should not exceed 20% of the depreciation charge. The office expense, transportation and equipment maintenance fees are calculated in 12 months. There are 47 workers, and their average salary are 4000 RMB per month. The water consumption of the whole project is about 7190.5 t/a, of which the production water consumption is 6314.5 t/a, and the domestic water volume is 876 t/a.

2.2.3. Annual income. The main source of income for FW treatment consists of three major components, one is the income from the sale of anaerobic digestion products (e.g. CH$_4$ and crude oil), one is the income from biogas power generation and the other is the subsidy income from the treatment of FW. Biogas mainly consists of CH$_4$ that is usually used for direct combustion for cooking, drying agricultural and sideline products, heating, lighting and gas welding. CH$_4$ can also be used as fuel for internal combustion engines and for the production of chemical raw materials such as methanol, formalin and carbon tetrachloride, and biogas power generation. The price of direct sales of biogas is 1-1.2 RMB/m$^3$. The 1m$^3$ biogas can be employed for electricity of 1.8-2.2 kW/h. According to the national electricity price of 0.538 RMB/(kW/h), the price of 1m$^3$ biogas is 0.97-1.18 RMB. The biogas also can be compressed and purified to a higher purity gas. The price of high purity CH$_4$ is 3.12-3.58 RMB/m$^3$. 1 m$^3$ biogas can purified into 0.5 m$^3$ of CH$_4$, and the price of CH$_4$ is 1.56-1.79 RMB/m$^3$. Nonetheless, it was difficult and expensive to purify biogas, especially in the developing countries according to previous report. In this section, 50% of biogas is used for power generation and
50% is sold directly. The crude oil obtained from the pretreatment process has an economic benefit of 780-1000 RMB/t. The subsidy income is divided into two parts, which are subsidies for the industry and subsidies for the local government. In recent years, China has paid more and more attention to FW treatment, and the subsidies have also been rising. The FW treatment plant is located in Shandong, the subsidy for treating 1 ton FW is 150 RMB. Thus, the local subsidy is the main income for the waste treatment plant, which can guarantee the economic benefits of FW disposal.

2.2.4. Investment payback period. The investment payback period is the length of time for obtaining the cumulative benefit. The standard investment payback period is the average investment payback period stipulated according to the technical and economic characteristics of the industry or department. And the investment recovery period is divided into static and dynamic investment recovery periods. The FW treatment plant doesn't consider the time value of funds, it is chosen to calculate the static investment recovery period Eq. (3). The return on investment (ROI) reflect the payback period of the investment, being described in Eq. (4). It refers to the value that should be returned through investment. The economic return is the enterprise receives from investment activity. Besides, the main equipment is depreciated for 17 years, and the depreciation expense is calculated according to the straight-line depreciation method. The method refers to the average amortization of the original value of the assets after deducting the net residual value within the estimated useful life. The straight line depreciation and the recovery cost per ton of FW are calculated according to Eqs.(5-6).

\[
S = \frac{C_1}{A_2 - A_1} \times 100\% \tag{3}
\]

\[
ROI = \frac{A_3}{C_1} \times 100\% \tag{4}
\]

\[
A_4 = \frac{C_1 - C_6}{Y} \tag{5}
\]

\[
C_7 = \frac{A_4 + \frac{A_4}{Q}}{Q} \tag{6}
\]

Here, S is static investment payback period (%), \( C_1 \) represents total investment (RMB), \( A_1 \) is annual operating cost (RMB); \( A_2 \) is related annual income (RMB). \( C_6 \) refers to residual value (RMB), being usually valued as 5% of the total investment, \( C_7 \) is the recovery cost per ton of FW (RMB); \( A_3 \) relates to annual profit after tax (RMB), \( A_4 \) represents annual depreciation (RMB), ROI is return on investment (%), Y is the effective lifetime of equipment (17 years), Q is fixed to the annual quantities of FW, being 100 ton/d in the plant, in total 36500 tons every year.

2.2.5. Sensitivity analysis. Parameter values impact operational costs and incomes, thereby affecting the profitability of FW treatment system. This work makes use of the fluctuations in prices of the largest part in each subtotal to reveal the fluctuant degree of the important data, such as the total capital investment, annual operational expenses and annual incomes, thus finding the sensitive factors affected the economic benefits. Subsequently it is important to analyze their influence degree, sensitivity to the economic benefit and the ability of the FW treatment to withstand risks. The fluctuation is set at ±20% to investigate the impact on corporate profits.

3. Results and Discussion

3.1. Technological Evaluation

Anaerobic digestion has multiple environmental benefits like reduction and treatment of waste, renewable energy generation, and decrease in mineral fertilizer application. Historically, some large-scale digesters are more popular in developed countries, since they require high capital
investment and larger infrastructure. In most cases, the generated biogas is employed for combined heat and power applications. The combined process for methane production from FW is described in Figure 1. The process can be divided into four systems: pretreatment, oil recovery and purification, anaerobic fermentation and biogas purification and utilization systems. Firstly, the FW is collected in the unloading room to drain. Then, the collected FW was pretreated through a mechanical sorting system to simple screening of the FW. Particles larger than 5mm, such as plastic and metal, cannot be completely crushed, so they were discharged. Then, the separated FW was subjected to high-temperature sterilization for wet-heat hydrolysis, eliminating adverse effect on the anaerobes of bio-CH₄ generation system. Next, the FW were performed solid-liquid separation. Subsequently the de-oiling process was carried out to further reduce the oil content from FW substrate. The liquid obtained from the above step was transported into a mechanical centrifugal oil-water separator to obtain crude oil and organic wastewater. The liquid effluent from anaerobic digestion was treated by using a wastewater treatment system. The continuous stirred tank reactor (CSTR) was employed to FW reduction and CH₄ generation. The bioprocess was performed with 10%-15% total solid (TS) under mesophilic (35°C) condition. The fresh FW was added to the fermenter continuously and the digestion process of the digested liquid was reduced, and the acid production and methanogenesis of the process were carried out in the single tank system. Finally, the biogas was collected and upgraded, while the digestate (residue liquid and solid) was separated and treated respectively. Thyberg and Tonjes also found that overall environmental burdens were lowered by separating FW and treating it with anaerobic digestion, subsequently composting the residue solid. Biogas was upgraded to produce natural gas, and the residue was dewatered to obtain low moisture solid. Besides, the treatment techniques of point and area source pollution were employed to reduce volatile organic compounds (VOCs). The two facilities belong to chemical and biological deodorization systems. Finally, the waste gas generated in the whole process is discharged through the 8-15m chimney after spray washing, the waste water is initially treated by anaerobic digestion and then transferred to the sewage treatment plant for further treatment, and the solid waste is transported to the waste incineration plant for incineration. The environmental indicators mainly follow standards and guidelines like the implementation of industry standards (CJJ184-2012) in China. Nonetheless, it was unavailable to the scarcity of information on the in-situ monitoring of VOCs emission from a full-scale FW treatment plant. The outflow of the wet-heat hydrolysis unit contained more compounds with low threshold. The olfactory nuisance mainly attributed to organosulfurs from the thermal hydrolysis, separating and crushing units. Along with VOC emission, NH₃ and H₂S also caused odorous nuisance problem. A similar study showed that resources investigation in environmental behavior had received insufficient attention. FW has a higher organic fraction compared to most anaerobic digestion feedstocks, thereby having a more biogas yield and lower greenhouse gases because no resources are required for feedstock generation. Although the aims of FW treatment were reduce, reuse and recovery, low emission and energy recovery strongly depended on technological option that affected business profits for the FW treatment plant. Therefore, FW, materials, and water as well as air are the main focuses in the waste management and resources conservation field.
3.2. Capital and Operational Costs

A full-scale AD systems for FW treatment need high capital investment and maintenance, where the economics of the plants are obviously different. Capital cost is the major contributor to the production cost for the FW anaerobic digestion systems. Operational cost lies on anaerobic digestion plant size, and was observed to be different from $20 to $110/t of feedstock treated by the plants. As mentioned above, the total investment was divided into fixed and current investment costs. The fixed investment was divided into equipment purchase and direct and indirect costs of civil engineering. Table 1 shows the total equipment purchase cost is 13,217,847 RMB, among which the pretreatment system equipment accounts for a large proportion of 30.26%. Solid phase pre-hydrolysis and anaerobic digestion also respectively make up 16.76% and 15.76%. Table 2 reveals the direct and indirect costs of the plant. The value is 27,530,753 RMB, of which the largest proportion is the site renovation. Therefore, the fixed investment cost is 40,748,600 RMB. In this work, the current asset investment cost is 5% of the fixed investment, which is 2,037,430 RMB. The total investment is 42,786,030 RMB, and the indirect and direct costs are the largest proportion of the total investment. The FW treatment plant is expected to run for 17 years, and the investment equivalent to each ton FW is 68.95 RMB. As described in Table 3, annual operational costs of the FW plant, containing the cost of raw material, the electricity fee, process water fee, maintenance and repair fee, laboratory cost, transport charge, labor costs, office fee and equipment lubrication and maintenance. In addition, the raw material includes some chemicals such as NaOH, N₂, NaHCO₃, H₂SO₄, flocculant, polyaluminum chloride and desulfurizer. Their total price is 208,000 RMB. The labor wages account for the largest proportion and due to its variability to the plant. The labor costs are the most important factor affecting the annual operational costs. Therefore, the annual operational costs are 3609342 RMB, which is 98.88 RMB per ton of treatment fee. The recovery cost can be calculated as 131.01 RMB/t according to Eq. (6).
Table 1. Equipment purchase costs.

| Equipment Function | Cost (RMB) | Ratio |
|--------------------|------------|-------|
| Pretreatment Crush | 4000315    | 30.26%|
| Solid-liquid separation Impurity separation | 1484560 | 11.23%|
| Organic liquid slag removal Sanding | 221650 | 1.68%|
| Solid phase deep hydrolysis Pulping | 2214930 | 16.76%|
| Oil extraction system Separation | 1162040 | 8.79%|
| Air compressor Compress | 58080 | 0.44%|
| Plate and frame filter press Sludge pretreatment | 137720 | 1.04%|
| Steam boiler Temperature control | 440000 | 3.33%|
| Anaerobic digestion Fermentation | 2083576 | 15.76%|
| Energy recovery Gas storage | 94600 | 0.72%|
| Deodorization Deodorization | 385000 | 2.91%|
| Receiving system Receiving | 830376 | 6.28%|
| Waste transportation truck Transportation | 105000 | 0.80%|
| Total / | 13217847 | 100% |

Table 2. Direct and indirect costs.

| Type | Composition | Cost (RMB) | Ratio |
|------|-------------|------------|-------|
| Direct | Device installation | 1070000 | 3.89%|
| | Pipeline cost | 504246 | 1.83%|
| | Electrical system | 1453250 | 5.28%|
| | Construction | 5201664 | 18.89%|
| | Site renovation | 11000000 | 39.96%|
| | Instrumentation and control | 886193 | 3.22%|
| | Spare cost | 135900 | 0.49%|
| Indirect | Engineering and supervision | 1160000 | 4.21%|
| | Legal fee | 205100 | 0.75%|
| | Contractor fee | 3000000 | 10.90%|
| | Fees for technical services | 964400 | 3.50%|
| | Leachate system engineering | 1950000 | 7.08%|
| Total / | 27530753 | 100% |

Table 3. Annual operational costs.

| Quantity | Unit price (RMB) | Price (RMB) |
|----------|-----------------|-------------|
| Raw material | / | / | 208000 |
| Process water fee | 7190.5 t | 4 RMB/t | 28762 |
| Electricity fee | 410000 kWh | 0.538 RMB/kWh | 220580 |
| Maintenance and repair fee | 12 month | 100 RMB/d | 360000 |
| Laboratory cost | 12 month | 100 RMB/d | 36000 |
| Transport charge | 12 month | 666.7 RMB/d | 240000 |
| Labor costs | 47 people | 48000 RMB/a | 2256000 |
| Office fee | 12 month | 333.3 RMB/d | 120000 |
| Equipment lubrication and maintenance | 12 month | 388.9 RMB/d | 140000 |
| Total / | / | / | 3609342 |

3.3. Profitability Analysis

The annual income of the FW treatment plant is divided into two parts of sales and subsidy incomes. Table 4 shows the detailed information of the annual income. The output of biogas is 6634 Nm³/d, which runs for 365 days. CH₄ production is 2421410 m³ per year. In this part, 50% of biogas is used for electricity generation, 50% of biogas is sold.1Nm³ CH₄ can generates 2.2 kW/h electricity.1 kW/h electricity can be sold 0.538 RMB. The profit of Electricity generation are 1432990 RMB. The price of 1Nm³ CH₄ in the market is about 1 RMB, the corresponding annual-sales of CH₄ are 1210705 RMB. Besides, the plant recovers 1.96 tons of crude oil per day. The price of crude oil on the market is 780
and the annual income from crude oil is 558012 RMB. Therefore, the annual income from CH4 and crude oil is 2979422 RMB. The subsidy for treating 1 ton of FW in local government (Shandong) is 150 RMB, and the annual income is 5475000 RMB, being the largest proportion of the main source of income for the FW treatment plant. The total annual income of the plant is 8676617 RMB. Corporate income tax is levied at 20%, which lead to the total annual income after tax of 6941293.6 RMB. It is equivalent to 190.1 RMB of income per ton of FW treatment fee while the recycling cost is 131.01 RMB/t. The return on investment (ROI) is calculated to be 7.79% according to Eq. (4). Therefore, the annual profit after tax of the FW treatment plant is 3331952 RMB. The static investment payback period based on Eq.(3) is 12.84 years. In other words, the FW plant need to operate about 12.84 years, then it can begin to obtain profits. Besides, the bio-CH4 has high potential for greenhouse gas emission savings if it served as a vehicle fuel. Geng et al. evaluated the environmental performance and cost effectiveness of various bus and taxi types in Shenyang (China), and concluded that the compressed natural gas buses had the lowest economic costs compared to new diesel and electric buses, showing the significant environmental effects. The operation of a passenger vehicle for 1km fueled by bio-CH4 derived from FW obviously lowered the generation of carcinogens and climate change influence. Browne et al. found that the FW-derived bio-CH4 could provide 2.8% of energy for transport in Ireland. Undoubtedly, to obtain better economics, upgrading biogas from some clustered anaerobic digestion plants at one large upgrading plant should make economic sense.

### Table 4. Waste treatment plant annual income.

| Production | Unit price  | Daily quantity | Annual output | Total price (RMB) |
|------------|-------------|----------------|---------------|------------------|
| Biogas     | 1 RMB/Nm³   | 3317 Nm³       | 1210705 Nm³   | 1210705          |
| Electricity| 0.538 RMB/(kW/h) | 7297.4 kW/h | 266351 kW/h   | 1432990          |
| Oil        | 780 RMB/ton | 1.96 ton       | 715.4 ton     | 558012           |
| Subsidy    | 150 RMB/ton | 100 ton        | 36500 ton     | 5475000          |
| Total      |             |                |               | 86766.17         |
| After tax  |             |                |               | 6941293.6        |

### 3.4. Sensitivity Evaluation

Sensitivity evaluation was carried out to quantify the influence of the most obvious parameters on the project profitability and environmental performance. The inflation rate in the first half of 2019 is 3.9%, and the annual discount rate is 3.24%. Net present value (NVP) refers to the difference between the net cash flow generated by the investment plan and the present value of the original investment amount after discounting the cost of funds as the discount rate. The NPV function is used to calculate the income of the waste treatment plant within 17 years (Figure 2), it shows that when NPV is close to zero, the discount rate is 3.39%. Obviously, the FW treatment plant is more attractive with the reduction of discount rate. The discount rate becomes the internal rate of return (IRR) when NPV is close to zero, resulting in 4.8% IRR. When the annual discount is 3.24% the corresponding NPV is more than the zero. It means that when the discount rate ranges from 3.24% to 3.39%, the NPV is always more than zero, indicating that the FW treatment plant is economically feasible. Based on the above analysis, the sensitive factors include raw material cost, CH4 and crude oil income, the subsidy income from local government, and labor costs. In order to investigate the change in annual profits, the changes of all sensitive factors is set ± 20%. The most sensitive factor needs to be found in order to find an approach to reducing sensitivity or increasing the rate on return. As described in Figure 3, the effect of prices sensitivity on the NPV is liner. Figure 3 also reveals that the sensitivity of labor cost is the most obvious when the change range is ± 20%, which is followed by electricity generation profit and biogas profit. It shows that labor cost is becoming the biggest restriction factor for the development of waste treatment plant. The two factors are the major part of the annual income. At the same time, raw material price and oil price have the opposite effect compared with other factors. Therefore, how to improve the productivity and quality of biogas is very important for the annual incomes. Due to the limitation of the site and equipment, the food waste handled every day is floating up and down 100 t. It is assumed that the fixed cost of treating 100 t FW/d is constant, such as

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maintenance and repair fee, laboratory cost, transport charge, office fee and equipment lubrication and maintenance. Energy costs, raw material costs, labor costs and product yields vary with the quantity of treatments (Figure 4). When the daily treatment quantity of 21 tons, the waste treatment plant starts to make profits. Profit is in direct proportion to the amount of treatment. Besides, the digestion effluent could be used for liquid and solid fertilizers. The nutrients of the liquid effluent can be employed to generate struvite, as low release fertilizer, or for algae farming. After solid-liquid separation, the liquid fraction accounts for 80-90% of the total of digestion effluent, retaining 70-80% of dissolved nutrients like ammonium (NH$_4^+$-N) and fulvic acid, promoting hydroponic food production and turf growth. Krishnasamy et al. found that 1 L of digestate liquid effluent from FW with 5 L H$_2$O led to the highest foliage production and plant growth, being alleviating the toxicity of NH$_4^+$-N in a small-scale hydroponic process. The diluted effluent of anaerobic digestion was comparable to a commercial nutrient liquid during the lettuce production process. However, no report on data has specifically assessed the treatment of liquid effluent from anaerobic digestion, or investigated the economic or operational feasibility of some available approaches. Moreover, the solid fraction can be composted. Interestingly, an economic benefit can be obtained from sharing one digestate (residue liquid and solid fractions) improvement facility within an anaerobic digestion network. Under such circumstances, the digestate improvement could become a major contributor the economic feasibility of the FW treatment plant itself. Supporting the key capital costs for the digestate improvement facility was observed to have little influence on economic feasibility. These approaches to extending the value chain are considered most profitable, which need for more collaboration between anaerobic digestion plants, government organizations, universities and enterprises. Therefore, the combined bioprocess and extended anaerobic digestion networks should be employed for CH$_4$ generation and fertilizer production from FW treatment engineering due to lower CH$_4$ production cost. The implementation could facilitate closing the waste-energy-food and likely allow further application of full-scale anaerobic digestion networks.

![Figure 2. Net present value (NPV) function.](image2.png)

![Figure 3. Sensitivity analysis of different factors at a charge of ±20%.](image3.png)

![Figure 4. The profit under different quantities of processed food waste.](image4.png)
4. Conclusion
A case of full-scale anaerobic digestion plant for FW was investigated. The total capital investment and annual operational cost were 42,786,030 RMB and 2413380 RMB, respectively. The annual pre-tax income was 8676617 RMB that included 1210705 RMB from biogas sales, 1432990 RMB from electricity generation profit, 5475000 RMB from local government subsidy, and 558,012 RMB from crude oil, obtaining the annual income after tax of 6941293.6 RMB. Besides, the investment and internal rate of returns, and payback period were 7.79%, 3.39% and 12.84 years respectively. When the daily treatment quantity of FW is 21 tons, the FW treatment plant starts to make profits. Although the FW treatment process is economically feasible, the digestate (residue liquid and solid fractions) should have great potential to be used as liquid and solid fertilizers in view of the pollution reduction and resource reuse. The findings of investigations can be employed to sustainable waste management in China.

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