# POTENTIAL BIOGAS BIOFERTILIZER RECOVERY FROM ORGANIC DOMESTIC SOLID WASTE IN LIAONING PROVINCE FOR SUSTAINABLE DEVELOPMENT AND ENVIRONMENTAL

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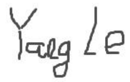
**A project report submitted in partial fulfilment of the requirements for the award of the degree of Master of Environmental Technology**

**Faculty of Engineering and Green Technology**
**Universiti Tunku Abdul Rahman**

**December 2021**

# DECLARATION

I Yang Le hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : 

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# APPROVAL FOR SUBMISSION

I certify that this project report entitled **"Potential Biogas and Biofertilizer Recovery from Organic Domestic Solid Waste in Liaoning Province for Sustainable Development and Environmental "** was prepared by **YANG LE** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Environmental Technology at Universiti Tunku Abdul Rahman.

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Signature : ____________________

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Date : _16 DECEMBER 2021_

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# POTENTIAL BIOGAS AND BIOFERTILIZER RECOVERY FROM ORGANIC DOMESTIC SOLID WASTE IN LIAONING PROVINCE FOR SUSTAINABLE DEVELOPMENT AND ENVIRONMENTAL PROTECTION

## ABSTRACT

As time goes on, the rapid increase of global municipal solid waste production has aroused people's attention to the environmental impacts such as gas emissions, landfill problems and water quality deterioration. In China, 90% of solid waste is disposed of in landfills and incineration, and China has a low level of awareness of recycling actions, which reminds the importance of good management of land use waste disposal. Among many types of municipal solid waste, organic waste is still the most concerned type. This study focuses on the conversion of organic waste into biogas and biological fertilizer to replace the traditional landfill and to support incineration treatment methods, which has a great potential to contribute to the economic cycle. Biogas is a clean energy and pollution-free emission, the sustainability and environmental impact of biogas production and organic of municipal solid waste (OFMSW) anaerobic digestion fertilizer recovery were evaluated. In order to evaluate the economic benefit and return on investment (ROI), the organic part of municipal solid waste was characterized through research and investigation, and the economic benefit evaluation was calculated. The research analysis provided includes the municipal solid Liaoning Province. The project resulted in producing clean electricity reducing the square value meters per day of land use, avoiding leachate production and treatment, production of biological fertilizer. In terms of economic benefits, electricity sales help to realize daily electricity sales through the feed in tariff (FIT), and also help to save RMB - selling biological fertilizer and daily landfill operation. In the initial capital expenditure (CAPEX) and operating expenditure (OPEX) of the biogas power plant are RMB 9103.281 million and RMB 1517.213 million / year respectively, and the OFMSW treatment fee is RMB 5.554 million / day, the ROI is 5.1 years.

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## LIST OF SYMBOLS / ABBREVIATIONS

| | |
|---|---|
| AD | Anaerobic Digestion |
| DM | Dry matter |
| WTE | Waste to Energy |
| MSW | Municipal Solid Waste |
| OFMSW | Organic Fraction Municipal Solid Waste |
| FW | Food Waste |
| CAPEX | Capital Expenditure |
| OPEX | Operational Expenditure |

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# CHAPTER 1

## 1.0 INTRODUCTION

### 1.1 Municipal Solid Waste (MSW)

Solid waste management is a hot issue, especially to the developing nations nowadays. In this chapter, the evaluation of solid waste in general was discussed. In the present decade, waste management is crucial and should be managed in more circumspect and prudent way. As the increase in the density population of a country, lead towards increment of the domestic waste generation, paves the way towards determination of environmental health when improper management of the solid waste was applied within a country.

Solid waste is solid and semi-solid waste produced by human production and consumption. It includes solid particles, garbage, sludge, waste products, damaged appliances, animal corpses, deteriorated food, human and animal feces, etc (Herman and Michael, 2002).

Starting from the analysis of solid waste at the source, we often divide it into solid waste generated in cities, solid waste generated in industrial and solid waste generated in the process of agricultural production and manufacturing. Municipal solid waste mainly refers to the solid waste generated in urban daily life or activities providing services for urban daily life, that is, municipal solid waste, mainly including human generated domestic waste, hospital waste, commercial waste and construction waste. Industrial solid waste refers to mining waste, fuel waste, chemical production and smelting waste and other solid waste generated in industrial, transportation and other production activities. Also known as industrial waste, including industrial waste, waste, sludge and other wastes. Agricultural solid waste refers to agricultural production activities. The raw solid wastes include the wastes from five agricultural industries, including planting, forestry, animal husbandry and sideline.

After years of development, China's solid waste treatment industry is already formed a relatively perfect industrial chain structure. The upstream of the solid waste treatment industry is mainly equipment manufacturing, including incineration equipment, tail gas purification equipment, dust removal equipment, kitchen waste treatment equipment, etc. The midstream industry is a solid waste treatment operation enterprise, and the downstream industry is divided into solid waste treatment, including solid waste burial, solid waste incineration and resource (Meng *et al.,*2010).

Base on Environmental Protection Agency, municipal solid waste can be sorted as our own generally known daily waste which also can be termed as garbage, consists of mixture of various types of compound and the source of these compounds can be obtained from domestic, industrial, mining or other activities (Hong, 2016). In fact, it is a group of matters that do not have any commercial value that could be a problem in the developed countries that have limited land-use space. Thus, it becomes a challenging task in the disposal of the solid waste for both developing and non-developing nations (Adhikari, Nam and Chakraborty, 2018). Thus, in overview, factors that would influence solid waste generation could be surmised due to the rapid increase in human population and urbanization.

### 1.2 Organic Fraction Municipal Solid Waste (OFMSW)

In recent years, China has developed rapidly in different aspects, great changes have taken place in the living standards of urban residents, which is reflected in the domestic waste: the composition of organic waste has increased significantly, and most of the organic waste in urban domestic waste is food waste. On the other side, China's rapid development in food trade and domestic food companies, the output of kitchen waste is also increasing. Food waste is characterized by high moisture content, a lot of organic matter and rich nutritional elements, which makes it a very important role in urban domestic waste treatment and has attracted more and more attention. The main treatment methods of food waste at home and abroad are: aerobic composting of food waste, small biochemical processor, vacuum frying technology, anaerobic fermentation of food waste, preparation of feed protein by microbial fermentation, earthworm treatment of food waste, but the existing treatment methods have different (Fu *et al.,* 2008).

In terms of environmental issues, landfill food waste accounts for nearly 50% of emissions. If there is still a lack of understanding and action on the reform of the waste management sector in the world, emissions are expected to continue increase to 2.38 billion tons of carbon dioxide per year by 2050 (World Bank, 2018). Fruit and vegetable wastes are a source of significant impact on municipal landfills because fruit and vegetable wastes have high biodegradability (Bouallagui *et al.,* 2005).

China's solid waste treatment industry started late and has a low degree of marketization. With the development of the times, China's environmental protection policies have been constantly changed and improved, and the solid waste treatment industry has achieved substantial growth. With the development of the market, the scale of China's solid waste treatment industry is gradually increasing, 785.99 billion RMB in 2013 to 961.06 billion RMB in 2019 (Wang *et al.,* 2017).

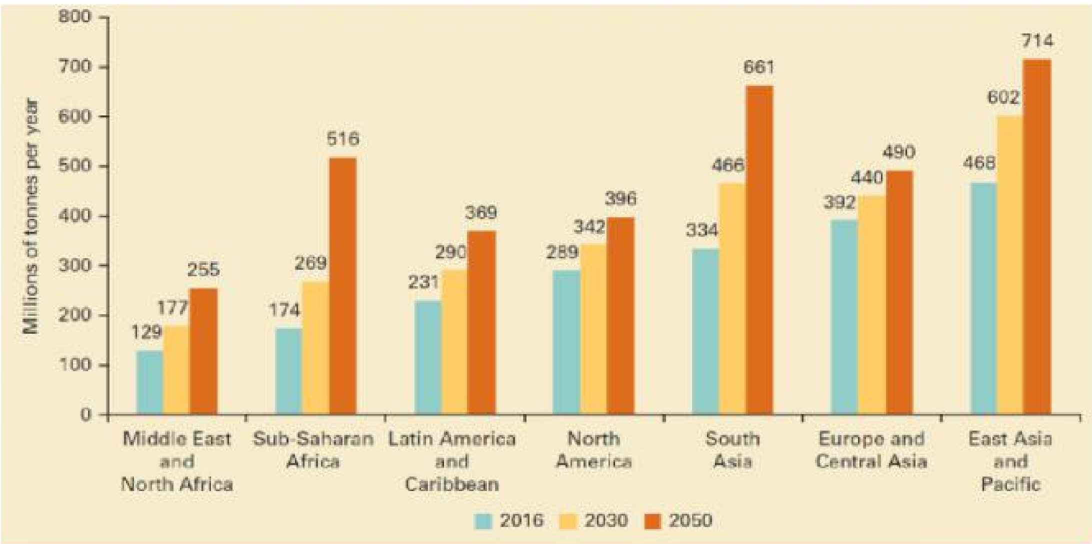


**Figure 1.1:** Global view of Municipal Solid Waste production （The World Bank，2018）

According to the renewable energy development plan issued by China's National Development Commission in 2007, the state plans to invest 3 trillion RMB in developing new energy in 2020. Now, it is continuing to pay close attention to the formulation of rural energy development plans and other plans. We will vigorously promote biogas technology, including centralized biogas energy projects in livestock and poultry farms, as one of the key development areas. The Chinese government has formulated many of preferential policies to improve the transformation of waste treatment to market-oriented. The investment in sanitation facilities is 111.5 billion RMB, including 51.6 billion RMB for domestic waste treatment facilities and 7.3 billion RMB for substandard treatment facilities (China government, 2014). The utilization of waste resources has great market potential in China. Promoting the resource utilization of waste and developing the downstream industry of organic waste biomass energy are the way to alleviate the energy and environmental crisis and solve the shortage of renewable energy. The success of this new industrial chain is related to China's waste recycling and renewable energy policies. Appropriate policies and supporting measures are not only the basis for promoting the development of related industrial chains, but also the guarantee for long-term and steady development. In recent years, China has policies and regulations to encourage and support related fields.

Anaerobic digestion refers to the process under anaerobic conditions, such as fermentation bacteria, hydrogen producing bacteria, acetic acid producing bacteria and other anaerobic microorganisms degrade complex organic matter into inorganic compounds such as N and P and gases such as methane and carbon dioxide, hydrogen consuming bacteria and acetic acid consuming bacteria, hydrogen methanogens and acetic acid methanogens (Hyun Kim *et al.,* 2015). Anaerobic treatment is mostly used for water treatment in waste treatment, especially in domestic waste treatment Garbage disposal is less used, especially in China. The principle of anaerobic treatment is the same whether in water treatment or organic waste treatment.

**1.3 Problem Statement**

In the past, the traditional landfill method was widely used in Laioning province, which has many disadvantages, such as large area, water pollution, odor emission and so on. Moreover, landfill sites in Liaoning province are facing the crisis of filling and sealing, which push waste operators and makers to explore other effective waste treatment measures. However, the method of waste classification and comprehensive utilization, which has been highly praised by environmentalists, has little effect. Recently, waste incineration and power generation projects, which have been promoted and implemented in many cities, have also caused many social problems.

If solid wastes are stacked randomly and not properly treated, they will flow into rivers or lakes and it will precipitation or surface runoff and deposit for a long time, reducing the water surface and causing greater harm to their harmful components. There are many harmful components in solid waste, such as mercury and other harmful heavy metal elements, which will improperly penetrate into the soil. At the same time, the polluted groundwater also seeps into the water network with rainwater, flows into rivers and nearby areas, is absorbed by plants through different ways, and then enters the human body through the food chain, affecting human health. Previous comprehensive investigations and studies show that the concentration, chromaticity, total bacterial count and heavy metal content of pollution sources in most urban areas exceed the standard (Che *et al.,* 2009). The dry matter in solid waste may pollute the atmosphere when it is blown away by the wind. Incineration is a common method to treat solid waste, but incineration will produce a large number of harmful gases and dust.

How to control the anaerobic digestion system correctly under the condition of high efficiency and stability is the long-term goal of designers and researchers. Seek the best environmental control conditions, including physical and chemical conditions and process conditions. Chemical conditions refer to temperature, pH value and redox potential; process conditions refer to microbial concentration, organic loading rate and agitation, in which methane production is the most important link (Walid *et al.,* 2021). There are some differences between methane production and the optimal environmental conditions required by anaerobic digestion system. It is necessary to distinguish the influence and control of these differences on anaerobic digestion process (Gaby *et al.,* 2017).

In Liaoning, 1839.54 ton/per day of organic MSW are produced and disposed of into landfill, there is a need to recover resources such as biogas and fertilizer from organic waste instead of throwing resources into the landfill. Anaerobic digestion could be a visible solution, yet there lack of knowledge concerning the potential economic and environmental impact of resource recovery from OFMSW using anaerobic digestion. Thus, this project aims to assess the potential energy and bio fertilizer recovery using AD as well as the return of investment, economic and environmental impact.

### 1.4 Objectives

(1) To determine the potential production of biogas and bio-fertilizer from OFMSW in Liaoning province by using anaerobic digestion

(2) To evaluate the energy and environmental impact of food waste processing through anaerobic digestion

(3) To estimate economic benefit and payback period

## 1.5 Hypothesis

The research hypotheses are as follows:

HO1:The existing amount of organic waste in Liaoning Province is enough to produce methane rich biogas and biofertilizer.

HO2: It is economically feasible to recover energy from OFMSW, and it can be environmentally sound by treating leachate to reduce the potential impact associated with traditional waste deposition.

## 1.6 Scope of the Project

The project aims to study the environmental and economic benefits as the return for the implementation of the project, estimate the value of the characteristics of food waste to be sent to the anaerobic digestion plant through prediction and data collection, which is usually related to the technical feasibility of anaerobic digestion.

In this project, the focus is also on the potential of recovering power generation from OFMSW food waste as raw materials such as electricity and organic fertilizer. From the perspective of economics, the scope of the food waste feasibility study covers the energy benefits obtained from bioenergy power generation through the data obtained and previous literature. As a result of economic research, the economic benefits (kWh and power) of power generation are evaluated.

Food waste is the main input source of anaerobic digester because it has biodegradation value compared with other types of solid waste, such as recyclable solid waste, hazardous waste. Waste characterization is the first process in any waste management policy to determine the composition of landfill waste that reflects energy productivity (Adeniran, Nubi and Adelopo, 2017). Therefore, the environmental sustainability approach and the respective economic potential of biogas recovery from OFMSW to power generation are evaluated.

# CHAPTER 2

## 2.0 LITERATURE REVIEW

### 2.1 Introduction

With the rapid development of the world and the improvement of human living standards, many different kinds of domestic waste have been produced at the same time. Renewable energy and the use of renewable resources have become important solutions. The method use of resources has become the trend of MSW treatment. We need to carry out a comprehensive waste recovery redevelopment - minimal impact on the environment and human beings to obtain economic returns, and finally to evaluate and manage.

The increase of domestic waste is a problem all over the world, but due to the rapid development of urbanization and industrialization in China, the increase of domestic waste is more serious. The total amount of municipal solid waste increased from 31.3 million tons in 1980 to 179.36 million tons in 2011. By 2030, China will increase to 480 million tons (Fan *et al.,* 2017). At present, China is facing a huge and rapid growth in the amount of solid waste. Traditional domestic waste treatment methods include landfill, combustion and composting. Methane gas in landfill can be burned to generate heat and can be used for power generation. Waste can be directly incinerated or burned to generate energy. Waste can be transformed or recycled into fertilizer through composting. For example, in In Liaoning Province (Liaoning Province in northern China), methane gas from landfills is collected and transported to the city's main power plants to replace natural gas for power generation. Other composting plants combine domestic waste with organic sediments in wastewater to produce compost through special treatment, which can recover most of the organic matter.

Landfills can help solve environmental problems, such as releasing methane gas $CH_4$ with a global warming potential of many times. Compared with carbon dioxide gas, carbon dioxide is produced by the partial decomposition of organic or biodegradable waste (Brander and Davis, 2012). The released landfill leachate pollutes the rivers or lakes and other areas, soil resources and ecosystem (Abuabdou *et al.,* 2020).

At present, there has many methods to treat solid wast, the most common way are sanitary landfill, incineration, and composting. Sanitary landfill is the most widely used, accounting for 60.32% of the total amount of transportation;incineration is usually limited in coastal areas, accounting for 37.5% of the total amount of transportation; composting has a good effect , but it is only used selectively in some areas, with great limitations, accounting for only 2.18% of the total amount of transportation. Moreover, the Chinese government spends a large part of every year on the management of municipal solid waste and public cleaning. At present, anaerobic digestion is the best and most sustainable way to deal with water containing OFMSW. After a series of organic wastes are produced, it can be used for composting. The sustainable economy can be achieved through AD by using OFMSW, and it can reduce pollution to the environment.

This chapter first describes the problems of organic waste treatment in solid waste and the possible impact on the environment, then analyzes the defects in the treatment process, and finally discusses the feasibility and economic benefits.

### 2.2 Issues on waste disposal and environmental impact in China

The continuous urbanization of China's economy and the improvement of living activities have led to amount of waste and a significant increase in the total energy, accelerating the urbanization process. The increase rate of waste production ranks first in the total amount of urban domestic waste, and the harmless waste treatment capacity of 8-10% is increasing year by year. In more than 600 cities in China, a quarter have no suitable landfill (Zheng *et al.,* 2014). This serious waste treatment situation has caused serious problems such as pollution to surface water, groundwater and soil, and damaged the ecological management of urban domestic waste, which is closely related to the environment and people's live places. With China's high attention and determination to environmental pollution management, urban domestic waste management is related to human life and health in urbanization. Therefore, in China local governments are pay more and more attention to waste management.

Data show that in China's major cities, municipal solid waste has the following characteristics (see table 2.1 and 2.2). Organic components based on wet weight account for 61-95% of municipal waste, including 38-73% of food waste, 2-12% of paper and paperboard, 2-14% of plastics, 1-6% of textiles and 0.5-13% of wood.

Inorganic components account for 5-39% of waste, including 0.2-36% of dirt and ash, 0.8-4% of glass, 0.2-1.7% of metal and 0-15% of others. The lower calorific value is 1800 – 6400 kJ/kg (average: 4695 kJ/kg); specific gravity 220 – 450 kg/$m^3$ (average: 353 kg/$m^3$), water content 45 – 70% (average: 55.38%) (EPA, 2018).

**Table 2.1:** The composition of MSW in some different cities (China Statistical Yearbook, 2018)

| Organic, % by Weight | | | | | | |
|---|---|---|---|---|---|---|
| City | Total | Food | Paper | Plastics | Textiles | Wood |
| Beijing | 91.68 | 56.01 | 11.75 | 12.60 | 2.75 | 8.56 |
| Tianjin | 65.78 | 53.88 | 5.88 | 4.10 | 0.82 | 1.10 |
| Shanghai | 93.04 | 58.55 | 6.68 | 11.84 | 2.26 | 13.71 |
| Shenyang | 84.35 | 62.38 | 6.83 | 3.76 | 1.58 | 9.80 |
| Hangzhou | 63.99 | 55.28 | 1.80 | 5.02 | 1.50 | 0.39 |
| Shenzhen | 93.32 | 57.00 | 4.65 | 14.05 | 6.55 | 11.07 |

| Inorganic, % by Weight | | | | | |
|---|---|---|---|---|---|
| City | Total | Ash | Glass | Metal | Others |
| Beijing | 8.32 | 2.79 | 3.84 | 1.69 | - |
| Tianjin | 34.22 | 66.21 | 0.76 | 0.24 | 0.01 |
| Shanghai | 6.96 | 2.23 | 4.05 | 0.68 | - |
| Shenyang | 15.65 | - | - | - | 15.65 |
| Hangzhou | 36.01 | 33.17 | 1.42 | 1.12 | 0.30 |
| Shenzhen | 6.68 | 3.50 | 1.25 | 0.35 | 1.58 |

**Table 2.2:** MSW physical data and energy data in some different cities (China Statistical Yearbook, 2018)

| City | Lower Calorific Value kJ/kg | Specific Weight kg/$m^3$ | Moisture Content % |
|---|---|---|---|
| Beijing | 6413 | 220 | 58.81 |
| Tianjin | 6413 | 330 | 60.02 |
| Shanghai | 4389 | 290 | 58.85 |
| Shenyang | 5080 | 450 | 63.89 |

| | | | |
|---|---|---|---|
| Hangzhou | 1849 | 430 | 57.28 |
| Shenzhen | 4605 | - | 55.0 |

If the garbage is disposed to landfill, it will have an unpredictable impact on the environment. The annual output of municipal solid waste in China is nearly 150 million tons, and it increases by about 8% every year. Nearly 2/3 of the cities are in the dilemma of garbage siege (Kuang and Lin, 2021). A large amount of garbage and sewage seeps into the ground from the surface, causing serious pollution to the atmosphere, soil and water environment and seriously endangering human health. China is rich in garbage resources and has great potential benefits. At present, with the economic development and the improvement of society, the problem of garbage is becoming increasingly prominent in Chinese cities every year. Most cities in China are surrounded by garbage. These wastes cause a series of serious hazards.

## 2.3 OFMSW by anaerobic digestion

### 2.3.1 Treatment by anaerobic digestion

Anaerobic digestion is usually a method of microbial transformation in the aquatic environment, which means that biomass sources with high water level can be treated without any pretreatment. Compared with other technologies, if the moisture content of biomass or waste is less than 60%, combustion can only provide a net positive energy balance (Liu *et al.,* 2021). Anaerobic digestion can be used as a solution in large factories, and it can also solve problems in small-scale enterprises and factories. At present, the most commonly used method in such factories provides opportunities for anaerobic digestion, especially in developing countries and rural areas with energy shortage and scarcity (Appels *et al.,* 2011).

AD is the one of most fully studied technologies for stabilizing organic waste (such as food waste). It can be used to treat organic solid waste Among the treatment technologies of, AD is very suitable for treat organic waste because of it is limited environmental impact and high energy recovery potential. These positive effects, combined with the rapid growth of population, the increasing demand for energy and the concern of global warming, promote the further research on the development and improvement of AD process, so as to improve biogas production, accelerate degradation rate and reduce the disposal of final residues. Generally speaking AD is a biological process. In the case of hypoxia, the complex matrix is transformed into biogas and digestive juice through four main steps, namely hydrolysis, acid production, acetyl production and methane production. However, in terms of environment footprint, pretreatment methods may not be sustainable, even if they improve the performance of AD process. The effects of various pretreatment methods vary greatly according to the characteristics of the matrix and the type of pretreatment (Ariunbaatar *et al.,* 2016).

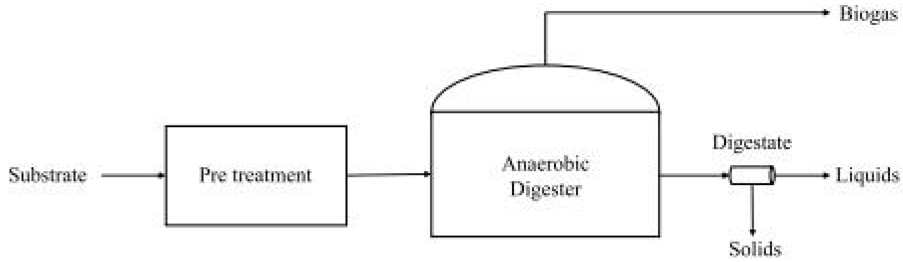


**Figure 2.1:** Diagram of anaerobic digestion

### 2.3.2 Improvement of anaerobic digestion

Anaerobic digestion of organic waste includes dry anaerobic digestion and wet anaerobic digestion. Dry anaerobic digestion process is mainly aimed at organic matter with low moisture content, such as organic matter in agricultural waste or domestic waste. The main feature of the dry anaerobic digestion process is that the solid content of digested material is between 20% and 40% because of the low moisture content of feed waste. Therefore, the dry anaerobic digestion reactor has the characteristics of small volume and large capacity. Typical technologies include Valorga dry anaerobic digestion process and BRV dry anaerobic digestion process. Wet AD mainly aims at organic wastes with high moisture content, such as kitchen waste, livestock manure, etc. The solid content of digested material is between 6-12%. The typical technology is Linde wet anaerobic digestion process.

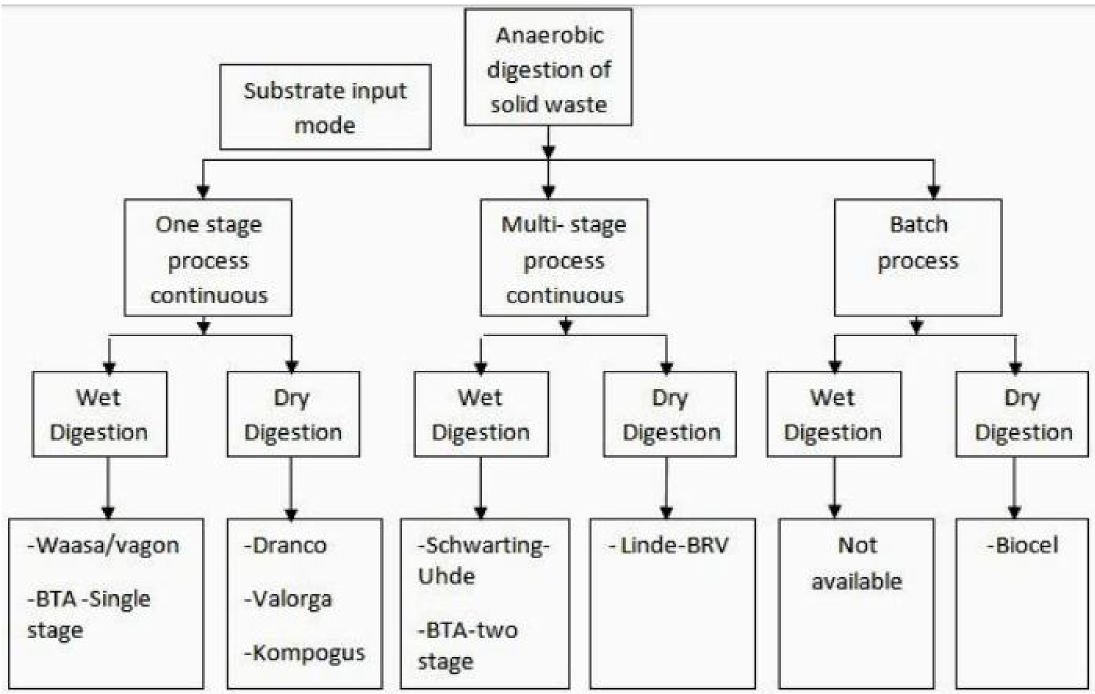


**Figure 2.2:** Available technology at present (Nalo *et al.,* 2013)

The first method is: valorga dry anaerobic digestion process (as shown in Fig 2.3), which is developed by Steinmueller valorga SARL company of France. It adopts a vertical cylindrical digester, which is a mature process. The solid content of waste in the reactor is 25% - 35%, the residence time is 22-28 days, and the gas production is 80-180 $Nm^3/T$. The solid stabilization after digestion needs aerobic composting for 10-21 days. In view of the characteristics of anaerobic digestion of municipal solid waste (MSW), such as difficult mixing, high solid content, and inhibitory activity, the valorga process was developed towards all kinds of MSW in the late 1980s. The technology of partial reflux of leachate and compression mixing of biogas has good economic and environmental effects. Medium temperature (such as amien waste treatment plant) or high temperature digestion (such as Freiburg waste treatment plant) are used in this process, and the average gas production of waste is $110nm^3/T$ (Fu *ea al.,* 2018). At present, there are more than ten waste treatment plants using this process in Europe.

The second method is BRV dry anaerobic digestion process. BRV anaerobic digestion process was first developed by an environmental protection company in Switzerland. In 1994, the first organic waste treatment plant using this process was successfully built in Baar, Switzerland, with an annual treatment capacity of 18000 tons of organic waste. In 1996, it first carried out a pilot scale of 4 tons /day in eurasburg quarzbichl, Germany. In 1997, it carried out a pilot scale of 1500 tons/year in Ravensburg, Germany, in order to further improve the process. In the dry digestion process, after the pretreatment of sorting and crushing, the organic waste is mixed with some digested materials and sent into the digestion reactor through the feeding system. The solid content of the digested materials is between 20% and 35% (Patinvoh *et al.,* 2017). The materials in the digestion reactor can be stirred by gas or mechanical stirring. After 25-30 days of anaerobic digestion, the materials are discharged from the tank by the discharge system and sent to the dehydration system for dehydration. During digestion, about 60% of organic matter is converted into biogas for energy utilization. BRV anaerobic digestion process has become the latest anaerobic digestion process in Germany (Vandevivere,Baere and Verstraete, 2003). It has been implemented in many waste treatment plants in Europe and achieved good operation results.

The third method is Linde wet process. Linde wet anaerobic digestion technology is a single-stage anaerobic digestion technology, which is a typical complete mixed digestion reactor. The process was first developed in 1968, aerobic digestion, aerobic treatment of industrial wastewater, feces. Since 1975, anaerobic treatment of faeces, aerobic and anaerobic treatment of wastewater from food industry, and complex multi-stage wastewater treatment have been carried out; since 1991, wet digestion process of household classified biological waste, including dehydration of digestion residue and treatment of filtrate; since 1993, combined digestion process of faeces and industrial and agricultural organic waste has been applied; in 1996, it has been applied to excess sludge and industrial/municipal waste (Granado *et al.,* 2017). In 1999, the mechanical biological treatment process of the final waste and the biological stabilization and ripening process of the organic residue were formed. The supporting processes of waste treatment include: mechanical pretreatment, composting, waste gas and wastewater treatment. When the concentration of total solid in the digester is 8% - 15%, it can be digested at high or medium temperature. The utility model is characterized in that a pipeline for gas circulation is arranged in the center of the reactor; the pollutants of the digested residue have been separated in the pretreatment process, so the residue can be used to produce high-quality organic fertilizer. It is mainly used to treat swill, sludge from domestic sewage treatment plants, landscaping waste and organic waste.

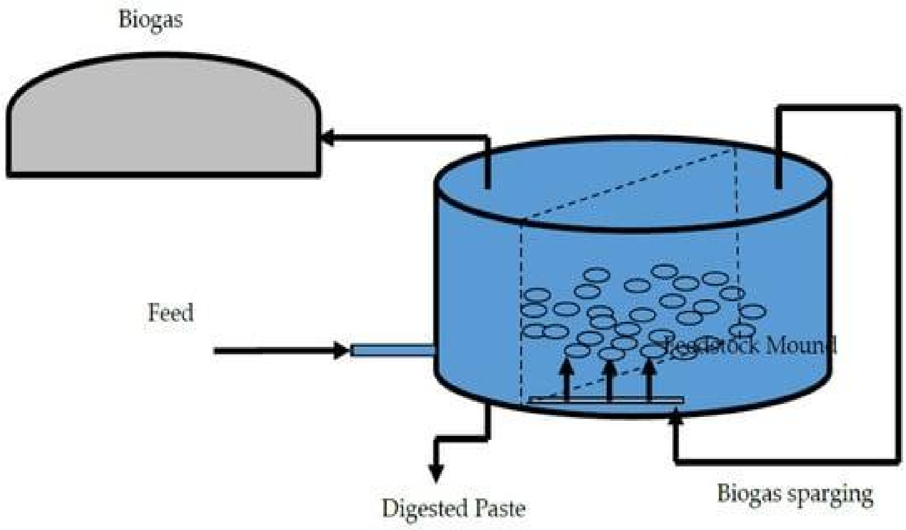


**Figure 2.3:** Valorga process diagram (Fu *et al.,* 2018)

### 2.3.3 Feasibility Study on Anaerobic Digestion

With the consumption of fossil fuels increased, human depend on fossil fuels has greatly challenged. Energy conflicts occur from time to time, and the energy crisis has aroused great attention of all countries, which directly threatens the economic development and national security of all countries. Therefore, all countries in the world have formulated corresponding energy strategies according to their national conditions and regional energy status. At the same time, governments are actively seeking more security.

Anaerobic digestion technology has the advantages of high treatment efficiency, low secondary pollution, high resource utilization, environmental and economic benefits. Anaerobic digestion technology has a long history in the treatment of high concentration wastewater. Europe is the most popular area in the world to treat biomass waste by anaerobic digestion technology. In 2000, compared with 1950, the anaerobic digestion capacity of European waste increased nearly 10 times. After decades of development, many mature processes have been formed, such as Linde process and BTA process in Germany, process in Switzerland, Draco process in Belgium, valoga process in France, etc. according to statistics, there are more than 200 bog plants in Sweden, 60% of which come from municipal sludge anaerobic bog, and 30% from biomass waste and landfill swamp to produce biogas or for biogas development Electricity, or purified into the gas pipe network, or used as motor vehicle power fuel.

China's urban biomass waste produces a large amount of energy, which has great potential for energy utilization. The high-end utilization of biomass waste can alleviate the shortage of fossil fuels and provide mainly support for the construction of the great wall of China's energy security. The resource utilization of biomass waste will greatly reduce the amount of waste required for landfill, which will greatly extend the service life of the existing landfill and save a lot of valuable land resources. At the same time, improve the surrounding environment of waste treatment facilities, improve the social image of landfill, and ease the problem of land acquisition.

### 2.3.4 Solution of leachate problem

Landfill leachate is a type of high concentration wastewater, which can comes from the water contained in the garbage itself, rain, snow and other water entering the landfill. After deducting the saturated water capacity of the garbage and overburden, it passes through the garbage layer and overburden. The water quality of landfill leachate is very complex, which always contain high concentrations of organic matter, heavy metal salts and ammonia nitrogen. Landfill leachate is not just pollutes soil and surface water, and will pollutes groundwater. There are many studies on the removal of CODCr from landfill leachate (Peters, 1998). Biological treatment is generally used, but the treatment effect is not ideal and the operation cost is high.

The treatment of landfill leachate always be a difficult problem in the design process, operation and management of landfill. In the process of liquid flow, there are many factors affecting the properties of leachate, including physical factors, chemical factors and biological factors, so the properties of leachate vary widely. If discharged directly run into the environment without treatment, it will cause serious environmental pollution. In order to protect the environment, it is very necessary to treat the leachate problem.

In view of the problems existing in the landfill, the following improvement suggestions should be put forward for the sewage treatment facilities (1) In the selection of treatment process, we should change the old thinking mode, abolish the process scheme that meet the treatment index, and adopt the Mechanical Vapor recompression pressurized steam evaporation process with high efficiency and energy saving. (2) Strengthen the operation and management of the oxidation pond.

It is hoped that through this improvement, the treated wastewater can be discharged up to the standard, and the pollution of leachate to the surrounding environment can be reduced effectively. (3) The introduction of an ion exchange process at the end as a security filtration system can effectively prevent the fluctuation of the ammonia nitrogen index (Biotechnology, 2014).

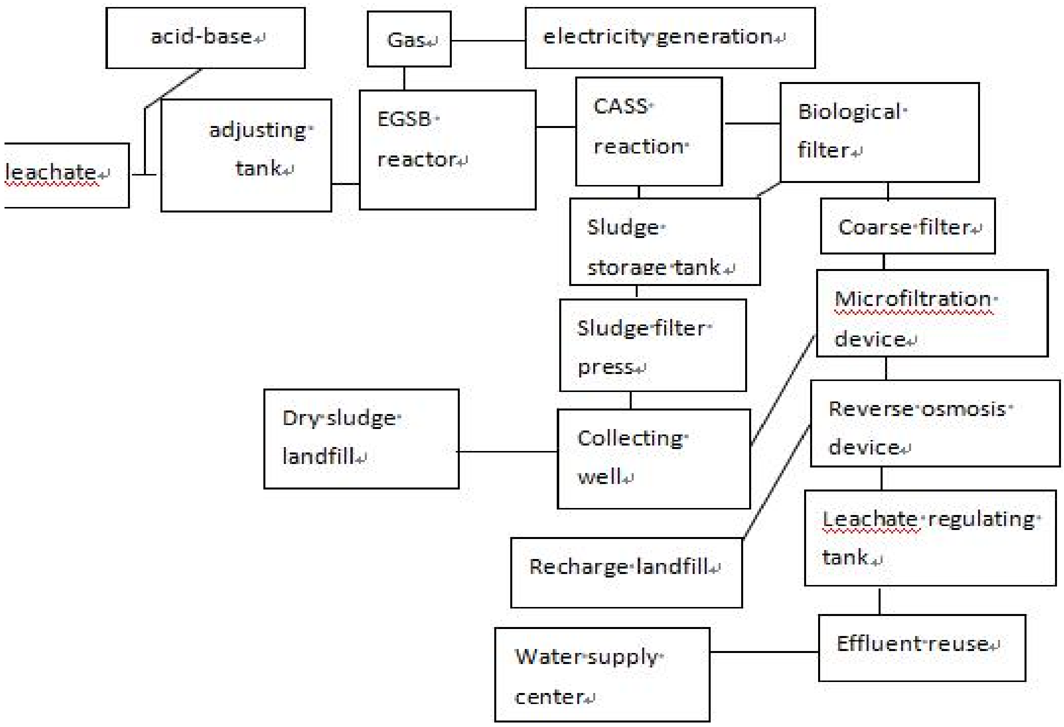


**Figure 2.4:** Treatment process

### 2.3.5 Control physical and chemical conditions on anaerobic digestion

Oxidation reduction potential (ORP) is the potential difference of chemical substance flowing from its reducing state to its oxidizing state. Because the anaerobic environment is needed, the proportion of oxidized substances in the system should be small. The less the oxidized substances, the lower the redox potential, the more suitable for the growth of anaerobic microorganisms; otherwise, the anaerobic digestion will be affected. The dissolution of oxygen and the existence of oxidizing substances (iron ion, potassium dichromate ion, sulfate, etc.) will cause rapid changes in the anaerobic digestion environment (Agarwal and Bui, 2019). In order to maintain a good anaerobic environment, there is a need to close the system; the second is to dissolve oxygen through biochemical reactions to reduce the impact of oxidized substances.

The influence of pH value on anaerobic digestion and the control of pH value is an important factor affecting the life activities of anaerobic digestion microorganisms. The pH values of acidogenic bacteria and methanogenic bacteria as two kinds of microorganisms in anaerobic digestion are not consistent. PH affects the state of fatty acids. In the acidic state, fatty acids are in a molecular state and can pass through the cell membrane. In alkaline state, fatty acids ionize to form acid radical ions, which repel the negatively charged cell membrane and are difficult to enter. A small amount of re ionization will change the pH value in the cell and affect the progress of many chemical reactions. More importantly, the stability of various enzymes is related to the oral H value, especially the methanogenic bacteria, which can adapt to a very narrow range, so it is necessary to strictly control the pH value (Zhai, 2015).

The influence and control of temperature on anaerobic digestion can be divided into mesophilic digestion and thermophilic digestion because there are two suitable temperature zones in anaerobic digestion: mesophilic zone. In some of experiments have proved that a positive correlation between temperature and biochemical rate below the middle temperature range, and the biochemical rate will accelerate with the increase of temperature. The optimum temperature for a large number of methanogens was 30 ℃. The results show that there is a positive correlation between the methane production rate and the biochemical rate, so the middle temperature stage is the stage with the highest methane production rate. The mesophilic zone also became an optimum temperature for anaerobic digestion. After middle temperature digestion, the digested liquid contains a lot of ammonia nitrogen, which can be used as high-quality liquid fertilizer for farmland irrigation (Kumar and Samadder, 2020). High temperature digestion can greatly shorten the digestion time, complete the treatment of garbage and high gas production rate. Whether it is medium temperature digestion or high temperature digestion, measures should be taken to make the reactants in the tank heated evenly to achieve the best treatment effect.

The relationship among redox potential, pH value and temperature a large number of experiments show that different redox potentials are needed for different temperatures. Generally, the higher the temperature is, the lower the redox potential is required. The redox potential of thermophilic anaerobic digestion is 200-250 MV lower than that of mesophilic anaerobic digestion. This shows that anaerobic digestion, especially thermophilic anaerobic digestion, has high requirements for anaerobic environment (Beylier *et al.,* 2011). The effect of pH value on redox potential was also significant. When pH value decreased, redox potential increased. If inhibitors or other toxic substances are mixed in the feeding process, the pH value will decline, which will increase the redox potential and destroy the anaerobic environment. Temperature can also cause pH changes. When the temperature increases, the pH value increases; otherwise, when the temperature decreases, the pH value also decreases. Only when the three factors are reasonably combined, the whole anaerobic digestion system will be in a stable and efficient state.

### 2.3.6 Resource recovery from OFMSW and its contribution to the economy

Since 2000, a series of national guidance catalogues have been published, such as the catalogue of industries, products and technologies that the State encourages to develop, the catalogue of comprehensive utilization of resources, the catalogue of guidance for industrial structure adjustment (2005 Edition), and the catalogue of high-tech industries with priority development. The guidelines for key areas of industrialization (2007) and the directory for the development of renewable energy industry indicate that renewable energy and waste recycling industries have been included in the key areas of national strategic adjustment of economic structure (Shi *et al.,* 2021), as well as in the areas of investment, examination and approval, tax incentives and other policy support.

In recent years, the supporting policies and guidance issued by the state include the outline of new and renewable energy development, the key points of new and renewable energy industry development planning, the “Eleventh Five Year” plan for energy development, and the “Eleventh Five Year” plan for national environmental protection. These laws and policies include the guidance on comprehensive utilization of resources in this plan. The outline of the national medium and long term scientific and technological development plan, the comprehensive work plan for energy conservation and emission reduction, and the agricultural development plan, China's biomass energy industry and China's national plan for coping with climate change (Junfeng *et al.,* 2002).

The objectives, requirements, policies and measures, key areas and preferential policies of renewable energy and waste recycling are planned from different perspectives of development, renewable energy, energy contained and emission reduction, recovery economy, industrial development strategy, layout and focus. These laws and regulations put renewable energy and garbage resources in an important position.

Renewable energy law provides great opportunities for biomass energy and waste recycling. China formulated financial policies including government special funds to support key projects and technologies, governments at or above the county level to provide financial support for rural renewable energy projects, government discount loans, government guarantees, preferential loan interest rates and other financial support policies, and proposed to provide preferential policies in investment, tax and loans for the listed energy and products, as well as in renewable energy Power price subsidy and allocation method. Support and encourage the development of renewable energy from various aspects (Liu, 2019). People's governments at all levels support key projects and pilot projects by means of subsidies and awards. We should gradually formulate and improve the relevant catalogue and incentive tax policy.

According to the above laws, the preferential policies for renewable energy and waste recycling industry in the fields of renewable energy, comprehensive utilization of resources and environmental protection mainly include the following aspects.

Tax policy (1) The state finance establishes a special fund for renewable energy development to support scientific and technological research. Governments at the county level will benefit from rural renewable energy. Provide financial support for the project.

(2) The State Council and the provincial government set up relevant special funds to support the development of circular economy: scientific and technological research and development of circular economy; Demonstration and promotion of circular economy technologies and products; Provide information services and other specific measures for improve circular economy.

(3) Financial support for rural environmental protection: according to the agricultural law, the ministry of agriculture is in charge, and the state finance supports rural environmental protection, with invested 1 billion RMB per year to support the development of rural biogas.

(4) Financial support for energy saved and reduct emissions (National Development and Reform Commission). The state sets up special funds every year

for promotion of energy conservation and emission reduction technologies, equipment transformation and upgrading, and development of new energy industry.

(5) For renewable energy development and utilization projects that meet the credit conditions, financial institutions can provide preferential loans and financial discounts (Zhen, Gang, Ying, 2021).

Tax preference (1) Income tax preference. According to the enterprise income tax law of the people's republic of China, preferential income tax treatment shall be given to industries listed in the catalogue of key encouraged industries, products and technologies of the state. Tax preference should be given to industries and products listed in the catalogue of energy conservation, emission reduction and utilization of resources. The investment in the purchase of special equipment for environmental protection, energy and water conservation and safe production can be offset by a certain proportion (Lan, Wang and Cao, 2020).

(2) Value added tax policy on renewable resources. According to the notice on the policy of value added tax on utilization of resources and other products, the value added tax shall be levied first and then withdrawn according to a certain proportion (70% in 2009 and 50% in 2010) of the value-added tax (VAT) on the sale of renewable resources for waste material recycling enterprises meeting certain conditions. Labor services in waste treatment and resource recycling industries are exempt from VAT (Yang and Zhang, 2021).

(3) Preferential tax policies for giving priority to the development of high-tech industries. For high-tech enterprises that need key state support, enterprise income tax shall be levied at the tax rate of 15%. The outline of the national medium and long term science and technology development plan has issued a number of supporting policies.

(4) According to the notice on enterprise income tax policy issues of China's Clean Development Mechanism (CDM) fund and CDM project implementation enterprises, certain income tax reduction and exemption policies shall be implemented for the part of the approved carbon trading income of CDM projects that enterprises turn over to the state (Liu *et al.,* 2021).

(5) Organic fertilizer products are exempt from VAT. From the Ministry of Finance and the State Administration of Taxation on the exemption of value added tax on organic fertilizer products (Yang and Zhang, 2021), in order to scientifically adjust the structure of agricultural fertilization and improve the agricultural

ecological environment, the production, sale, wholesale and retail of organic fertilizer products by taxpayers are exempted from value-added tax.

Regulations: (1) The part where the on grid price of renewable energy power generation projects is higher than the on grid benchmark price of local coal-fired units and the part where the operation and maintenance cost of power system is higher than the average sales price of power grid shall be solved by adding electricity price to the power users within the service scope of power grid enterprises above the provincial level. The subsidy price of its power generation project will be cancelled after 15 years of operation.

(2) According to the proportion of the increased electricity sales of provincial power grid enterprises in the increased electricity sales of national power grid, the additional amount of renewable energy price that should be shared by provincial power grid enterprises is determined.

(3) Another supporting regulation, the regulations on the administration of renewable energy power generation, stipulates that power generation enterprises should more invest in renewable energy power generation projects, and large power generation enterprises should give priority to renewable energy in power generation projects. Undertake the obligation of renewable energy power generation quota stipulated by the state (renewable energy accounts for 30%) (Fang, Zhao and Yu, 2018).

According to the development advantages and existing problems of the biomass energy and waste recycling industry, these measures are needed.

(1) Formulate special implementation rules of organic waste recycling and renewable energy integration development to make it an important part of low-carbon economic policy system. The ownership of support and encouragement policies in different stages of the industrial chain is clarified, and the policies and measures are systematically sorted out and improved. For example, in the stage of waste classification and resource utilization, the preferential policies of laws related to comprehensive utilization of resources are applied; in the stage of biomass energy power generation, grid connection and consumption, the preferential policies related to renewable energy, circular economy, energy conservation and emission reduction are applied, and the relevant policies and incentive measures are refined.

(2) This study defines the development goals of the waste recycling and renewable energy integration industry, makes regional analysis, budget and

development forecasts, predicts the potential of carbon emission reduction, and plans the development of regional waste recycling and renewable energy industry integration.

(3) The development of integrated industry needs to consider the effective cooperation between policies from the overall development of the industrial chain. In the industrial development of organic waste recycling and renewable energy integration, the front-end waste classification collection and transportation, the end of the biogas residue are the bottlenecks restricting the development of the industry, and also an important factor affecting private capital investment.

(4) It should establish a good market investment environment, implement various incentive policies, encourage enterprises to actively participate, and build a long-term and stable market environment and policy environment for enterprises joining such industries.

## 2.4 Significance of resource recovery from OFMSW by Anaerobic digestion

Solid waste has the characteristics of scattered sources, complex composition, large output and sluggishness. If it is not properly handled, it will cause many socio-economic and environmental problems. Solid waste does great threat to the environment, mainly in the following aspects:

(1) Occupation of land: If solid waste is treated and disposed of in time, random stacking will not only occupy a lot of land, but also damage the landform, vegetation, natural landscape and agricultural production.

(2) Contaminated soil: If the solid waste treatment method is incorrect, the harmful components in it can easily flow into the soil through the ground surface, which will affect the beneficial microorganisms in the soil and destroy the soil structure, so it will lead to the deterioration of the whole soil.

(3) Polluted water: Solid waste can enter the ground surface through precipitation caused by weather changes, flow into branches, drift with the wind, and enter rivers, lakes and other water bodies, which will cause serious pollution to the water on the ground surface.

(4) Destroy the atmosphere: Some solid wastes produce a lot of harmful gases due to chemical reaction, such as sulfur dioxide, and some solid wastes release a lot of flammable, toxic and harmful gases due to fermentation. These gases will diffuse directly into the atmosphere and pollute the atmosphere.

(5) Toxic and harmful: Some solid wastes may also cause special damage, such as combustion, explosion, contact poisoning.

(6) Toxic to humans: Solid waste can also indirectly damage human health, such as heavy metal pollution in the food chain.

At present, the US, Japan and many other countries have relatively perfect methods to manage systems and legal policy, while the domestic research is relatively backward, and the comprehensive management system of solid waste classification, transportation, storage, treatment and disposal has not been established.. Nowadays, with the increase development of science and technologies, the application of solid waste treatment technology not only minimizes the consumption of resources use and energy use, but also reduce the generation of solid waste, it makes stakeholders realizing huge environmental and economic benefits (Pooja and Sunil, 2021).

**Figure 2.5:** Environmental pollution caused by waste

Important role - renewable energy

(1) With the continuous development of the city, renewable energy is the basic requirement to determine the scientific outlook on development, build a resource saving and recyclable society and realize sustainable development. Adequate, safe and clean energy supply is the basic guarantee for economic development and social

progress. China has a large amount of population, low per capita energy consumption and great pressure on the growth of energy demand.

In order to fundamentally solve the problem of energy shortage and shortage in China, meet the increasing demand of modern social development, protect the environment and achieve the goal of sustainable development, we can not only improve energy utilization efficiency, but also accelerate the development and utilization of renewable energy. Renewable energy is not only an important development in the construction of resource-saving society, but also the basic requirement for establishing a good ecological environment and human comfortable residence.

(2) Developing different ways and using renewable energy is one of the important solutions to protect the environment and deal with current climate change. China's environmental pollution problem is extremely serious, and the ecosystem is facing many severe challenges. The large scale development and utilization of fossil energy has many impacts on the environment. Renewable energy is clean and environment-friendly, and the development and utilization process will not increase greenhouse gas emissions. The development and utilization of renewable energy plays an indispensable role in energy supply, environmental and ecological protection, reducing greenhouse gas emissions and coping with climate change.

(3) The development and utilization of renewable energy is an important way to build a new renewable energy social city. Rural areas have the weakest economic and social development in China, and their energy infrastructure is very backward Many rural energy sources are still dominated by traditional inefficient biomass direct combustion, such as straw and firewood. Rural areas are rich in renewable energy resources. In order to speed up the application of renewable energy in society. Firstly, we can use urban resources to solve the problem of power supply in remote areas and energy consumption shortage of rural residents; Secondly, transforming rural biomass energy resources into commercial energy, making renewable energy a unique industry, effectively extending the agricultural industrial chain, improving the quality of life and agricultural benefits, increasing farmers' income and interests, improving the rural environment and promoting the sustainable development of rural economy and society.

(4) The use of renewable energy is an important factor in new economic growth. At the same time, it can promote economic cycle and expand residents' employment.

Renewable energy is widely distributed, and each region has certain conditions for the development and utilization of renewable energy. The development and utilization of renewable energy is mainly the use of local natural and human resources, which is of great significance to promote local economic development. At the same time, renewable energy is also a new branch of high-tech industry. The rapid development of renewable energy has become the main fulcrum of new economic growth, which can effectively promote the development of various related industries. This is of great significance to the sustainable development of society (NREL, 2012).

## 2.5 Environmental

(1) Occupation of land: Garbage occupies a lot of land resources and human living space, which can affects agricultural and industrial production. A large amount of garbage destroys the plants on the earth's surface, which not just affects the original status of the environment, and also affect the balance between natural ecological organisms.

(2) Solid waste contains many types of harmful components. Improper treat solid wastes will directly pollute soil, air and water, and eventually cause direct or indirect effect to all kinds of organisms, including human beings.

(3) Garbage from wastes have many microbial elements, which is the breeding ground and breeding ground of pathogens, pests and so on, so it will seriously endanger human health.

(4) Pollution of soil and water body: The liquid exuded by waste will change the composition and soil, and toxic waste will affect human health through direct or indirect food chain. Garbage destroys the structure and different properties of soil and greatly reduces the ability of soil to maintain nutrients and water of fertilizer.

(5) Air pollution: Small solid waste will be blown everywhere by the wind, aggravating air pollution. Some areas have a lot of garbage is stacked, there are many pests such as odor, mice, insects and mosquitoes. Many harmful gases such as ammonia and sulfide are released into the atmosphere. Volatile organic gases have many carcinogens.

**2.6 Economic**

Generation of the bioenergy and organic fertilizer via the construction of the biogas plant to overcome the increases in the energy capacity related to the Gross Domestic Product (GDP); Anaerobic digestion is beneficial by performing cost benefit in the final product of electricity and organic fertilizer commercialization and hence able to boost up additional income for the local authority; Construction of the biogas power plant until the commercialization of the fertilizer and clean energy widen the job opportunities in the construction, technology innovation, maintenance field for the local people.

Recovery economy is shown in Figure 2.6. Starting from the manufacturing process, we can plan and calculate the additional income, power and fertilizer that can be generated, so that we can achieve the goal of circular economy. Then invest and implement according to the scheme designed.

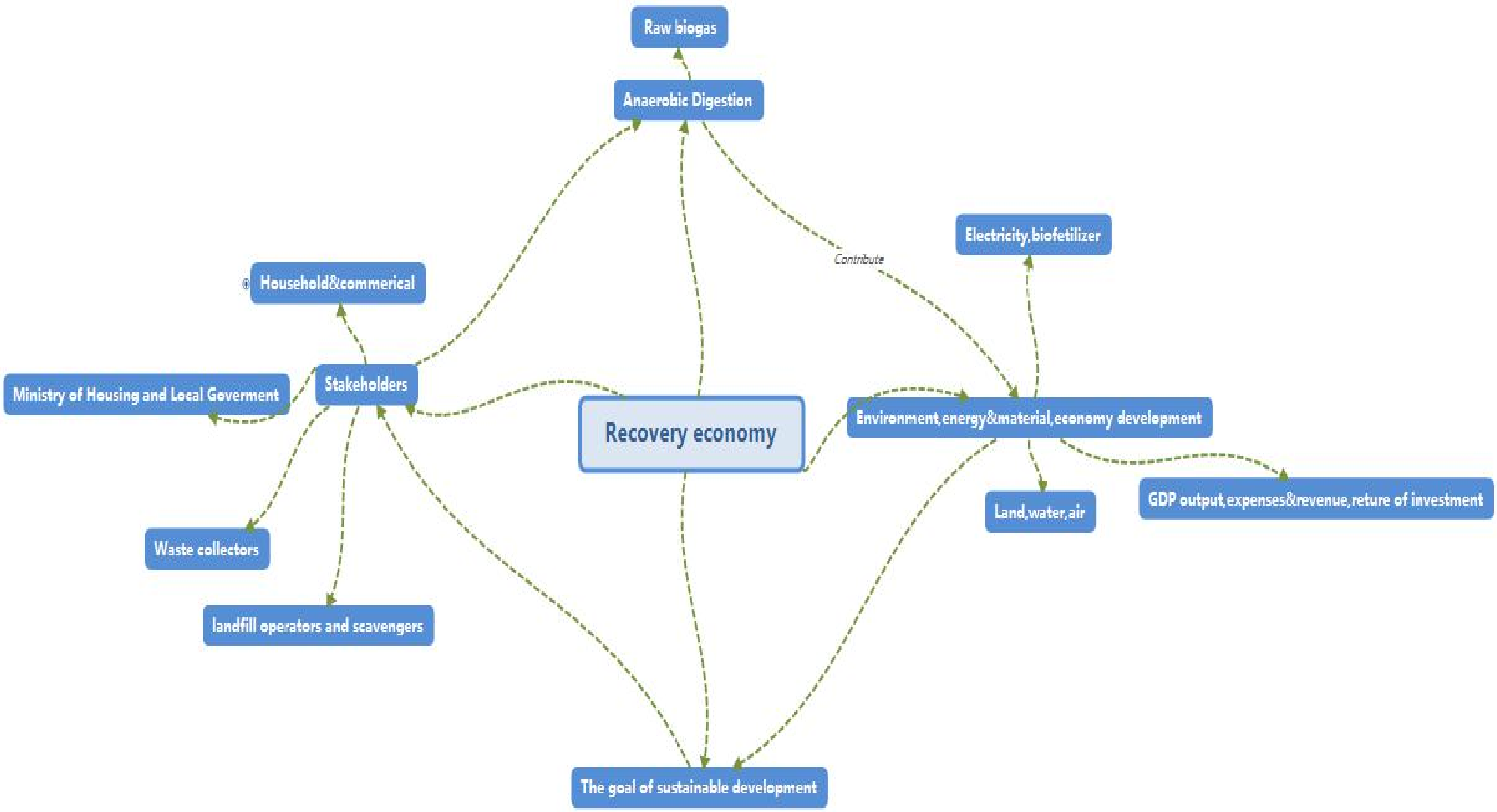


**Figure 2.6:** Recovery economy

### 2.7 Summary

Generally, the previous literature has evaluated different situations and prospected the best methods, from which we can see that anaerobic digestion is the best way of OFMSW digestion. The experiment and conversion rate can be improved by using AD of different methods, and thus the overall circular economy can be improved. Moreover, the best treatment method and solution of landfill leachate can be found.

However, in the current society, China needs to carry out economic evaluation or situation analysis of the whole process. Therefore, the deficiency of the previous literature is that only one-sided evaluation and observation analysis are not comprehensive. If we integrate the previous literature, we will have an impact on the prospect of China's renewable energy economy, the impact of anaerobic digestion on the environment based on the management and prospect of solid waste and the best environment for process treatment, we can analyze the renewable resources and environmental impact generated by OFMSW and its economic feasibility.

# CHAPTER 3

## 3.0 METHODOLOGY

### 3.1 Introduction

In this chapter, methodology discussed the research method used in this project, including calculating the economic feasibility of biogas and bio fertilizer production from Liaoning province data. In order to determine the potential of microbial fuel conversion to bioenergy and fertilizer production, this chapter explained organic solid waste transfer to final product through data calculation and chart explanation to predict and estimate the energy generated from organic solid waste, environmental benefits and economic benefit.

### 3.2 Study Area

The study area is located in the densely populated Liaoning Province of China. There are 14 cities in the province, with a total area of 148600 square kilometers (Figure 3.1) and a total population of 43.517 million.

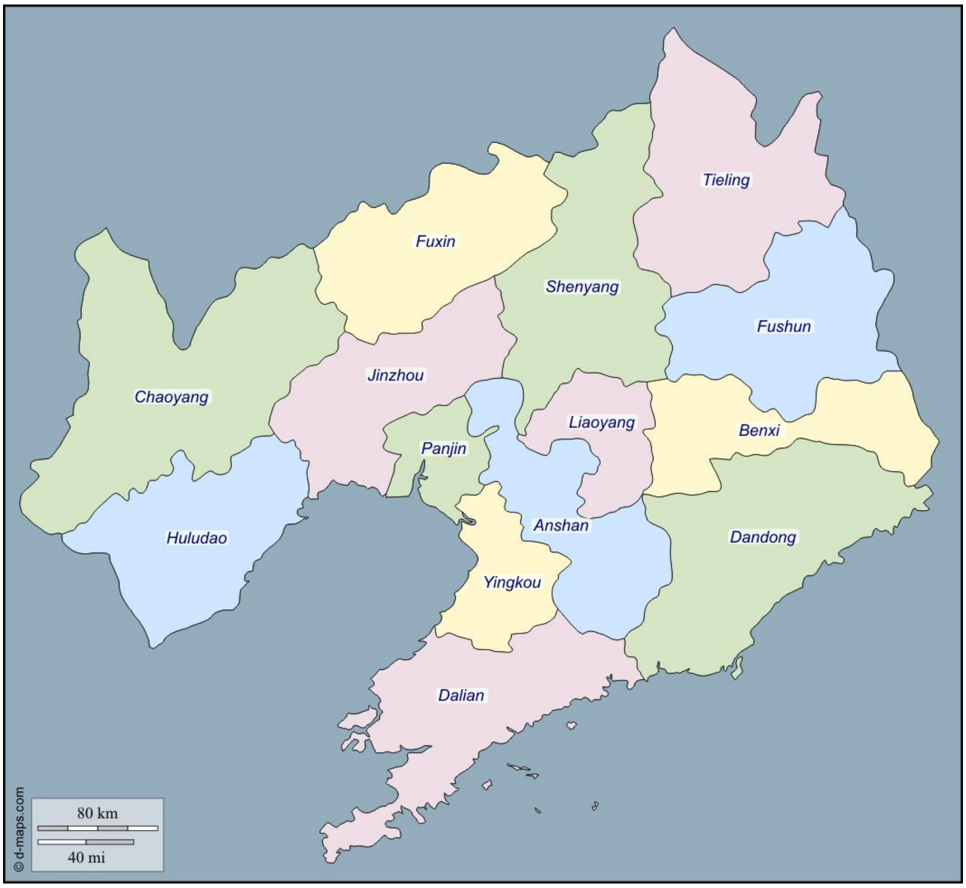


**Figure 3.1:** Liaoning province map

### 3.3 Research Design Process

In this study, a random sampling technique was applied to waste collection in Liaoning Province, China. Organize all the data collected to ensure the data required by different formulas. This study is divided into three stages

Stage 1: Sort out the data.

Stage 2: Feasibility study of anaerobic digestion (AD).

Stage 3: Mathematical calculation of bioenergy and economic evaluation of anaerobic digestion (AD).

In this study, data analysis was applied in which is located at Liaoning province. Theoretically prior to the data projection, the laboratory characterization data is required to determine the physical and chemical characteristics in waste. From the characterization of ultimate analysis, value obtained from the characterization will be used to calculate the bioenergy production and economic benefits. Overall in this project study, three phases were planned (refer Figure 3.2), including determination of the waste characterization value, followed by feasibility study of Aerobic

Digestion (AD) and lastly mathematical calculations of bioenergy and economic evaluation from Aerobic Digestion (AD). In the end of the discussion, the environmental and the economic evaluation data obtained will be used to evaluate the potential and the feasibility of the amount of energy to be applied in Liaoning.

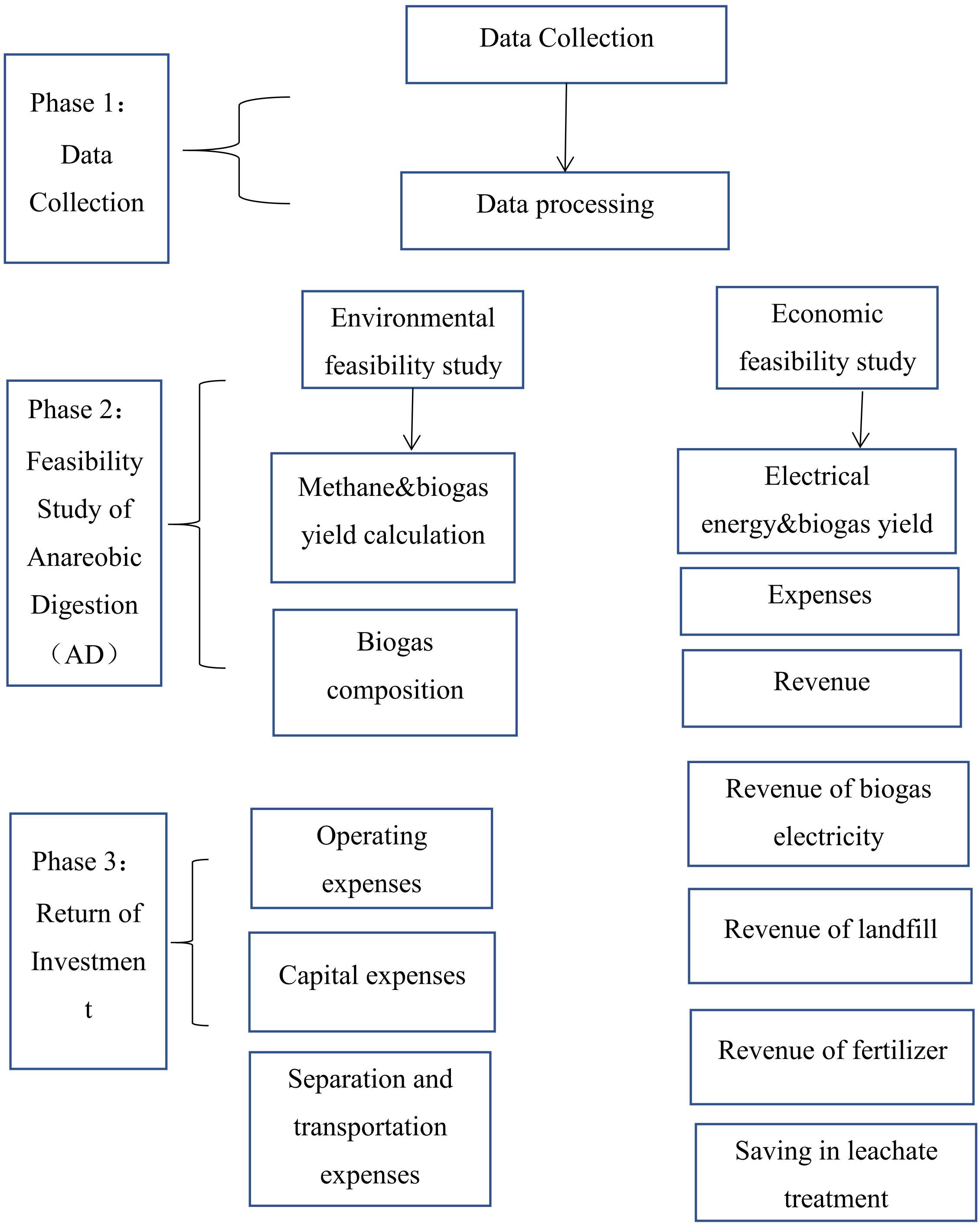


**Figure 3.2:** Methodology

### 3.4 Waste Characterization in Liaoning Province

According to the data of Liaoning Province, the total amount of garbage in Liaoning Province is 853.51 tons, and the total amount of food waste is 914.55 tons, including 59.4% of organic matter and 72.6% of moisture content.

**Table 3.1:** Liaoning Province Organic,％ by Weight (China Statistical Yearbook, 2014 ~ 2018)

| | Total | Food | Paper | Plastics | Textiles | Wood |
|---|---|---|---|---|---|---|
| Liaoning Province | 914.55 | 671.43 | 83.90 | 27.53 | 17.27 | 114.42 |

**Table 3.2:** Organic and Moisture and Percent by Weight（dry basis）China (Statistical Yearbook, 2014 ~ 2018)

| Component | Organic％ | Moisture％ | C％ | H％ | O％ | N％ | S％ |
|---|---|---|---|---|---|---|---|
| Food waste | 59.4 | 72.6 | 26.6 | 3.7 | 23 | 1.6 | 0.2 |
| Fruit | 28.0 | 76.1 | 38 | 3.7 | 35.6 | 1.9 | 0.2 |
| Paper | 6.8 | 5.6 | 4.1 | 4.4 | 39.3 | 0.7 | — |
| Textiles | 2.1 | 15.3 | 41.8 | 4.7 | 43.2 | 0.8 | — |
| Grass,leaves | 1.3 | 56.6 | 46.0 | 6.0 | 38.0 | 3.4 | — |
| Wood | 2.4 | 20.2 | 49.5 | 6.0 | 42.7 | 0.2 | — |

Determination of the composition of that landfill waste could reflect the productivity of the energy by using the calculation and formula which can be discussed later. The categorization of the landfill waste based on the origin, composition, toxicity and the management able to reflects the performance of the energy generation. Consequently, characterization is the main key for the improvement of the technology design to ensure the sustainability for the clean and renewable energy production.

In general, data collection of physical properties in this study include temperature, pH, dry mass, moisture content (MC), total solids (TS), volatile solids (VS), whereas chemical properties only include calorific value. Determination of the environmental feasibility raw data can be obtained from the ultimate properties laboratory test from Liaoning landfill as references which includes the 5-basic element of organic waste namely: Carbon (C), Hydrogen (H), Nitrogen (N), Sulphur (S) and Oxygen (O).

**3.5 Moisture Content (MC), Total Solids (TS), Dry Matter (DM) and Volatile Solids (VS)**

The balance of nutrients and water content is very important for the digestion and matrix of food waste, which can increase the total yield of methane (Ren *et al.,* 2018). The water content, total solids, dry matter, and volatile solids in the project are used to characterize the production of bioenergy and organic fertilizer. The formula in the table below evaluates the physical properties of the waste.

Equation (1) in Table 3.3 is the formula for the water content of the sample (MC,%). The need for moisture content determination aims to study the production of methane gas during anaerobic digestion, because excessive moisture content between 97% and 89% during anaerobic digestion will reduce methane production from 330 ml/g-vss to 280 ml/g-vss (Fujishima, Miyahara and noike, 2000). In general, the moisture content of food waste on a wet basis is estimated to be 70% (Sikarwar *et al.,* 2016)

Equation (2) is used to determine the dry matter, that is, the solid mass left in the sample after water evaporation, that is, the residue left in the crucible after the oven drying process. According to the data of (Kelly Orhoro, 2017), the total solid is most suitable for the best biogas production of 10%, and the reduction of total solid is very important to obtain higher biogas production efficiency. In other words, dry matter is also the sum of total solids plus volatile solids.

Equation (3) is used to determine the percentage of total solids, that is, the theoretical amount of solids remaining after furnace ignition. However, for the data estimation method, equation (3) is a formula for estimating the total solids in dry matter as a function of OFMSW input volume.

**Table 3.3:** The equation includes calculating the percentages of moisture content (MC), total solids (TS), dry matter (DM) and volatile solids (VS) (Kelly Orhoro, 2017; Yong, 2020; Yong, Bashir and Hassan, 2021).

| Unit | Equation | |
|---|---|---|
| Moisture Content (MC; %) | Moisture Content (%) | (1) |

| | | |
|---|---|---|
| | $= \frac{Ws-Wt}{Ws} \text{ x } 100$ | |
| Dry Matter (DM; %) | Dry Matter (%) = 100% - Moisture Content (%) | (2) |
| Total Solids (TS; %) | Total Solids (%) $= \frac{(TS)}{(OFMSW)} \times (OFMSW)$ | (3) |
| Volatile Solid (VS; % ) | Volatile Solids (%) = 100-TS | (4) |

($W_s$ = Wet sample and dish (g); $W_t$ = Oven dried residue and dish (g); $W_d$ = Dish (g); $W_s$ = Wet sample and dish (g); $W_t$ = Oven dried residue and dish (g); $W_d$ = Dish (g); $W_t$ = Oven dried residue and dish (g); $W_v$ = Furnace ignited residue and dish (g))

Equation 4 is the volatile solid, that is, the organic compound lost when the solid is dried at 550 ℃ and ignited. The concentration of volatile fatty acids in anaerobic digestion will lead to toxicity and inactivation of microorganisms, which will affect biogas production (Lide and Howard, 2014). However, for the data estimation method, the volatile solids estimation method is calculated by subtracting the total solids from the dry matter residue.

**3.6 Biogas and bio fertilizer recovery**

**3.6.1 Biogas composition**

This research focuses on the biogas potential using a simplified model to determine the theoretical total amount of biogas that can be produced by organic waste. The theoretical amount of biogas generated from organic waste can be calculated according to the relative amount of carbon, hydrogen, oxygen, nitrogen, and sulfur in the material (Banks, 2009). Not all materials can be processed.

Buswell created an equation to estimate the products from the anaerobic breakdown of a generic organic material of chemical composition $C_cH_hO_oN_nS_s$. The Buswell equation can be used to estimate biogas composition. Modified equation (5) and (6) by Buswell and Mueller :

$$\left(\frac{1}{8}\right) x[\ (4\ x\ mass\ \%\ C) + (\ mass\%\ H) - (\ mass\ \%\ O) - (3\ x\ mass\ \%\ N) - (2x\ mass\ \%\ S\ )] \qquad (5)$$

$$\left(\frac{1}{8}\right) x[\ (4\ x\ mass\ \%\ C) - (\ mass\%\ H)\ + (\ mass\ \%\ O) + (3\ x\ mass\ \%\ N) + (2x\ mass\ \%\ S\ )] \qquad (6)$$

And $CH_4$ = ratio of methane gas; $CO_2$ = ratio of carbon dioxide gas;C = % weight of carbon; H = % weight of hydrogen; O = % weight of oxygen; N = % weight of nitrogen; S = % weight of sulphur.

### 3.6.2 Volume of biogas and $CH_4$ gas generation

After understanding the composition of $CH_4$ and $CO_2$ in biogas, formula eqn 7 and formula eqn 8 need to be used as volatile solids (VS), % to calculate the exact volume of methane production per unit mass of volatile solids (VS) in OFMSW. The constant value is 0.75, which is derived from the carbon balance of Buswell equation. In the concept if 75% of VS is degraded, this also means that anaerobic digestion performs up to 75% of the organic part into biogas (Banks, 2009; Yong, 2020).

$$V_{CH4} = \left(\left(\frac{C\ x\ (CH)_4}{M_{carbon}\ x\ V\ stp}\right) x\ \left(VS\ x\ 0.75\ xM_{organic}\right)\right) x\ 100 \qquad (7)$$

$$V_{biogas} = \frac{V_{CH4}}{CH_4} \qquad (8)$$

C = Constant 75% VS degrades for biogas production; $CH_4$ = Methane fraction obtained from Buswell and Mueller formula; (M)carbon = Molecular weight of carbon; (V)stp = Volume of 1 mole gas at standard condition; VS = Volatile solid percentage of organic MSW; $M_{organic}$ = Incoming mass of organic MSW stream, kg/day; $V_{CH4}$ = Volume of pure methane gas yield.

### 3.6.3 Bioenergy and biofertilizer potential

The electric energy and power generation are calculated according to the amount of methane gas produced by anaerobic digestion, in m3, using equation 9 and 11 respectively. In order to cross check the power and energy output, this value will be calculated again using equation 10 and 12, the average value of the two formulas is used to calculate the subsequent calculation (refer to table 3.4). The expression of power generation will be evaluated in kilowatts, kilowatts or megawatts (MW). According to the definition, $1m^3$ of biogas contains 3.6 kWh of energy; 1 kWh of electric energy contains 3.6mJ of energy. Therefore, $1m^3$ of biogas is equivalent to 10 kWh of electric energy, which also means that $1m^3$ of biogas can provide 10 kWh of electric energy (Banks, 2009).

**Table 3.4:** Equation used in the electrical energy and power yield (Yong, Bashir and Hassan, 2021).

| Criteria,unit | | Equation | |
|---|---|---|---|
| **$E_{bio}$,** Electrical energy output | kWh/day | $(V)CH4x\ E\ x\ N_{el}$ | **(9)** |
| | | *Crosscheck equation:* $P_{bio} \times 24$ | **(10)** |
| **$P_{bio}$,** Electrical power output | kW | $E_{bio}/24$ | **(11)** |
| | | *Crosscheck equation:* $\left(\frac{M_{organic}}{24}\right) x\ Y\ x\ D\ x\ P\ x\ LHV\ x\ C\ x\ N_{el}$ | **(12)** |

* $M_{organic}$ = Incoming mass of organic MSWstream, kg/day; $Y$= biogas yield, $m^3/kg$; $D$ = Methane fraction; $P$ = Methane density, $ton/m^3$;$LHV$ = Lower heating value of methane, MJ/kg; $C$ = Conversion constant from MJ/hr to MW; $N_{el}$ = Electrical efficiency of biogas engine; $V_{CH4}$ = volume of pure methane gas yield; E= Energy constant of methane (10 $kWh/m^3$); $P_{bio}$ = Electrical power output

The wastewater discharged by anaerobic digestion is valuable, which is conducive to the production of biological fertilizer. The wastewater discharged contains rich nutrients and is beneficial to the soil As shown in equation 13, when methane production is 0.3 $m^3/kg$ VS, the energy conversion rate is 70% - 75% (Oosterkamp, 2020). Therefore, the remaining 25% VS content can be used for biofertilizer production

**Table 3.5:** Equation uesd in the biofertilizer yield

| Criteria, unit | | Equation | |
|---|---|---|---|
| **$F_{bio}$,** Bio-fertilizer yield | kg/day | (DM-VS) +(0.25 x VS) | **(13)** (Yong,2020) |

* DM = Dry mass, mass of solid components of organic waste (weight after 24 hours of oven at 105 °C), kg/tonne; VS = Volatile solids, portion of dry matter that

can be potentially converted to biogas, (weight after 1 hour of furnace at 550 ºC), kg/tonne

### 3.6.4 Environmental protection: avoidance in $CO_2$, leachate, and land-use

The environment related calculation includes equation 14 for determining the amount of carbon dioxide avoided; Equation 15 for determining the area required for landfill of organic waste; Equation 16 is used to determine the leachate discharge. The calculation is consistent with the objectives of the project. The focus of the project is to analyze the impact of air, water and land and the sustainability of the contribution of anaerobic digestion to the environment. According to the research, the main environmental problems of the landfill site are the potential risk of leachate to land and groundwater, landfill gas emission and land pollution. The avoidance of these elements by anaerobic digestion is explicitly evaluated by the following equation and a simple mathematical formula.

**Table 3.6:** Equation used in calculating the avoidance in carbon dioxide emissions, leachate generation and land-use.

| **Criteria, unit** | | **Equation** | |
|---|---|---|---|
| **$CO_2$,** Carbon dioxide avoidance | tonne/day | $E_{bio} \times C_C$ | **(14)** (SEDA, 2019) |
| **A,** Area required to landfill organic waste | $m^2$/day | $M_{organic} \times 1/B \times 1/H$ | **(15)** (Ibrahim *et al.,* 2017) |
| **V,** Volume of leachate discharge | $m^3$/day | $V = 0.15 \times R \times A$ | **(16)** (Ibrahim *et al.,* 2017) |

* $E_{bio}$ = Electrical energy output; $C_C$= Baseline constant for off-setting $CO_2$ by producing electricity from renewable in Liaoning province; $M_{organic}$ = Incoming mass of organic MSW stream, kg/day; B= Bulk density of waste; H= Depth of landfill; R= Annual rainfall; A= Area required to landfill organic waste

### 3.6.5 Economic analysis

The economic evaluation includes considering the economic benefits and expenses generated by OFMSW anaerobic digestion and the calculation of return on investment (ROI) (see Table 3.4). The increase of biogas methane production will have a significant impact on the economic balance of biogas power plant construction. The cash flow of capital expenditure (Equation 17) is calculated based on the initial capital expenditure of power output, while operating expenditure (equation 18) covers annual operation and maintenance expenditure and other expenses including isolation and transportation expenses. In terms of revenue, the revenue covered is biogas power generation equation 19, in which a fit mechanism is adopted to determine the sales rate of renewable power back to Liaoning public utility companies, in which fit mechanism is the rate approved by the Sustainable Energy Development Bureau of Liaoning Province. Next is the benefit cost of the landfill as shown in equation 22. The fertilizer and leachate savings generated by conventional treatment of the landfill in Liaoning Province are calculated according to equation 20 and equation 23. In order to analyze the overall economic benefits, the return on investment is used to determine the return period. As shown in equation 24, the income cost (Eqn 25) and net cash flow (Eqn 26) will be determined and tabulated in the table, and the accumulated income and expenses will be further calculated to provide a chart description, showing the return on investment and the rate of return on investment.

**Table 3.7:** Equation involves calculating the OPEX and CAPEX expenses and revenue of electricity (Yong, 2020).

| Criteria | Equation | |
|---|---|---|
| $(\text{EXPENSES})_{\text{CAPEX}}$ | $7.085 \times P_{bio}$ | **(17)** |
| $(\text{EXPENSES})_{\text{OPEX}}$ | $1.1 \times P_{bio}$ | **(18)** |
| Revenue of Electricity | FiT rate x $E_{bio}$ | **(19)** |
| Revenue of Fertilizer | Average market value x $F_{bio}$ | **(20)** |

| | | |
|---|---|---|
| (EXPENSES) segregation and transportation fee | Tipping fee of MSW x Incoming mass of OFMSW | **(21)** |
| Revenue Landfill | Landfill OPEX x Mass of OFMSW that can be avoided | **(22)** |
| Savings in leachate treatment | Rate of leachate treatment in general x volume of leachate | **(23)** |
| ROI, return of investment | $\frac{\text{Total Initial Investment (RM)}}{\text{Net Profit } \left(\frac{\text{RM}}{\text{year}}\right)}$ | **(24)** |
| Cost of Expenses | Capital Expenditure (CAPEX)+ Operating Expenditure (OPEX)+ Separation and transportation fee | **(25)** |
| Cost of Revenue | Sales of Biogas + Sales of Electricity+ Sales of Bio-Fertilizer+ Savings in Landfill OPEX | **(26)** |

# CHAPTER 4

## 4.0 RESULTS AND DISCUSSION

### 4.1 Introduction

In this chapter, results obtained from the analysis of the data are presented. Findings and data collection from the literature reviews and past studies contribute to the data analysis together with the use of Microsoft Excel is shown in appendixes (Shown in Appendix E). Environmental (carbon dioxide avoidance; area required to landfill organic waste; volume of leachate discharge) and energy (electrical energy generation) economic (selling of renewable energy and bio-fertilizer) evaluation of the life cycle assessment of waste to power plant via utilization of food waste to bioenergy. From the theoretical calculations above, the study on the food waste characterization with the potential performance of the anaerobic digestion biogas power plant are discussed in the Environment, Energy and Economic and technology aspect.

### 4.2 Basic characterization result from data analysis

The determination of characteristic tests is very important to determine the accurate fluctuation of OFMSW sample quality. In order to ensure the successful implementation of biogas power plants, the fluctuation in OFMSW quality analysis should be evaluated to ensure the effective performance of anaerobic digestion. This fluctuation will significantly affect biogas productivity, thus affecting power generation and fertilizer production, which will affect the return on investment and the return on investment of the proposed project. Domestic waste in Liaoning Province has always been the key to the reference of waste generation.

According to this study, it was found that the total amount of domestic waste collected in Liaoning Province of China is 914.55 tons. Food, kitchen and organic wastes account for 73.42% of the total municipal solid wastes in Liaoning Province, followed by paper (9.17%), plastics (3.01%), garden and wood wastes (12.51%) and textiles (1.89%).

Volatile solids (VS) and total solids (as show in Table 4.1) are an indicator for monitoring the solid content of the organic part of the waste fed into the digester, which makes few people assume that a higher VS/Ts ratio means more energy generation, because bacteria have more food to digest food waste. In contrast, higher biogas production will lead to less surplus biofertilizer production from the following two tables, the range required by the standard experiment and the basic data of movement content and input our experimental data. From the calculation and standard data requirements, conclude that the output ratio of carbon is 0.03919, hydrogen is 0.0675, nitrogen is 0.001842, sulphur is 0.0001625, oxygen is 0.02043.

**Table 4.1:** Input of basic data of organic waste

| Parameter | Unit | standard value | value input |
|---|---|---|---|
| temperature | celcius | | 27 |
| pH | | 4.02-7.17 | 4.59 |
| oxidation reduction potential | mV | | 145.11 |
| moisture content | % | 21.15- 85.6 | 70 |
| dry matter | | | 30 |
| total solid | | 7.94- 40 | 0.73593 |
| volatile solid | | 6.74- 39.2 | 99.26 |
| | | 70% of VS is biogas | 69.48 |
| | | 30 % VS is fertilizer | 29.779221 |

**Table 4.2:** Output ratio of CHNOS data

| Parameter | Unit | standard value | | value output |
|---|---|---|---|---|
| carbon | % | 37.6- 51.3 | 47.03 | 0.03919 |
| hydrogen | | 5-7.66 | 6.75 | 0.0675 |
| nitrogen | | 1.5- 3.9 | 2.58 | 0.001842 |
| sulphur | | 0.1- 0.9 | 0.52 | 0.0001625 |
| oxygen | | 32.7 | 32.7 | 0.02043 |
| Total incoming OFMSW, M organic | tonne/day | 18400 | | |
| All waste | tonne/yr | 11175084.4 | | |

### 4.3 Electrical Energy-Power and Biofertilizer Generation

**Table 4.3:** The volume of biogas and pure methane gas yield from OFMSW for Liaoning Province and the potential electrical energy and power yield from the generated biogas-methane.

| Parameter | | Unit | value output |
|---|---|---|---|
| $(CH)_4$ | ratio of methane gas | | 0.02 |
| $(CO)_2$ | atio of carbon dioxide gas | | 0.02 |
| $(CH)_4$ % | percentage composition of methane gas | % | 56.62 |
| $(CO)_2$% | percentage composition of carbon dioxide gas | | 43.38 |
| $(V)_{CH4}$ | volume of pure methane gas yield | $m^3$/day | 5067734.07 |
| (V) biogas | volume of biogas yield | $m^3$/day | 8949648.55 |
| $E_{bio}$ | Electrical energy output | kWh/day | 20270936.30 |
| $P_{bio}$ | Electrical power output | kW | 844622.35 |
| $E_{bio}$ , Double Check | Electrical energy output | kWh/day | 20188088.98 |
| $P_{bio}$, Double Check | Electrical power output | kW | 841170.37 |
| $CO_2$ | Carbon dioxide avoidance | tonne/day | 14068.03 |
| A | Area required to landfill organic waste | $m^2$ /day | 1858.59 |
| V | Volume of leachate discharge | $m^3$ /day | 791.76 |
| $F_{bio}$ | Bio-fertilizer yield | kg/day | 1684009.96 |

As mentioned earlier, according to the commercial gas engine catalogue , the efficiency of the actual biogas engine is limited to 40%, so the value used to calculate nel is fixed at 40%.

According to the calculation, $E_{bio}$ is 20270936.30 kwh/day. For power generation, the value obtained by pbio from OFMSW is 841170.37 kW. Using the cross check formula, the difference between the results is 0.4%. Therefore, in the subsequent calculation, the average value from, i.e. 20229512.64kwh/day, will be used for the power output of Liaoning Province, Pbio is 36359.58 kW, while 1666380.501 kwh / day is used for the power output of the Liaoning province, Pbio is 842896.36 kW (refer to Table 4.3 and Table 4.4).

The biological fertilizer production in Liaoning province is 1684009.96 kg / day. The general knowledge of biological fertilizers is environmentally friendly and can reduce the dependence on chemical fertilizers, which will worsen soil conditions. In theory, food waste in landfills has no chance to recover nutrients from source organic materials.

**Table 4.4:** The potential electrical energy and power yield from the generated biogas-methane for Liaoning province

| Parameter | | Unit | Value |
|---|---|---|---|
| Input | $V_{CH4}$ | $m^3$/day | 5067734.07 |
| | E | kWh/$m^3$ | 10 |
| | $N_{el}$ | %/100 | 0.400 |
| Output | $E_{bio}$ | kWh/day | 20270936.30 |
| | $P_{bio}$ | kW | 844622.35 |

**Table 4.5:** The cross-check formula for biogas-to-electrical energy and power potential for Liaoning province

| Parameter | | Unit | Value |
|---|---|---|---|
| Input | $M_{organic}$ | kg/hr | 766666.667 |
| | Y | $m^3$/kg | 0.486 |
| | D | %/100 | 0.566 |
| | P | tonne/$m^3$ | 0.001 |
| | LHV | MJ/kg | 50.00 |
| | C | - | 0.278 |
| | $N_{el}$ | %/100 | 0.40 |
| Output | $E_{bio}$ | kWh/day | 20188088.98 |
| | $P_{bio}$ | kW | 841170.37 |

**Table 4.6:** The biofertilizer yield for Liaoning province

| Parameter | | Unit | Value |
|---|---|---|---|
| Input | DM | %DM | 100 |
| | VS | %DM | 0.3 |
| | Mass of dry mass ($M_{DM}$) | tonne /day | 5518.603 |
| Output | $F_{bio}$ | kg/day | 1684010 |

**4.4 Environmental Analysis**

In calculation, factor Cc = 0.928 tonne $CO_2$/MWh is the baseline for $CO_2$ emission in generating per MWh of electricity in Liaoning province (https://www.gov.cn), which is an indicator show greenhouse gas emission from fossil fuel power stations. The constants B is the bulk density of organic waste and H is the height of landfill which is based on the Chaoyang city landfill data reference in this project calculation.

In general, Liaoning province able to achieve 14068.02979 tonne/day of $CO_2$ avoidance, 1858.585859 $m^2$/day and 791.7575758$m^2$/day of landfill savings and, 65.22 $m^3$/day and 34.15 of leachate avoidance via conventional treatment (refer Table 4.7). From study, methane is a well-known gasses that is able more effectively to traps heat in the atmospheres compared to carbon dioxide, whereby via 86 times more powerful heat absorption in 20 years as compared to carbon dioxide (Environmental and Energy Study Institute, 2017). AD is a very good technology that potentially reduces the greenhouse gas emissions and also provides a set of renewable sources of energy. The potential of AD reveals when the OFMSW from Liaoning province is potentially be collected and used as renewable energy generation via AD with $CO_2$ avoidance, landfill savings and leachate avoidance benefits. The summary of the combination of Liaoning province data analysis was tabulated in Table 4.8.

**Table 4.7:** Contribution to environmental protection for Liaoning province.

| Parameter | | Unit | Value |
|---|---|---|---|
| Input | $C_C$ | tonne $CO_2$/MWh | 0.928 |
| | $E_{bio}$ | kWh/day | 20270936.30 |
| | $M_{organic}$ | tonne /day | 18400000 |
| | B | tonne / $m^3$ | 0.45 |
| | H | m | 22 |

| | | | |
|---|---|---|---|
| | R | m | 2.84 |
| Output | $CO_2$ emission reduction | tonne /day | 14068.02979 |
| | Landfill area saving | $m^2$/day | 1858.585859 |
| | Leachate avoidance | $m^3$/day | 791.7575758 |

**Table 4.8:** Summary of Liaoning province data analysis.

| | Aspect | Unit | Value output |
|---|---|---|---|
| $(CH)_4$ | ratio of methane gas | | 0.02 |
| $(CO)_2$ | ratio of carbon dioxide gas | | 0.02 |
| $(CH)_4$ % | percentage composition of methane gas | % | 56.62 |
| $(CO)_2$% | percentage composition of carbon dioxide gas | | 43.38 |
| $(V)_{CH4}$ | volume of pure methane gas yield | $m^3$/day | 5067734.07 |
| $(V)_{biogas}$ | volume of biogas yield | $m^3$/day | 8949648.55 |
| $E_{bio}$ | Electrical energy output | kWh/day | 20270936.30 |
| $P_{bio}$ | Electrical power output | kW | 844622.35 |
| $E_{bio}$ , Double Check | Electrical energy output | kWh/day | 20188088.98 |
| $P_{bio}$, Double Check | Electrical power output | kW | 841170.37 |
| $CO_2$ | Carbon dioxide avoidance | tonne/day | 14068.03 |
| A | Area required to landfill organic waste | $m^2$ /day | 1858.59 |
| V | Volume of leachate discharge | $m^3$ /day | 791.76 |
| $(F)_{bio}$ | Bio-fertilizer yield | kg/day | 1684009.96 |

**4.5 Economic Analysis**

Market potential for the WTE industry especially for the conversion of OFMSW to bigas via AD technology is great. As AD possesses a very low and harmless disposal method for the food waste, the increment amount of the waste tends to make the industry sustainable. The transformation of the heterogenous waste into homogenous residues via biogas power plant construction that takes food waste as input source is believed able to reduce the waste up to 45% as food waste generally contributes to 45% of total waste.

In economic evaluation, costs for the waste to energy plant mainly separated into investment costs and operational costs, whereby in this project only include both the capital expenditures expenses and also the operational cost, which is a result of a complex balance calculation by definition, CAPEX involving big purchases that are planned to utilize the asset over the long-term period while OPEX involves the day-to-day expenses that incurs in a company to keep industry operational. In short, the CAPEX expenses for this project involve RM 1080 million/yr while OPEX expenses include RMB 180 million per year (refer Table 4.9 and Table 4.10).

It is clearly shown that the project is sustainable and highly feasible with such a huge amount of food waste, stable net profit margin and a high ROI amount was performed within the calculation in this project. Waste arrival to the plant should undergo pre-treatment and segregation , which is quoted as RMB 2027.56/tonne per year. Within this project, the separation and transportation fees including the segregation of the non-OFMSW waste transportation to disposal facility, which involves around RMB 5554960 per day (refer Table 4.11). The revenue calculated is based on the savings in Landfill OPEX for RMB 1380000 per day ( refer Table 4.12), the sales of biogas electricity which is estimated at RMB 11247609.03 per day ( refer Table 4.13) , sales of biofertilizer estimated for RMB 1936611.453 per day( refer Table 4.14), savings in leachate treatment with RMB 7410.850909 per day ( Table 4.15) The summary of the economy analysis from the product yield has been summarized at Table 4.16.

The ROI in this project is calculated which also can be found via the cumulative expenditure versus cumulative revenue graph presented in Figure 4.1. Figure 4.1 labeled with an arrow which shows the point of ROI when the two lines were intersect, also refer to point of breakeven. It can be said when the net profit is sufficient to cover all initial starting investment including the separation and transportation cost for non-OFMSW, the subsequent year of return of investment is calculated and tabulated at Table 4.17. Overall, the ROI was found to be 5 years and 1 month.

$$\text{ROI} = \frac{\boldsymbol{OPEX + CAPEX\ million\ (RMB)}}{\boldsymbol{net\ profit\ million\ \frac{RMB}{year}}} = 5.1 \text{ years}$$

In the first year of operating, the net profit is RMB -7329.409 million and is estimated to recoup their investments within 5 years 1 month (refer Table 4.17) However, the sensitivity analysis in this project including the feed-in tariff and tipping fees which, the major income is directed from the biogas electricity sales and tipping fees. Also, the Waste to Energy power plant dominated by the policy, which have direct impact on the cash flow and income from the biogas power plant and consequently bring impact to the net profit margin (Zhao *et al.,* 2016).

**Table 4.9:** CAPEX calculation.

| Parameter | Unit | Value |
|---|---|---|
| (CAPEX) | RMB, million/MW | 10.8 |
| $(P_{bio})_{avg}$ | MW | 842.89636 |
| CAPEX expenses | RMB, million/ yr | 9103.28 |

**Table 4.10:** OPEX calculation

| Parameter | Unit | Value |
|---|---|---|
| (OPEX) | RMB, million/MW/yr | 1.8 |
| $(P_{bio})_{avg}$ | MW | 842.89636 |
| OPEX expenses | RMB, million/ yr | 1517.213448 |

**Table 4.11:** Separation and transportation expenses

| Parameter | Unit | Value |
|---|---|---|
| Separation and transportation fee | RMB/ tonne | 301.9 |
| Incoming mass of OFMSW | Tonne/day | 18400 |

| | | |
|---|---|---|
| Separation and transportation expenses | RMB/day | 5554960 |

**Table 4.12:** Revenue of landfill

| Parameter | Unit | Value |
|---|---|---|
| General Landfill OPEX for Liaoning province | RMB/tonne | 75 |
| Incoming mass of OFMSW | tonne/day | 18400 |
| Revenue of landfill | RMB/day | 1380000 |

**Table 4.13:** Revenue of biogas electricity.

| Parameter | Unit | Value |
|---|---|---|
| $(E_{bio})_{avg}$ | kWh/day | 20229512.64 |
| FiT rate | RMB/ kWh | 0.556 |
| Revenue of biogas electricity | RMB/day | 11247609.03 |

**Table 4.14:** Revenue of Fertilizer

| Parameter | Unit | Value |
|---|---|---|
| Average market value of fertilizer | / tonne | 1150 |
| $(F)_{bio}$ | tonne/day | 1684.0099 |
| Revenue of fertilizer | RMB/day | 1936611.453 |

**Table 4.15:** Savings in Leachate by conventional treatment

| Parameter | Unit | Value |
|---|---|---|
| Rate of treatment in general | RMB /$m^3$ | 9.36 |

| | | |
|---|---|---|
| Volume of leachate treatment via conventional method | $m^3$/day | 791.7575 |
| Savings in leachate treatment | RMB/day | 7410.8509 |

**Table 4.16:** Summary and detail parameters of economic analysis.

| PARAMETER | | Daily ( RMB/day) | Monthly (RMB thousand / month) | Anually (RMB million/yr) |
|---|---|---|---|---|
| Expenses | CAPEX | - | - | 9103.281 |
| | OPEX | - | - | 1517.213 |
| | Separation and transportation Fees | 5554960.000 | 166648.800 | 2027.560 |
| Revenue | Biogas electricity | 11247609.028 | 337428.271 | 4105.377 |
| | Bio-fertilizer | 1936611.453 | 58098.344 | 706.863 |
| | Landfill OPEX | 1380000.000 | 41400.000 | 503.700 |
| | Saving in leachate treatment by conventional method | 7410.850909 | 222.3255273 | 2.705 |

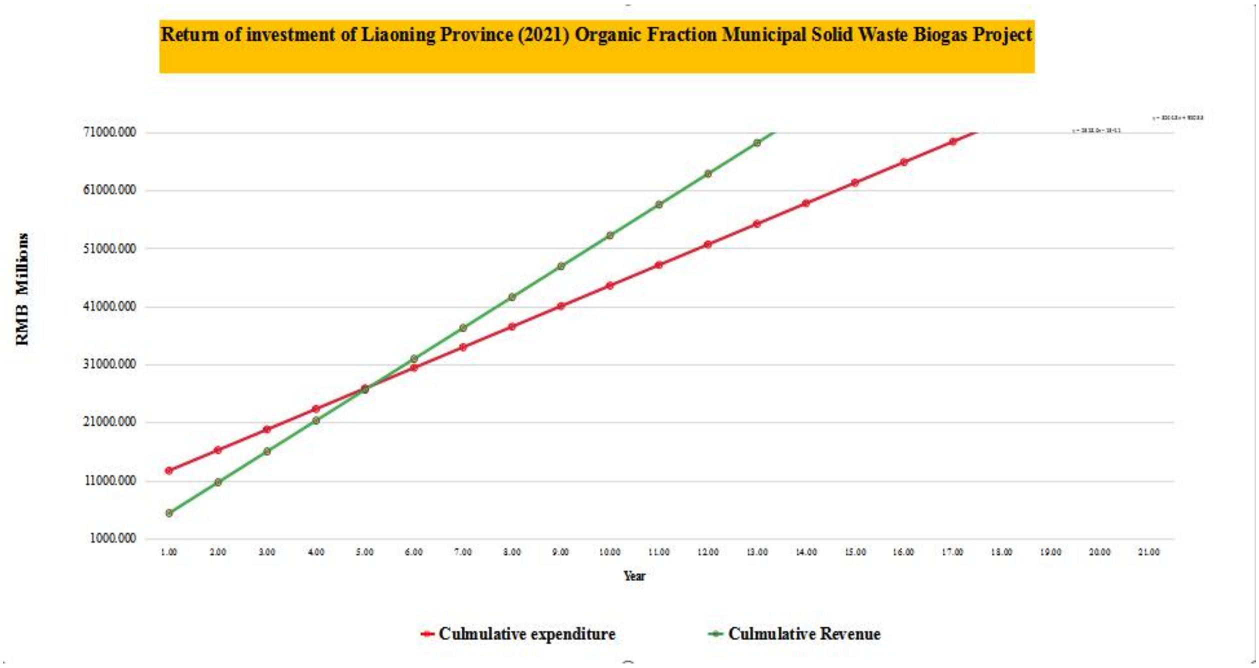


**Figure 4.1:** Return of investment graph to determine ROI of Liaoningprovince 2021 Organic Fraction Municipal Solid Waste Biogas Project.

| Year | RMB( Millions) | | | | | | | | Paybackperiod |
|---|---|---|---|---|---|---|---|---|---|
| | Total expenses | | | Total Revenue | | | | Net cash flow | if - = in debt If 0= break even if + = earning |
| | CAPEX | OPEX | Separation and transportation fee | Electricity sales | Fertilizer | Saving in Landfill (OPEX) | Saving in Leachate | | |
| 1 | 9103.281 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | -7329.409 | -7329.409 |
| 2 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | -5555.538 |
| 3 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | -3781.666 |
| 4 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | -2007.794 |
| 5 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | -233.923 |
| 6 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 1539.949 |
| 7 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 3313.820 |
| 8 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 5087.692 |
| 9 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 6861.564 |
| 10 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 8635.435 |
| 11 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 10409.307 |
| 12 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 12183.178 |
| 13 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 13957.050 |
| 14 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 15730.922 |
| 15 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 17504.793 |
| 16 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 19278.665 |
| 17 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 21052.536 |
| 18 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 22826.408 |
| 19 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 24600.279 |
| 20 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 26374.151 |
| 21 | 0 | 1517.213 | 2027.560 | 4105.377 | 706.863 | 503.700 | 2.705 | 1773.872 | 28148.023 |

**Table 4.17:** Summary of ROI analysis for 21 years period for the biogas power plant implementation.

### 4.6 Sustainable Development of WTE (Waste To Energy) Plant In Complies With SDGs Goals

**Table 4.18:** Summary of the relationship with quantifiable results of this study with the United Nations Sustainable Development Goals and targets (United Nations Sustainable Development, no date; Environmental and Energy Study Institute, 2017).

| SDG goals | Quantifiable Numbers |
|---|---|
| **Goal 2**: To end hunger and promotion of sustainable agriculture | OFMSW through AD able to provide 30% of bio-fertilizer from VS, as well as 0.736 % of TS based on DM, also provide sustainable bio-fertilizer production which essential for the growth of plants and increasing crop yields with yielding amount of:<br><br>Daily= RMB 1936611.453 |
| **Goal 6:** Ensure availability and sustainability management of water and sanitation for all | Reduction of carbon loading of wastewater, Avoid chemical fertilizer that deteriorates the water and soil condition. Water pollution is potentially avoided from landfilling OFMSW, via leachate avoidance:<br><br>Daily= RMB 7410.8509 |
| **Goal 7:** Ensure access to affordable, reliable, sustainable, and modern energy for all. | Reduce the conventional fossil fuel dependence power generation method, in which AD is able to generate renewable energy from OFMSW, via heat and methane gas capture to produce power. The earning yield of selling the biogas is:<br><br>Daily=8949648.551 kW |
| **Goal 11:** Ensure sustainable consumption and production patterns | Potentially sustainable and production from daily amount of 2309.4 tonnes OFMSW was diverted away from Penang landfill which able to produce 0.8446 TWh annually of clean electricity power and1684009.959 kg/day of biofertilizer. |

| | |
|---|---|
| **Goal 13:** Take urgent actions to combat climate change and its impacts. | $CO_2$ avoidance from the clean source of energy which is non-polluting and carbon-neutral, which provide daily avoidance of 14068.02979 tonne, also land savings area about 1858.585859 $m^2$/day. |

The construction of a biogas power plant and the collection of OFMSW provide employment opportunities for local people. Therefore, skilled personnel are required for technical pretreatment, management and monitoring. Therefore, due to the increasing trend of waste, employment opportunities are also expanded. In addition, through AD, OFMSW can provide biofertilizer from VS and DM based TS to provide sustainable biofertilizer production, which is very important for plant growth and increasing crop yield

Anaerobic digestion has the potential to reduce the carbon load of wastewater while providing a sustainable biosolid cycle to restore natural soil nutrients and avoid deterioration of water and soil conditions by chemical fertilizers. Landfill MSW treatment can avoid water pollution by avoid leachate

Anaerobic digestion of OFMSW can reduce traditional fossil fuel power generation, which AD can generate renewable energy from OFMSW through heat and methane gas capture, so as to generate electricity and power generation. At the same time, the yield can be obtained by selling biogas

The potential sustainability and sustainable waste generated by transferring daily waste from Liaoning landfill can produce a large amount of clean power and biological fertilizer every year.

Avoid carbon dioxide emissions from traditional fossil fuel energy, uncontrolled decomposition emissions from landfills, and deforestation for coal production. OFMSW is a clean energy source for power generation. It is pollution-free and carbon neutral.

Protect the land and promote the sustainable land use of the landfill, in which OFMSW uses anaerobic digestion.

# CHAPTER 5

## 5.0 CONCLUSION

In conclusion, a waste incineration power plant plays a very important role in promoting the realization of energy conservation and emission reduction targets. It is technically feasible to build a power plant by anaerobic digestion. Anaerobic digestion is a method widely used in many countries all over the world. Because anaerobic digestion has the ability to capture energy, it has great potential to recover biogas and biological fertilizer in food waste treatment

In China, the recycling of organic municipal solid waste through anaerobic digestion can make a significant contribution to environmental sustainability, renewable energy expansion and positive economic development. The potential avoidance of carbon dioxide emission, landfill area and leachate are 14068 tons of carbon dioxide/day, 1859 square meters/day and 792 cubic meters/day respectively. The potential of using biogas with methane content of 56.62% and carbon dioxide content of 43.38% to produce renewable bioenergy is 20270936 kwh/day. In addition, the output of organic fertilizer is 1684 tons/day. According to the financial analysis of total income and total expenditure, it is found that the return on investment is within 5.2 years.

Consequently, the implementation of multiple biogas facilities for organic fraction municipal solid waste anaerobic digestion can encourage a positive paradigm shift in the Chinese solid waste management towards a more sustainable practice with an economic revenue generating activity.

Methane gas released by microbial digestion. Food waste is a kind of easily digestible material, which has sufficient nutrition level required for anaerobic digestion and a suitable range of water content, total solids and volatile solids. Food waste is used as the raw material of the digester to promote sustainable pollution control and energy recovery with the efficient degradation of organic waste.

The moisture content, together with the total amount of solid and volatile solids and the final characteristics of waste elements, is also the key to determine the biogas production efficiency. Ts and vs are very important for understanding microbial activities in ad system. The benefits of anaerobic digestion can generally be summarized as: helping to improve air quality, biogas collection focusing on greenhouse gases, groundwater and surface water protection, biogas power generation, marketable electricity and heat, increasing plant and crop production, reducing greenhouse gases through conventional methods and promoting climate change mitigation, The low harvest period and the sale of renewable energy and bio fertilizer also bring cost-effectiveness. The challenges of obtaining accurate results of characterization prediction include accurate location of rainfall and accurate landfill area, which will lead to slight changes in environmental assessment results.

In terms of economic proposals, it is recommended to use local expertise and technology for trade, and its investment capital will be much lower than imported equipment will effectively shorten the investment payback period (Zhao et al., 2016).

In terms of technical suggestions to provide better biogas production performance, it is very important to expand the range of bacterial strains, which should be tested in AD plant before operation to understand the behavior of microorganisms and the optimal concentration of macro and micronutrients (Oosterkamp, 2020). The average residence time of a certain volume of sludge in the tank should be long enough to maximize biogas production (Lide and Howard, 2014).

Through proper selection of microorganisms, the key to effective biogas production lies in the environment of the digester. Therefore, maintaining a good temperature consistency environment is very important to the stability of the cooking process. In addition, the pH value also plays an important role in maintaining the healthy population of methanogens, so the pH value in the anaerobic digestion tank should be between 7 and 7.5 (Gray, 2008). Basically, the redox potential (ORP) is an indicator for controlling the anaerobic digester. Therefore, an appropriate ORP level (- 100 to - 200mV) plays an important role in the production of volatile fatty acids during acid production and fermentation, aiming to improve the productivity of the digestion unit (Yin *et al.,* 2016; Vongvichiankul, Deebao and Khongnakorn, 2017).

To improve the performance of AD, it can be carried out through the co-digestion process, that is, diluting the existing potentially toxic compounds. This method is to enter an oversized digester through additional energy rich organic waste, such as rice husk as a co-substrate for OFMSW (FW) digestion (David *et al.,* 2018).

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# APPENDICES

**Appendix A** : Liaoning Province Waste Amount Projection.

| | Total | Food | Paper | Plastics | Textiles | Wood |
|---|---|---|---|---|---|---|
| Liaoning Province | 853.51 | 671.43 | 83.90 | 27.53 | 17.27 | 114.42 |

| Component | Organic% | Moisture% | C% | H% | O% | N% | S% |
|---|---|---|---|---|---|---|---|
| Food waste | 59.4 | 72.6 | 26.6 | 3.7 | 23 | 1.6 | 0.2 |
| Fruit | 28.0 | 76.1 | 38 | 3.7 | 35.6 | 1.9 | 0.2 |
| Paper | 6.8 | 5.6 | 4.1 | 4.4 | 39.3 | 0.7 | − |
| Textiles | 2.1 | 15.3 | 41.8 | 4.7 | 43.2 | 0.8 | − |
| Grass,leaves | 1.3 | 56.6 | 46.0 | 6.0 | 38.0 | 3.4 | − |
| Wood | 2.4 | 20.2 | 49.5 | 6.0 | 42.7 | 0.2 | − |

## **Appendix B** : Liaoning Province Environmental Feasibility

| BIOGAS COMPOSITION | | |
|---|---|---|
| c | % weight of carbon | 0.039191667 |
| h | % weight of hydrogen | 0.0675 |
| o | % weight of oxygen | 0.0204375 |
| n | % weight of nitrogen | 0.001842857 |
| s | % weight of sulphur | 0.0001625 |

| METHANE AND BIOGAS YIELD | | | |
|---|---|---|---|
| C | constant 75% VS degrades for biogas production | gC / gVS | 0.375 |
| CH4 | methane fraction obtained from Buswell and Mueller formula | %/100 | 0.566 |
| (M)carbon | molecular weight of Carbon | g/mole | 12.000 |
| (V)stp | volume of 1 mole gas at standard condition | L/mole | 22.400 |
| VS | Volatile solid percentage of organic MSW | %/100 | 0.993 |
| (M)organic | Incoming mass of organic MSW stream | kg/day | 18400000.000 |

| ELECTRICAL ENERGY AND POWER YIELD | | | |
|---|---|---|---|
| (V)CH4 | Volume of pure methane gas yield | m3 /day | 5067734.075 |
| E | Energy constant of methane | kWh/m3 | 10 |
| (N)el | Electrical efficiency of biogas engine | (%/100) | 0.400 |
| D | Methane fraction | (%/100) | 0.566 |
| P | Methane density | ton/m3 | 0.001 |
| LHV | Lower heating value of methane | MJ/kg | 50.000 |
| C | Conversion constant from MJ / hr to kW | | 0.278 |
| Ebio | Electrical energy output | kWh/day | 20270936.298 |
| Y | biogas yield | m3/kg | 0.486 |
| (M)organic | Incoming mass of organic MSW stream | kg/hr | 766666.667 |

### GENERATION YIELD

| | | |
|---|---|---|
| (CH)4 | ratio of methane gas | 0.022192262 |
| (CO)2 | ratio of carbon dioxide gas | 0.016999405 |
| (CH)4 % | percentage composition of methane gas | 56.62495064 |
| (CO)2% | percentage composition of carbon dioxide gas | 43.37504936 |

| | | | |
|---|---|---|---|
| (V)CH4 | volume of pure methane gas yield | m3/day | 5067734.075 |
| (V) biogas | volume of biogas yield | m3/day | 8949648.551 |

| | | | |
|---|---|---|---|
| Ebio | Electrical energy output | kWh/day | 20270936.3 |
| Pbio | Electrical power output | kW | 844622.3458 |

Double Check

| | | | |
|---|---|---|---|
| Ebio | Electrical energy output | kWh/day | 20188088.98 |
| Pbio | Electrical power output | kW | 841170.3742 |

Average value

| | | | |
|---|---|---|---|
| Ebio, Avg | Electrical energy output | kWh/day | 20229512.64 |
| Pbio, Avg | Electrical power output | kW | 842896.36 |

**Appendix C** : Liaoning Province Environmental Feasibility Calculation.

| Avoidance in Carbon Dioxide emissions, Leachate generation and Land-Use | | | |
|---|---|---|---|
| (C)C | Baseline constant for off-setting CO2 by producing electricity from renewable in Peninsular Malaysia | tonne/MWh | 0.694 |
| Ebio | Electrical energy output | kWh/day | 20270936.3 |
| Morganic | Mass of organic waste inflow, tonne/day | tonne/day | 18400 |
| B | bulk density of organic waste | tonne/ m3 | 0.45 |
| H | depth of landfill | m | 22 |
| R | Annual rainfall | m | 2.84 |
| A | Area required to landfill organic waste | m2 /day | 1858.585859 |

| BIOFERTILIZER YIELD | | | |
|---|---|---|---|
| DM | Dry Mass, mass of solid components of organic waste | % | 1 |
| VS | Volatile Solids, portion of DM that can be potentially converted to biogas, (weight after 1 hour of furnace at 550,C) | % | 0.99264 |
| | 30% of the VS is Fbio | | 0.3 |
| | Mass of dry mass ( Dry basis) | tonne/day | 5518.6 |

| | | | |
|---|---|---|---|
| CO2 | Carbon dioxide avoidance | tonne/day | 14068.02979 |
| A | Area required to landfill organic waste | m2 /day | 1858.585859 |
| V | Volume of leachate discharge | m3 /day | 791.7575758 |

| | | | |
|---|---|---|---|
| (F)bio | Bio-fertilizer yield | kg/day | 1684009.959 |

# **Appendix D** : Liaoning Province Economic Feasibility Calculation

| | | | |
|---|---|---|---|
| (CAPEX) | initial capital expenditure | RMB, million/MW | 10.8 |
| (OPEX) | annual operation and maintenance expenditure | RMB, million/ MW/ yr | 1.8 |
| Pbio | Electrical power output | MW | 842.89636 |
| | FiT rate | RMB/ kWh | 0.556 |
| (EXPENSES )CAPEX, $, million / yr | | | 9103.280688 |
| (EXPENSES)OPEX, $, million / yr | | | 1517.213448 |

| | | | |
|---|---|---|---|
| | speration and transportation fee | RMB /tonne | 301.9 |
| | incoming mass of OFMSW | tonne/day | 18400 |
| | general landfill OPEX for Malaysia | RMB/tonne | 75 |
| | (EXPENSES) seperation and transaportation fee ,$ /day | | 5554960 |
| note: not remove 42 | RevenueLandfill,$/day | | 1380000 |

| | | | |
|---|---|---|---|
| $ | Average market value | /tonne | 1150 |
| (F)bio | Bio-fertilizer yield | tonne/day | 1684.009959 |
| | Rate of treatment in general | RMB/m3 | 9.36 |
| | volume of Leachate discharge | m3/day | 791.7575758 |
| Revenue of Fertilizer, $/day | | | 1936611.453 |
| Saving in Leachate by conventional treatment , $/day | | | 7410.850909 |

**Appendix E** : Liaoning Province Physical Characteristic Data Calculation.

| | *key in data here* | *100-MC* | *key in data here* | $\frac{\%DM}{100}(OFMSW)$ | $\frac{TS_{ref}}{OFMSW_{ref}}(OFMSW)$ | *( TS/DM) (100)* | | *autocount* | *autocount* | *autocount* | *autocount* | *autocount* | *autocount* | *autocount* | *autocount* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | %MC | %DM | OFMSW ( tonne/yr) | DM ( tonne/yr) | TS ( tonne/yr) | TS% | | VS% | VS( tonne/yr) | 90% of food waste DM | 91% of food waste DM | 92% of food waste DM | 93% of food waste DM | 94% of food waste DM | 95% of food waste DM |
| ref data | 90.01 | 9.99 | 6714300 | 670758.57 | 14823.7644 | 2.210 | | 97.79 | 655934.81 | 603682.713 | 610390.2987 | 617097.8844 | 623805.4701 | 630513.0558 | 637220.6415 |
| estimation data of MC to VS | 70 | 30.00 | 6714300 | 2014290 | 14823.7644 | 0.736 | *Double check VS with range of percentage ( 90- 95 )%* | 99.26 | 1999466.24 | 1812861 | 1833003.9 | 1853146.8 | 1873289.7 | 1893432.6 | 1913575.5 |
| | 71 | 29.00 | 6714300 | 1947147 | 14823.7644 | 0.761 | | 99.24 | 1932323.24 | 1752432.3 | 1771903.77 | 1791375.24 | 1810846.71 | 1830318.18 | 1849789.65 |
| | 72 | 28.00 | 6714300 | 1880004 | 14823.7644 | 0.788 | | 99.21 | 1865180.24 | 1692003.6 | 1710803.64 | 1729603.68 | 1748403.72 | 1767203.76 | 1786003.8 |
| | 73 | 27.00 | 6714300 | 1812861 | 14823.7644 | 0.818 | | 99.18 | 1798037.24 | 1631574.9 | 1649703.51 | 1667832.12 | 1685960.73 | 1704089.34 | 1722217.95 |
| | 74 | 26.00 | 6714300 | 1745718 | 14823.7644 | 0.849 | | 99.15 | 1730894.24 | 1571146.2 | 1588603.38 | 1606060.56 | 1623517.74 | 1640974.92 | 1658432.1 |
| | 75 | 25.00 | 6714300 | 1678575 | 14823.7644 | 0.883 | | 99.12 | 1663751.24 | 1510717.5 | 1527503.25 | 1544289 | 1561074.75 | 1577860.5 | 1594646.25 |
| | 76 | 24.00 | 6714300 | 1611432 | 14823.7644 | 0.920 | | 99.08 | 1596608.24 | 1450288.8 | 1466403.12 | 1482517.44 | 1498631.76 | 1514746.08 | 1530860.4 |
| | 77 | 23.00 | 6714300 | 1544289 | 14823.7644 | 0.960 | | 99.04 | 1529465.24 | 1389860.1 | 1405302.99 | 1420745.88 | 1436188.77 | 1451631.66 | 1467074.55 |
| | 78 | 22.00 | 6714300 | 1477146 | 14823.7644 | 1.004 | | 99.00 | 1462322.24 | 1329431.4 | 1344202.86 | 1358974.32 | 1373745.78 | 1388517.24 | 1403288.7 |
| | 79 | 21.00 | 6714300 | 1410003 | 14823.7644 | 1.051 | | 98.95 | 1395179.24 | 1269002.7 | 1283102.73 | 1297202.76 | 1311302.79 | 1325402.82 | 1339502.85 |
| | 80 | 20.00 | 6714300 | 1342860 | 14823.7644 | 1.104 | | 98.90 | 1328036.24 | 1208574 | 1222002.6 | 1235431.2 | 1248859.8 | 1262288.4 | 1275717 |
| | 81 | 19.00 | 6714300 | 1275717 | 14823.7644 | 1.162 | | 98.84 | 1260893.24 | 1148145.3 | 1160902.47 | 1173659.64 | 1186416.81 | 1199173.98 | 1211931.15 |
| | 82 | 18.00 | 6714300 | 1208574 | 14823.7644 | 1.227 | | 98.77 | 1193750.24 | 1087716.6 | 1099802.34 | 1111888.08 | 1123973.82 | 1136059.56 | 1148145.3 |
| | 83 | 17.00 | 6714300 | 1141431 | 14823.7644 | 1.299 | | 98.70 | 1126607.24 | 1027287.9 | 1038702.21 | 1050116.52 | 1061530.83 | 1072945.14 | 1084359.45 |
| | 84 | 16.00 | 6714300 | 1074288 | 14823.7644 | 1.380 | | 98.62 | 1059464.24 | 966859.2 | 977602.08 | 988344.96 | 999087.84 | 1009830.72 | 1020573.6 |
| | 85 | 15.00 | 6714300 | 1007145 | 14823.7644 | 1.472 | | 98.53 | 992321.24 | 906430.5 | 916501.95 | 926573.4 | 936644.85 | 946716.3 | 956787.75 |
| | 86 | 14.00 | 6714300 | 940002 | 14823.7644 | 1.577 | | 98.42 | 925178.24 | 846001.8 | 855401.82 | 864801.84 | 874201.86 | 883601.88 | 893001.9 |
| | 87 | 13.00 | 6714300 | 872859 | 14823.7644 | 1.698 | | 98.30 | 858035.24 | 785573.1 | 794301.69 | 803030.28 | 811758.87 | 820487.46 | 829216.05 |
| | 88 | 12.00 | 6714300 | 805716 | 14823.7644 | 1.840 | | 98.16 | 790892.24 | 725144.4 | 733201.56 | 741258.72 | 749315.88 | 757373.04 | 765430.2 |
| | 89 | 11.00 | 6714300 | 738573 | 14823.7644 | 2.007 | | 97.99 | 723749.24 | 664715.7 | 672101.43 | 679487.16 | 686872.89 | 694258.62 | 701644.35 |
| | 90 | 10.00 | 6714300 | 671430 | 14823.7644 | 2.208 | | 97.79 | 656606.24 | 604287 | 611001.3 | 617715.6 | 624429.9 | 631144.2 | 637858.5 |
| | 91 | 9.00 | 6714300 | 604287 | 14823.7644 | 2.453 | | 97.55 | 589463.24 | 543858.3 | 549901.17 | 555944.04 | 561986.91 | 568029.78 | 574072.65 |
| | 92 | 8.00 | 6714300 | 537144 | 14823.7644 | 2.760 | | 97.24 | 522320.24 | 483429.6 | 488801.04 | 494172.48 | 499543.92 | 504915.36 | 510286.8 |
| | 93 | 7.00 | 6714300 | 470001 | 14823.7644 | 3.154 | | 96.85 | 455177.24 | 423000.9 | 427700.91 | 432400.92 | 437100.93 | 441800.94 | 446500.95 |
| | 94 | 6.00 | 6714300 | 402858 | 14823.7644 | 3.680 | | 96.32 | 388034.24 | 362572.2 | 366600.78 | 370629.36 | 374657.94 | 378686.52 | 382715.1 |
| | 95 | 5.00 | 6714300 | 335715 | 14823.7644 | 4.416 | | 95.58442 | 320891.24 | 302143.5 | 305500.65 | 308857.8 | 312214.95 | 315572.1 | 318929.25 |