Comparative analysis of development potential for biomass- vs coal-fired power plants in Henan province, China

Dongcan Wang
Abstract

Coal-fired power plants' typically large capacity and relatively low electricity generation costs in the Chinese power market can be compared with their typically low specific thermal efficiency and older age on average. At the same time, the environment pollution caused by local coal-fired power plants has started to receive due attention.

Sustainable renewable energy sources and the application of effective conversion technologies for those has become a top priority of China's current energy strategy. Biomass in general and anaerobic biogas in particular can be regarded as clean, locally available renewable energy resources. Replacing coal with biomass-derived energy is especially relevant for certain locations in China. For the case of Henan province, work has already been undertaken by the local authorities for the proper estimation of the biomass potential and the selection of most applicable energy conversion technologies with the lowest environmental footprint to replace aging coal-fired plants with various biomass-based power generation facilities.

Key words: Coal-fired power plant; biomass, biogas; steam turbine; GTCC system; environment; pollution; electricity generation cost
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När det gäller Henanprovinser har en del arbete redan gjorts av de lokala myndigheterna för en korrekt uppskattning av biomasspotentialen och en analys av de mest tillämpliga teknologier för omvandling av bioenergi med lägsta miljöpåverkan som ersätter åldrande kolbaserade anläggningar med olika biobränslen.

Nyckelord: kolkraft; kolkraftverk; biogas; biogasanläggning; ångturbin; GTCC system; utsläpp; växthuseffekten; miljöförstöring; energiproduktionskostnad
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Abbreviations

CFCs (chlorofluorocarbons)
CH₁ (Methane)
CO₂ (Carbon dioxide)
GHG (Greenhouse gases)
GTCC (gas turbine combined cycle)
HCFCs (Hydrochlorofluorocarbons)
HFCs (hydrofluorocarbons)
LCOE (Levelized cost of energy)
N₂O (Nitrous oxide)
O₃ (Ozone)
PFCs (Perfluorocarbons)
SF₆ (Sulfur hexafluoride)
SO₂ (Sulfur dioxide)
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Dongcan Wang
1. Introduction

The introduction is included in background, aim and objective, key research questions and outline of the project goals. *(to be edited)*

1.1 Background

China is a typical representative country of developing countries especially in coal using. It consumed nearly half of the coal in the world. Thermal power plant burned half of them in 2012 [1]. By the end of 2013, the national power generation capacity of China had reached 1.247 billion kilowatts, ranking first in the world. Among them, thermal power is 862 million kilowatts, accounting for 69.13% of all installed capacity [2]. The coal-dominated energy structure in China cannot fundamentally be changed in the short term. Therefore, the construction of thermal power will remain a critical large-scale investment, and sustained growth in the future. With the high level for thermal power installed capacity, it has caused serious environmental problems and will cause more serious environmental problems in future. Because in China, when the coal-fired power plant burn 1 ton coal, it will produce 0.2 ton coal ash and a lot of greenhouse gasses, dusts, sulfur dioxide, nitrogen oxides, waste water, thermal pollution and noise pollution [3]. These pollutants cause the environment pollution because they cannot be processed by nature. The environment pollution affects the people’s health and development of the national economy.

For a long time, biomass has been seen as an environment friendly energy resource without any or quite small contribution to the greenhouse effect. The biomass is also a kind of clean and low-cost fuel for heat and power generation based on modern biomass technologies. In addition, since sustainable use of biomass leads to no net increase in CO2 emissions, there would be global climate benefits arising from the widespread use of biomass [4].

For biomass-fired power plant, to develop it can significantly reduce carbon dioxide and sulfur dioxide emissions, generating enormous environmental benefits. Compared with traditional fossil fuels, biomass belongs to cleaner fuels. The carbon dioxide emissions
when combusting biomass belongs to the natural carbon cycle, which means the biomass cannot cause the extra greenhouse gases to change the climate. It is estimated that compared with the same type of thermal power units, operating a station which belongs to 25000 kW biomass generators, can reduce carbon dioxide emissions around 100 000 t / a [5].

Biomass fuels have a large calorific value. The calorific value of the biomass fuels is from 3900 to 4800 kcal / kg or so. After carbonization, the calorific value of the biomass fuels will up to 7000-8000 kcal / kg [6]. In a standard coal-fired power plant in China, the calorific value of the coal only needs 5500 Kcal / kg, circulating fluidized bed thermal power plant requires more than 3,500 Kcal / kg [7]. Biomass includes agricultural wastes, animal manure, energy crops. Agricultural waste mainly refers to by-products after harvest, such as straw, wheat straw or corn stalks. The agricultural waste is one of China's major biomass resources [8]. The use of biomass resources have various forms: the 25% of them is feed, the 15% of them is fertilizer, the industrial raw materials accounted for 9%, and the remaining 51% can be used as energy resources [8]. So, according to China's "long-term renewable energy development plan" statistics, China's biomass resources can be converted to energy potential is about 500 million tons of standard coal [9]. With the development of economy and society, China's biomass resources can be converted to energy potential even though up to 1000 million tons of standard coal [9].

Henan province is an agricultural province in China. It is rich in biomass resource, especially in agricultural wastes and animal manure. According to Agricultural Statistics of Henan Province which published by Statistics Bureau of Henan Province in 2011, we can get Standard Conversion Coefficients of Agricultural Wastes and the standard coal equivalent amount in a year. The data will show in table 1.
Table 1 Agricultural Wastes energy in Henan Province [10]

<table>
<thead>
<tr>
<th>Types of biomass</th>
<th>Annual output ($\times 10^4$ t)</th>
<th>lower heating value / (kJ / kg)</th>
<th>Standard coal conversion coefficient</th>
<th>Standard coal($\times 10^4$ t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn stalks</td>
<td>2272.8</td>
<td>17746</td>
<td>0.6063</td>
<td>1378.0</td>
</tr>
<tr>
<td>Corn cob</td>
<td>473.5</td>
<td>17730</td>
<td>0.6057</td>
<td>286.8</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>4070.0</td>
<td>18532</td>
<td>0.6331</td>
<td>2576.7</td>
</tr>
<tr>
<td>Cotton stalks</td>
<td>478.4</td>
<td>18089</td>
<td>0.6180</td>
<td>295.7</td>
</tr>
<tr>
<td>Straw</td>
<td>577.8</td>
<td>17636</td>
<td>0.6025</td>
<td>348.1</td>
</tr>
<tr>
<td>Rice husk</td>
<td>173.3</td>
<td>16017</td>
<td>0.5472</td>
<td>94.9</td>
</tr>
<tr>
<td>Peanut shells</td>
<td>154.3</td>
<td>21417</td>
<td>0.7317</td>
<td>112.9</td>
</tr>
<tr>
<td>Total</td>
<td>8200.1</td>
<td>—</td>
<td>—</td>
<td>5093.1</td>
</tr>
</tbody>
</table>

From the table 1, we can know that the agricultural waste energy can be converted to 50.931 million ton standard coal per year in Henan province. Then, viewed from above, we know that there is about 51% of agricultural waste can be used as energy in China. So, the agricultural waste energy can be used in Henan is about 25.97 million ton standard coal per year.

Then, we can also get the total amount of energy resources which produced by animal manure. The data will show in table 2.

Table 2 Animal manure converts to energy resources [10]

<table>
<thead>
<tr>
<th>Livestock and poultry type</th>
<th>Number of animals ($\times 10^4$)</th>
<th>Dry manure output per year ($\times 10^4$ t)</th>
<th>Biogas annual output ($\times 10^4$ m$^3$)</th>
<th>Standard coal conversion coefficient</th>
<th>Standard coal($\times 10^4$ t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>1010.20</td>
<td>438.9</td>
<td>89980.2</td>
<td>0.7236</td>
<td>65.1</td>
</tr>
<tr>
<td>Pig</td>
<td>4547.00</td>
<td>1105.5</td>
<td>469850.0</td>
<td>0.7972</td>
<td>374.6</td>
</tr>
<tr>
<td>Poultry</td>
<td>62104.00</td>
<td>32.6</td>
<td>10119.0</td>
<td>0.8217</td>
<td>8.3</td>
</tr>
<tr>
<td>Total</td>
<td>67661.20</td>
<td>1577.1</td>
<td>569949.2</td>
<td>_</td>
<td>448.0</td>
</tr>
</tbody>
</table>
From the table 2 we can know that animal manure can be converted to 4.48 million ton standard coal per year in Henan province. Animal manure is useless. If put animal manure in to the environment, it will cause environment pollution. So, all of the animal manure can be converted to standard coal, and the number is 4.48 million ton per year.

The GDP of Henan province ranked fifth in China, and the economic data seems good. However, it costs by environment, and the use of coal is increasing year by year. Moreover, through analysis from above, Henan is a truly biomass resources province. So Henan is a good pilot province of using biomass power plant to replace coal fired power plant.

Using biomass to heat and generate power in different ways, the heat utilization efficiency is also in big difference, the same number and quality biomass resources using in different heating and power generation methods will provide a different amount of heat and electricity. This thesis will use biogas as biomass resource in biomass power plant. Because some people mix small stones into straw and sale them to the biomass power plant in some places in China. This caused the biomass power plant which directly burn straw is still burn coal to generate electricity.

1.2 Aim and objectives

According to the background, we know that coal-fired power plant causes serious environmental problem in China and the biomass is a renewable energy resource which is easy to get in China, especially in Henan province. Then, this thesis will analyze and discuss the technology, environment and economic between the biogas power plant and the coal-fired power plant in Henan which is selected as a pilot province. In order to find which type of the power plant is more suitable for Henan, even in China. This thesis will also give some suggestions to the government of China whether using biogas power plant to replace coal-fired power plant is a good way to relief environmental problem in China. If the answer is yes, the Chinese government should vigorously advocate and subsidize biogas power plants.
1.3 Key research questions

1. What is the difference in technology between biogas and coal fired power plant?
2. How many emissions of the GHG and air pollutants would be reduced if a power plant in Henan replaces coal with biogas?
3. What are the differences in LCOE between biogas and coal fired power plants in Henan?
4. Does the Chinese government should vigorously advocate and subsidize biogas power plants?

1.4 Outline

This thesis has six sections. The first section is situation introduction of the China’s power plant and Henan province biomass resources. The second section is about what methods are used to achieve the purpose in this thesis. The third section is about the theories which are from books and journal for coal fired power plant and biomass power plant which used biogas as a biomass resource. The fourth section is to analyze and finds the results about the key research questions. The fifth section is about discussing the answer to the research questions, showing some incomplete work and giving the suggestions to the future research. The final section gives the conclusion for this thesis and indicates the related purpose.
2. Method

The method is mainly to make the readers know how this thesis performed, what have to be done to finish this thesis, how can I answer the research questions and achieve the purpose.

2.1 Data Collection

There are two different ways to collect data. One is primary data collection, the other one is secondary data collection. The primary data is the nearest way to the truth, and it can be collected by interview, questionnaires, do the experiment and recorded by observations. It's better than the secondary data collection. In order to write this thesis, I went to these two types of power plant and worked with them about totally three months. These two types of power plant are coal fired power plant and biomass power plant which used the biogas as the biomass resource. During working with them, I did the interview and recorded the observations. So, I got the technical data, economic data and some environment data from these two power plants.

The secondary data collection means that the data and information collect from
published sources. Most of them come from books, journals and periodicals. To answer the research questions a literature review of the potential to using biomass instead of coal has to be done. They are mainly about biogas and biogas power plant, coal fired power plant, boiler, turbine and so on. There are also some introduction and discussion details collected from secondary data. The different opinions of these articles are discussed and concluded in this thesis. Some of these articles come from the books which I borrowed from the power plant. Some of them come from the internet.

2.2 Research method

2.2.1 Deductive and Inductive

Deductive is from general to specific. It begins from a theory what we interest in, and then, we can put forward a specific hypothesis. Through the observation, we can use the data from the observation to confirm the hypothesis and theory. Inductive works from the other way. It begins from observation, the second step is pattern, the third step is tentative hypothesis, when finish these methods at all, we can get a theory.

This thesis use deductive method. In the beginning, this paper said the biomass is renewable energy resource, which is much cleaner than fossil fuels especially compared with coal. Then, this thesis put forward a specific hypothesis that biogas power plant is better than coal-fired power plant in some areas. Thirdly, according to experience in the power plants and acknowledge from the literature, I got lots of data and information. After Comparing biogas and coal-fired power plant in technology, environment, economy, this thesis can confirm the hypothesis and the theory.

2.2.3 Qualitative and Quantitative method

This thesis mainly uses quantitative method. The quantitative method is focus on numerical data collection and analyzation. The tables and figures are often used in the papers. In the technology part, the thermal efficiency would be compared between coal-
fired power plant and biogas power plant. The pressure, temperature, advantages and disadvantages among different types of turbines are also compared between coal-fired power plant and biogas power plant.

In environment part, the GHG mitigation (mainly CO₂) and the pollutants emissions of the electricity production in the two types of plants will be done through a literature review.

In economic part, the economical comparison with the LCOE in USD/kWh will be done for each of the power plants.

2.3 Limitation

There are two mainly limitations in my work.

The first one is that I only went to one power plant for each type of the power plant. Maybe some data, information and technology are only suitable for their own power plant. Because of the time limitation, I can only use the details which they give me or through my observation. Then some details are from other people’s papers.

The second limitation is that there is only medium size of biogas power plants I can found in Henan, China. In order to compare these two types of power plant, I had to find a medium size of coal-fired plant.
3. Theory

This part mainly describes how the coal-fired power plant works, how the biogas power plant works, and what the LCOE means in energy area.

3.1 Coal-fired power plant

This part mainly gives the definition and describes how the coal-fired power plant works. Fig.1 shows the basic workflow diagram of a typical coal-fired power plant.

Figure 1 Basic workflow diagram of coal-fired power plant
Firstly, put the coal full into coal hopper from coal bunker. Then, coal feeder sends the original coal into coal mill, and coal mill makes the original coal become pulverized coal. At the same time, pulverized coal is dried by the primary air which from the air preheater and the primary air is also bring pulverized coal to the coarse powder separator. The unqualified pulverized coal would be back to the mill and grind again, and the primary air brings the qualified pulverized coal to the cyclone. After separating coal and air, the coal would be into the coal warehouse.

Secondly, according to the needs of the boiler, the pulverized coal is fed into the primary air duct by the adjustable coal feeders. Then, the exhauster put the pulverized coal which in the primary air duct into the combustion chamber and pulverize coal start burning when it through burner. The high-temperature flue gas which formed by the boiler furnace is cooling through the superheaters, economizer and air preheater, then remove 90% to 99% dust by precipitator, the flue gas would be through the draft fan into the chimney. In the end, the flue gas goes to sky. At the same time, after the pulverized coal combustion in the furnace, there would be produced small ash particles. They are collected by dust collector and then go through sluiceway to the ash field.

Thirdly, the superheated steam which is generated by the boiler enters the steam turbine along the main steam pipe. High-speed steam impulses steam turbine blade rotation, and then drive the generator rotation to generate electricity. Electricity through the main transformer, the high-voltage power distribution devices, transmission lines and then goes into the power grid. After working in the steam turbine, the temperature and the pressure of the steam are greatly reduced. Then, the steam goes into the condenser becoming water again. Condensate water heated by the low-pressure heater and it hits to the low-pressure heater by the condensate pump. Then the condensate water is deoxygenized by deaerator and continue heating. The water which out of the deaerator would go through feed pump and high-pressure heater to increase the temperature and the pressure, and finally goes into the boiler drum.
3.2 Biogas power plant

This part mainly gives the definition and describes how the biogas power plant works. Here is the basic work flow diagram of biogas power plant and the description is in the follow.

*Figure 2 Basic work flow diagram of biogas power plant*
Firstly, the biogas through the pipe goes into gas holder. The relative humidity of biogas is 100% which is in the gas holder. Then, the biogas goes into compressor. The biogas is pressurized to 2.5MPa by the compressor. At the same time, the circulating cooling water needs to reduce the temperature of the biogas. The temperature of the gas is reduced to 10 - 20 °C. It orders to remove the water vapor and trace of harmful gases by condensing. Then the biogas would go into gas tank.

Secondly, the biogas from gas tank goes into filters. It mainly makes the biogas become cleaner in filtering system. II level filters mainly remove the water, liquid foam and impurities which diameter is 50μm or more than 50μm. This process makes the water content of the outlet gas saturation and dust particle size is less than 50μm. At the same time, trace hydrogen sulfide, ammonia and other harmful gases are dissolved in the condensation liquid, and discharged out of the system. After filtering in II level filters, the biogas would go into fine filters. Fine filters make dust particle size less than 3μm in biogas.

Thirdly, the clean biogas through pipe goes into heater. Heater makes the temperature of the biogas up to 25-40 °C. Then the biogas would go into gas turbine beginning to burn to generate the electricity. The electricity would go through the transformer to increase the voltage and then go into the grid. At the same time, when the biogas is burning in gas turbine, it would produce high-temperature gas. The high-temperature gas goes in to dual pressure waste heat boiler. The boiler utilizes high-temperature flue gas to produce steam and hot water. Then send steam and hot water to customers or help to produce the biogas.
3.3 Technical and economic indicators

Technical and economic indicators in power plant reflect the operating technical and economic performance data in thermal power plant. They mainly refer to the heat-electricity conversion efficiency of the generating units which belong to power plant or the whole plant operating indicators. The technical and economic indicators mainly include thermal efficiency of power plant, coal consumption rate, power plant electricity consumption rate and levelized cost of energy (LCOE).

3.3.1 Thermal efficiency of power plant

The thermal efficiency \( \eta \) of the power plant is the ratio of the amount of the calorific value which converted by electricity generated (kW · h) and calorie expenditure HRe. The thermal efficiency can be calculated as eq.1, the equation is:

\[
\eta = \frac{3600}{HRe} \times 100\%
\]  

eq. 1

HRe is the heat consumption of generating 1 kW · h electricity. HRe can be calculated as eq. 2, the equation is:

\[
HRe = 29.308b_0 \text{ (kJ / kw·h)}
\]  

eq. 2

\( b_0 \) is the coal consumption rate when generating 1 kW · h electricity. The coal consumption can be calculated as eq. 3, the equation is:

\[
b_0 = \frac{B_0(kg)}{W_0(kW·h)} = \frac{B_0}{W_0} \times 1000
\]  

eq. 3

In the equation 3, the \( B_0 \) is the amount of standard coal consumed by the power plant, \( W_0 \) is amount of the power production.
3.3.2 Coal consumption rate

The coal consumption rate generally refers to the coal consumption rate of the power supply, \( b_n \ (g/\text{kw} \cdot \text{h}) \). It is the consumption of the standard coal which is used to supply 1kw \cdot h electricity to external. The coal consumption rate equation is:

\[
b_n = \frac{B_0}{(W_o - W_a)} \times 1000 \ (g/\text{kw.h}) \tag{eq. 4}
\]

Where:

- \( B_0 \) -- is the amount of standard coal consumed by the power plant (kg).
- \( W_0 \) -- is amount of the power production (kw\cdot h).
- \( W_a \) -- is power plant own demand

3.3.3 Power plant electricity consumption rate

The power plant electricity consumption rate is the ratio of power plant own demand and the amount of the power production. The power plant electricity consumption rate can be calculated by equation 5, the equation is:

\[
r_a = \frac{W_a}{W_0} \times 100\% \tag{eq. 5}
\]

3.3.4 Levelized cost of energy (LCOE)

Levelized cost of energy (LCOE) is one of the important metrics for the utility industry. It mainly refers to the cost of electricity generation. The cost of electricity generation is the total cost of electricity generated by the power plant. It’s including fuel and water fee, material fee, repair cost, depreciation cost, wages, employee welfare fund and other fees. There are totally eight parts. The first three are variable costs. They can be changed by electric energy production, becoming more or becoming less. The latter five are fixed costs, regardless of the amount of power production and they are required to spend.

Fuel fee is the largest cost in the total cost of electricity generation. It’s account for 50%
to 70% of the cost of electricity. The water fee consists of two parts. The one is the cost of water resource which is used to generate the electricity. The other one is the cost of purchasing water from the water company. The material fee is the cost of materials, spare parts, consumables, and other else which can be used in the maintenance of power plant. These three are variable costs.

In the fixed costs, the repair fee is planned at in the beginning of each year. It’s accrued as a percentage of the original value of the fixed assets. The basic depreciation cost is the compensation for fixed assets. The wages and worker welfare funds would be changed by the power plant staff number and level of wages. The other costs include office expenses, research and education funding and production of working capital loans interest.

Power plants supply the electricity to the grid, and electricity supply management departments need to pay electricity with the contract price. The electric charge is the main income for a power plant. The reduction of the generation cost depends on the reduction of the coal consumption rate and the power plant electricity consumption rate. The reduction of the generation cost also depends on the increase in external power supply and power generation equipment utilization efficiency. These all depend on improving the level of power production and operation technology and the power plant management level.
3.4 Environment pollution

For a thermal power plant, there are several ways to pollute the environment. They are air pollution, greenhouse effect, water pollution, noise pollution and solid waste pollution.

3.4.1 Air pollution

The first and the most serious one is air pollution. When the thermal power plants processing, the dust, nitrogen oxides, sulfur dioxide would be discharged to the air.

Dust particles can not only pollute the environment, but also exacerbate environmental damage, when the dust particles combine with sulfur dioxide, nitrogen oxides and other harmful gases. Especially when the dust particles size is smaller than 10 microns, the dust particles would become more harmful to the human body.

The sulfur dioxide oxidizing to sulfur trioxide is very slow in the atmosphere, but when the relative humidity is bigger and there are particles in the air, catalytic oxidation can be occurred. In addition, when solar ultraviolet light irradiation and the nitrogen oxide exist in the atmosphere, the sulfur dioxide can be occurred to produce sulfur trioxide and sulfuric acid mist by photochemical reaction. These gases are very harmful to the human body, animals and plants.

The emission of nitrogen oxides for a thermal power plant is mainly nitric oxide (NO) and Nitrogen dioxide (NO₂). The nitric oxide (NO) and Nitrogen dioxide (NO₂) are account for more than 90% of the total concentration of nitrogen oxides. The nitric oxide (NO) production rate is increased when the combustion temperature is increased. The percentage of the nitric oxide’s content also depends on the type of fuel and the content of nitride. Nitric oxide can damage the human’s central nervous system and cause methemoglobinemia. Nitrogen dioxide stimulates respiratory organs, and causes significant damage to the lungs.
3.4.2 Greenhouse effect

The greenhouse effect is that the solar short-wave radiation can penetrate the atmosphere into the ground, but after the ground has been warmed up, the long-wave radiation which released by the ground is absorbed by the carbon dioxide and other substances in the atmosphere. This process results in the effect of atmospheric warming. Carbon dioxide in the atmosphere is like a thick layer of glass, making the earth into a large greenhouse.

The mainly reason of the greenhouse effect is the emission of greenhouse gases (GHG). Greenhouse gases are gases that can strongly absorb infrared light. There are several types of greenhouse gases:

1. Water vapor (H₂O). Water vapor is the most important greenhouse gas in the atmosphere. The water vapor caused greenhouse effect is accounting for about 60% - 70% of the whole greenhouse effect [11];
2. Carbon Dioxide (CO₂). Carbon dioxide accounts for about 26% in the atmosphere [11];
3. Ozone (O₃);
4. Methane (CH₄);
5. Nitrous oxide (N₂O);
6. Hydrochlorofluorocarbons (HCFCs), chlorofluorocarbons (CFCs), and also hydrofluorocarbons (HFCs);
7. Perfluorocarbons (PFCs);
8. Sulfur hexafluoride (SF₆);

Because water vapor and ozone are vary greatly in distribution of spatial and temporal. They are not normally included in the development of reduction measures. The famous "Kyoto Protocol" proposed control and reduction of six kinds of greenhouse gases, and they are: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF₆). Among them, the last three kinds of gas have the strongest ability to form greenhouse effect, but for the influence of global warming, CO₂ plays the most important role. Because the content of CO₂ is the largest one in GHG and it has a great impact.
For a thermal power plant, GHG emission is mainly carbon dioxide (CO$_2$). Reducing them is the most important thing to control the GHG emission when the thermal power plant processes.

### 3.4.3 Water pollution

Thermal power plant wastewater mainly includes ash-water, dust water, industrial sewage, domestic sewage, acid-alkali waste, hot water and so on. Dust water and industrial effluent are generally discharged into the gray water system. Some of them PH value are exceeded, because the gray water is alkaline. Hot water is mainly the circulating water which is discharged after the condenser, the general drainage temperature is 8 ℃ higher than the inlet temperature [12]. The hot water would be discharged into the water when the temperature beyond the limits of aquatic organisms to bear. It would cause thermal pollution. The reproduction and the growth of aquatic organisms would be effected by thermal pollution.

### 3.4.4 Noise pollution

The noise pollution of thermal power plant mainly includes high frequency noise of boiler exhaust, aerodynamic noise, mechanical vibration noise and low frequency electromagnetic noise of electrical equipment.
4. Results

It will be compared between coal-fired power plant and biomass power plant which use biogas as the resource in this part. It mainly includes the technology comparison, the environmental comparison and the economic comparison between these two types of power plant. *(to be modified)*

4.1 Technology comparison

The coal-fired power plant uses steam turbine to generate the electricity. The biogas power plant uses gas turbine combined-cycle (GTCC) to generate the electricity. It’s also named gas – steam turbine combined cycle. This part manly analyses these two technologies.

4.1.1 Steam turbine

The Figure 3 shows the principle of a classical power plant.

*Figure 3 the principle of a classical power plant*

*Source: ABC of Coal-Fired Power Plant [13]*
Firstly, the chemical energy is released by the combustion of the fuel by the boiler. The chemical energy can heat the feed water and make the water evaporation, overheating through the heated surface. This process converts the chemical energy into thermal energy. Then, the steam turbine converts the thermal energy which belongs to the steam into high-speed rotation of the mechanical energy. In the end, the steam turbine drives the generator to generate the electricity. This is the principle of a classical power plant.

*Figure 4 Steam turbine*

Steam turbine is an external combustion engine. The external combustion engine can use various fuels, including solid fossil fuels such as coal. The steam turbine has two main components. The first component is nozzles (also known as static leaves) and the second main component is moving blades (also known as leaves). The nozzle is fixed to the case or partition, and the blade is fixed on the disc. When the steam passes through the nozzle, the pressure drops down, and the steam volume is expanded to form high-speed steam flow. The steam flow pushes the impeller to rotate and work.
The coal-fired power plant use steam turbine and the process which is shown on figure.4. The coal consumption rate of the medium size of the coal-fired power plant is 340g/kw·h in China. So, we can calculate the thermal efficiency of the power plant.

\[
\eta_e = \frac{3600}{H \cdot Re} \times 100\%
\]

\[H \cdot Re = 29.308\text{b.}\]

\[b = 340\text{g/kw·h}\]

So, the HRe is equal to 9964.72 kJ/kw·h.

The, the thermal efficiency of the coal-fired power plant is 36.12%.

### 4.1.2 Gas-Steam Turbine Combined Cycle (GTCC)

The GTCC forms the Rankine cycle and the Brayton cycle into a total system cycle. The Rankine cycle is steam turbine working in the low temperature zone. The Brayton cycle is gas turbine operating in the high temperature zone. Because it has a very high initial gas temperature (1200 °C ~ 1500 °C) and a very low temperature (30 ~ 40 °C) after the steam working, and it achieves to the use of heat cascade. So, the total cycle efficiency is high.

The GTCC consists of three parts. The first part is gas turbine (compressor, combustion chamber, turbine, control system and auxiliary system). The second part is heat recovery boiler (boiler). The third part is the steam turbine.

There are two mainly methods used to generate the power for the GTCC. The first one is waste-heat utilization and the second one is exhaust refueling. We can see the system in Figure. 5.
The biogas power plant uses waste-heat utilization to generate the power. First, the compressor draws air in it and compresses the air, then send the compressed air into the combustion chamber. Then, it makes the fuel combustion. After the combustion, the fuel becomes high temperature and high pressure gas. Next, the high temperature and high pressure gas go into the gas turbine to generate the power. Then, the gas emitted from the gas turbine would be a boiler heat source. The heat recovery boiler produces the steam, and the steam goes into the steam turbine to generate the power. The waste heat utilization system is simple. The output of the gas turbine accounts for a large proportion of the total output, and the steam turbine cannot run separately.

Source: 燃气—蒸汽联合循环及 IGCC 发电技术 [14]
There are several characteristics of the combined cycle unit. They are: High efficiency; Less emission; Units output is in large influenced by ambient temperature; High reliability; Small footprint; Less water consumption; High level of automation, and less running personnel.

The first one is high efficiency. Due to the full use of the gas turbine exhaust heat, and do the cogeneration, the thermal efficiency of the combined cycle power plant can be up to 50%-55%. It's much higher than the same capacity of the conventional thermal power plant. The efficiency of the combined cycle unit can be reached to 58%.

The second one is less emissions. It can significantly reduce the growing environmental pressure. This would be analyzed detail in chapter 4.2.

The third one is that the units’ output is in large influenced by ambient temperature. It’s shown in table 3 and Figure 6.

<table>
<thead>
<tr>
<th>Units’ power output (MW)</th>
<th>402</th>
<th>400</th>
<th>397</th>
<th>395</th>
<th>391</th>
<th>387</th>
<th>380</th>
<th>370</th>
<th>360</th>
<th>350</th>
<th>340</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature (°C)</td>
<td>-10</td>
<td>-5</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 3 the relationship between units power output and ambient temperature
From Figure 6, we can see that when the ambient temperature increases, the units’ power output will decrease. There are two reasons causing this phenomenon. The first one is that when the ambient temperature rises, the air density decreases but the intake volume of the gas turbine is basically constant. Therefore, the ambient temperature increases, which will inevitably lead the mass flow rate of the gas turbine to decrease. So, the units’ power output decreases. The second reason is that the power consumption of the compressor in the gas turbine is increased with the increase of the ambient temperature, but the expansion of the turbine’s work does not increase with the ambient temperature increases. Therefore, when the ambient temperature rises, the efficiency of the gas turbine is necessarily reduced.

The forth one is high reliability. The speed to start and stop the system is fast. When the system is in trouble, it can make system and people safe. Gas turbine from start to full load needs about 15 minutes. Heat recovery boiler use hot start to achieve full load needs 45 minutes, and use cold start to reach full load needs 2 hours. The system is relatively simple and auxiliary machine is relatively small. So the system has high reliability. The last
one is that the system can truly achieve AGC (Automatic power generation control).

The fifth one is that the system has a small footprint. As the main body of the combined cycle power plant is a gas turbine generator set, so the power plant equipment is compact. There is no coal field, ash field and flue gas purification system in GTCC power plant. Gas turbine, heat recovery boiler and steam turbine are the compact modular structure, so it has small footprint. Compared with the same capacity of the coal-fired power plant, the area of the GTCC power plant is only 30%-40%.

The sixth one is less water consumption. The gas turbine does not require a lot of cooling water, so the water consumption of the GTCC power plant is only 1/3 of the coal-fired power plant.

The last characteristic of the GTCC is that high level of automation, less running personnel. Compared with the coal-fired power plant, people who work in the GTCC power plant is only 20%-25% of them.

4.2 Environmental comparison

This part mainly analyses the pollutant emission concentration of the coal-fired power plant and the biogas power plant, and finds which one is better for the environment.

4.2.1 Pollutants emission of the coal-fired power plant

As discussed in chapter 3, the coal-fired power plant has several types of pollution. They are: Dust pollution, Sulfur dioxide (SO\textsubscript{2}), Nitric oxide (NO\textsubscript{x}), waste water pollution, Noise Pollution and GHG emission.

According to “Emission standard of air pollutants for thermal power plants (GB 13223-2011)” [15], there are several standard limit emission value about dust, Sulfur dioxide (SO\textsubscript{2}) and Nitric oxide (NO\textsubscript{x}) emissions which belong to coal-fired power plant. They are shown in table.4.
Because Henan Province has serious air pollution, so it uses a strict emission standard. In a coal-fired power plant, the emission of air pollutants is mainly from the combustion process, it means that the coal-fired boiler produce the air pollutants. As is shown in table 4, we can see that in a coal-fired power plant, the limit concentration of dust emission is 20 mg/m³; the limit concentration of Sulfur dioxide emission is 50 mg/m³; the limit concentration of Nitric oxide emission is 100 mg/m³. In order to make it easier to be compared, the limit emission value would be seen as air pollutants emission value of coal-fired power plant.

The next one is waste water pollution. According to “Integrated Wastewater Discharge Standard (GB8978-1996)” [16], there are several standard data about waste water discharge which belong to coal-fired power plant. They are shown in table 5.

As is shown in table 5, we can see that in a coal-fired power plant, the pH value in waste water is 6-9; the limit concentration of suspended solids which belong to waste water is 150 mg/L; the limit concentration of COD which belongs to waste water is 150 mg/L;
the limit concentration of BOD₅ which belongs to waste water is 30 mg/L. In order to make it easier to be compared, the limit concentration value would be seen as concentration value of the wastewater which is discharged by a coal-fired power plant.

Then, another environment pollution of the coal-fired power plant is noise pollution. Some of the equipment's operating noise level in the coal-fired power plant is very high. For example, the pulverizer near-field noise level close to 110dB (A), the noise level around the primary air fan enclosure exceeds 100 dB (A), the noise level between the boiler and the primary air fan is 84 to 85 dB (A). So, the coal-fired power plant in China can only achieve the third class standard which belong to “Emission standard for industrial enterprises noise at boundary (GB 12348—2008)”. [17] The standard of noise emission data of the third class standard is shown in table.6.

<table>
<thead>
<tr>
<th>Time</th>
<th>Limit noise level (dB (A))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>65</td>
</tr>
<tr>
<td>Night</td>
<td>55</td>
</tr>
</tbody>
</table>

As shown in table.6, we can see that in a coal-fired power plant, the limit noise level is 65 dB (A) in day time, and the limit noise level is 55 dB (A) at night.

The last one is GHG emission. In a coal-fired power plant, the main GHG is CO₂. The CO₂ emission can be calculated by equation 6. The equation 6 is:

\[
G_{CO_2} = B \times Q \times E \times K_{CO_2} \times \lambda_{CO_2}
\]

Where:

- \(G_{CO_2}\) -- emission rate of the CO₂ (kg)
- B—Standard coal consumption (kg)
- Q-- Calorific value of the standard coal (MJ/kg)
- E-- Potential carbon emissions (t/TJ)
- \(K_{CO_2}\)-- The oxidation rate of carbon
- \(\lambda_{CO_2}\)-- The molar mass ratio between CO₂ and C

In China, calorific value of the standard coal is 29.3 MJ/kg, potential carbon emissions is 24.74 t/TJ, the oxidation rate of carbon is 0.9 and the molar mass ratio between CO₂
and C is about 3.667. In China when generate 1 kWh electricity, the coal-fired power plant consume 340g standard coal. So B is equal to 0.34kg. Then, the emission rate of the CO2 when generate 1 kWh electricity can be calculated:

\[ G_{CO_2} = 0.34 \times 29.3 \times 24.74 / 1000 \times 0.9 \times 3.667 = 0.91 \, \text{kg} \]

So, when the coal-fired power plant generates 1 kWh electricity, it would produce 0.91 kg CO2.

### 4.2.2 Pollutants emission of the biogas power plant

The biogas power plant still has several types of pollution. They are: air pollution, waste water pollution, noise pollution and GHG emission.

The air pollutants of the biogas power plant also have dust, Sulfur dioxide (SO2) and Nitric oxide (NOx) emission. According to “Emission standard of air pollutants for thermal power plants (GB 13223-2011)” there are several data about dust, Sulfur dioxide (SO2) and Nitric oxide (NOx) emissions which belong to biogas power plant. They are shown in table.7.

<table>
<thead>
<tr>
<th>Pollutant Project</th>
<th>Limit emission value (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>5</td>
</tr>
<tr>
<td>Sulfur dioxide (SO2)</td>
<td>35</td>
</tr>
<tr>
<td>Nitric oxide (NOx)</td>
<td>50</td>
</tr>
</tbody>
</table>

In a biogas power plant, the emission of air pollutants is mainly from the combustion process. It means that the gas turbine makes the air pollutants. As is shown in table.7, we can see that in a biogas power plant, the limit concentration of dust emission is 5 mg/m³; The limit concentration of Sulfur dioxide emission is 35 mg/m³; the limit concentration of Nitric oxide is 50 mg/m³. In order to make it easier to be compared, the limit emission
value would be seen as air pollutants emission value of biogas power plant.

The next one is waste water pollution. According to “Integrated Wastewater Discharge Standard (GB8978-1996)”, there are several standard data about waste water discharge which belong to coal-fired power plant. They are shown in table.8.

Table 8 Integrated Wastewater Discharge Standard of biogas power plant

As is shown in table.8, we can see that in a biogas power plant, the pH value in waste water is 6-9; the limit concentration of suspended solids which belong to waste water is 150 mg/L; the limit concentration of COD which belongs to waste water is 150 mg/L; the limit concentration of BOD₅ which belongs to waste water is 30 mg/L. We can also know that the coal-fired power plant and the biogas use the same waste water discharge standard. They have the same limit concentration emission value.

The next one is noise pollution. The noise pollution is mainly caused by gas turbines, gas turbine intake systems, steam turbines, generators and boiler to air exhaust. In which the gas turbine, gas turbine intake system, steam turbine and generators make the continuous noise, boiler to air exhaust makes the instantaneous discontinuous noise. The noise level of these components is between 75 and 110 dB (A). Due to the electricity generation process and the technology, the biogas power plant in China should achieve the second class standard which belongs to “Emission standard for industrial enterprises noise at boundary (GB 12348—2008)”. The standard of noise emission data of the second class standard is shown in table.9.

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Limit Concentration Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH value</td>
<td>6-9</td>
</tr>
<tr>
<td>Suspended solids (SS)</td>
<td>150 mg/L</td>
</tr>
<tr>
<td>Chemical oxygen demand (COD)</td>
<td>150 mg/L</td>
</tr>
<tr>
<td>Five days of biochemical oxygen demand (BOD₅)</td>
<td>30 mg/L</td>
</tr>
</tbody>
</table>
As is shown in table 9, we can see that in a coal-fired power plant, the limit noise level is 60 dB (A) in day time, and the limit noise level is 50 dB (A) at night.

The last one is GHG emission. For the biogas power plant, we all know that the main chemical composition of the biogas is CH₄. The CH₄ content of biogas is 60%. When producing 1 kWh power it would combust 0.48 m³ biogas. The CH₄ content of 0.48 m³ biogas is 0.288 m³. When combusting 0.288 m³ CH₄, it can reduce 4.3 kg CO₂ emission.

Then, in a biogas power plant, the standard coal consumption rate is 0.193 kg/kWh. When saving 1 kg standard coal, it can reduce 2.493 kg CO₂. In China when generating 1 kWh electricity, the coal-fired power plant consumes 340 g standard coal. So, it can reduce 0.37 kg CO₂ when using the biogas power plant replaces the coal-fired power plant to generate 1 kWh of electricity.

### 4.3 Economical comparison

This part mainly analyses the power generation costs of the coal-fired power plant and the biogas power plant. In terms of power stations, the cost of electricity generation consists of the following four components: depreciation costs C_d; fuel costs C_f; operation and maintenance costs C_m; financial costs C_p. However, the financial costs vary greatly in different power plants. So, the financial costs are ignored in the cost of electricity generation. All of us should know that the number of utilization hours which belong to the units has a direct influence on financial costs. The low number of utilization hours would take high financial costs.
So the cost of electricity generation:

\[ \sum \mathcal{C} = C_d + C_f + C_m \]  

where:

\[ C_d = \frac{\mathcal{L}_E}{\tau t (1-s)} \]  

\[ C_f = \frac{3.6 \mathcal{L}_F}{\eta (1-s)} \]  

\[ C_m \]  

Where:

- \( \mathcal{L}_E \) -- Dynamic investment costs (USD/kW)
- \( \tau \) -- Operation hours (h/a)
- \( t \) -- Economic life of power plant (a)
- \( s \) -- The line loss rate between the generator terminal and the sales settlement point

The fuel costs:

\[ C_f = \frac{3.6 \mathcal{L}_F}{\eta (1-s)} \]  

where:

- \( \mathcal{L}_F \) -- Fuel cost (USD/MWh)
- \( \mathcal{L}_F \) -- Fuel prices (USD/GJ)
- \( \eta \) -- efficiency of the unit

The maintenance costs \( C_m \) of coal-fired power plant are 0.0044 – 0.0055 USD/kWh. This paper uses 0.005 USD/kWh. The maintenance cost of biomass power plant is 0.009 USD/kWh. Then, the cost of electricity generation between coal-fired power plant and the biogas power plant can be compared.

4.3.1 The power generation costs of coal-fired power plant

For a medium size of coal-fired power plant in China, the dynamic investment costs are 580.9 USD/kW and 726.1 USD/kW. The operation time is 5500 hours. The economic life is 20-30 a in China. The line loss rate between the generator terminal and the sales settlement point is 0 now. Then, the depreciation cost can be calculated.

When the dynamic investment cost is 580.9 USD/kW and the economic life is 20 a

\[ C_d = \frac{\mathcal{L}_E}{\tau t (1-s)} = \frac{580.9}{5500 \times 20} = 0.0053 \text{ USD/kWh} \]

When the dynamic investment cost is 580.9 USD/kW and the economic life is 30 a

\[ C_d = \frac{\mathcal{L}_E}{\tau t (1-s)} = \frac{580.9}{5500 \times 30} = 0.0037 \text{ USD/kWh} \]
When the dynamic investment cost is 726.1 USD/kW and the economic life is 20 a

\[ C_d = \frac{i_{stc}}{\tau t(1-s)} = \frac{580.9}{5500 \times 30} = 0.0035 \text{ USD/kWh} \]

When the dynamic investment cost is 726.1 USD/kW and the economic life is 30 a

\[ C_d = \frac{i_{stc}}{\tau t(1-s)} = \frac{726.1}{5000 \times 30} = 0.0044 \text{ USD/kWh} \]

So, for a medium size of coal-fired power plant, the depreciation cost is between 0.0035-0.0066 USD/kWh.

The coal price always changes. In Henan province, the lowest price of standard coal is 86.4 USD/t and the highest price of standard coal is 185.6 USD/t. The calorific value of the standard coal is 29.3 MJ/kg, so the fuel prices \( C_{f1} \) can be calculated. When the price of the standard coal is 86.4 USD/t, the fuel price \( C_{f1} \) is 2.95 USD/GJ. When the price of the standard coal is 185.6 USD/t, the fuel price \( C_{f1} \) is 6.33 USD/GJ. The efficiency of the unit is 36.2%. Then, the fuel cost can be calculated.

When the fuel price is 2.95 USD/GJ:

\[ C_f = \frac{3.6C_{f1}}{\eta(1-s)} = \frac{3.6 \times 2.95}{0.362} = 29.3 \text{ USD/MWh} = 0.029 \text{ USD/kWh} \]

When the fuel price is 6.33 USD/GJ:

\[ C_f = \frac{3.6C_{f1}}{\eta(1-s)} = \frac{3.6 \times 6.33}{0.362} = 62.95 \text{ USD/MWh} = 0.063 \text{ USD/kWh} \]

So, the fuel cost of a coal-fired power plant in Henan province is between 0.029-0.063 USD/kWh.

Then, the power generation costs of the coal-fired power plant can be calculated. The lowest power generation cost is 0.0375 USD/kWh. The highest power generation cost is 0.0746 USD/kWh. So the power generation cost of the coal-fired power plant is between 0.0375 USD/kWh-0.0746 USD/kWh. Table.10 shows the results about the power generation costs of coal-fired power plant.
### 4.3.2 The power generation costs of biogas power plant

For a medium size of biogas power plant in China, the dynamic investment cost is 581.1 USD/kWh. The operation time is 6700 hours. The economic life is 20-30 a in China. The line loss rate between the generator terminal and the sales settlement point is 0 now. Then, the depreciation cost can be calculated.

When the dynamic investment cost is 581.1 USD/kW and the economic life is 20 a

\[
C_d = \frac{i_{SIC}}{\tau t (1-s)} = \frac{581.1}{6700\times20} = 0.0043 \text{ USD/kWh}
\]

When the dynamic investment cost is 581.1 USD/kW and the economic life is 30 a

\[
C_d = \frac{i_{SIC}}{\tau t (1-s)} = \frac{581.1}{6700\times30} = 0.0029 \text{ USD/kWh}
\]

So, for a medium size of biogas power plant, the depreciation cost is between 0.0029-0.0043 USD/kWh.

The price of biogas is between 0.12-0.29 USD/m³. The calorific value of the biogas is 23.5 MJ/m³, because the CH₄ content used 60% in this paper. So the fuel prices \(C_{f1}\) can be calculated. When the price of the biogas is 0.12 USD/m³, the fuel price \(C_{f1}\) is 5.11 USD/GJ. When the price of the biogas is 0.29 USD/m³, the fuel price \(C_{f1}\) is 12.34 USD/GJ. The thermal efficiency of the medium size biogas power plant is 58%. Then, the fuel cost can be calculated:

When the fuel price is 5.11 USD/GJ:

\[
C_f = \frac{3.6C_{f1}}{\eta(1-s)} = \frac{3.6\times5.11}{0.58} = 31.72 \text{ USD/MWh} = 0.032 \text{ USD/kWh}
\]

When the fuel price is 12.34 USD/GJ:

\[
C_f = \frac{3.6C_{f1}}{\eta(1-s)} = \frac{3.6\times12.34}{0.58} = 76.59 \text{ USD/MWh} = 0.077 \text{ USD/kWh}
\]
So, the fuel cost of medium size biogas power plant in is between 0.032-0.077 USD/kWh last year.

Then, the power generation costs of the biogas power plant can be calculated. The lowest power generation cost is 0.0439 USD/kWh. The highest power generation cost is 0.0903 USD/kWh. So the power generation cost of the biogas power plant is between 0.0439 USD/kWh-0.0903 USD/kWh. Table 11 shows the results about the power generation costs of biogas power plant. *(to be checked)*

<table>
<thead>
<tr>
<th>$C_{fi}$ (USD/GJ)</th>
<th>$\Sigma C$ (USD/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$i_{siC}$ (581.1 USD/kW)</td>
</tr>
<tr>
<td></td>
<td>$t = 20$ a</td>
</tr>
<tr>
<td>5.11 USD/GJ</td>
<td>0.0453</td>
</tr>
<tr>
<td>12.34 USD/GJ</td>
<td>0.0903</td>
</tr>
</tbody>
</table>
5. Discussion

The first key research question in this paper is to analyses the different technology used between the coal-fired power plant and the biogas power plant. The chapter 4.1 suggests that the coal-fired power plant uses steam turbine to generate the electricity and the biogas power plant uses the GTCC system to generate the electricity. Compared with the steam turbine, the GTCC system has higher thermal efficiency, less pollutant emission, higher reliability, less water consumption, less footprint, higher degree of automation and less staff. However, the capacity of the coal-fired power plant is much larger than the biogas power plant in the same size. Then, the output of the biogas power plant is highly influenced by the ambient temperature.

The second key research question is to find how many pollutants and GHG emissions reduce if using the biogas power plant to replace the coal-fired power plant. The chapter 4.2 suggests that if using the biogas power plant to replace the coal-fired power plant, the limit concentration of dust emission is reduced 15 mg/m³; the limit concentration of Sulfur dioxide emission is reduced 15 mg/m³; the limit concentration of Nitric oxide emission is 50 mg/m³; the limit noise level is reduced 5 dB (A) in day time, and the limit noise level is reduced 5 dB (A) at night. Then when generating 1 kWh power, the coal-fired power plant would produce 0.91kg CO₂. If using the biogas power plant to replace the coal-fired power plant, it can reduce 0.37 kg CO₂. Because the CH₄ is also a greenhouse gas, when use biogas power plant to produce 1 kWh power can also reduce 4.3 kg CO₂ emission.

The third key research question is to find the LCOE about the coal-fired power plant and the biogas power plant. As is shown in chapter 3.3.4, the LCOE refers to the cost of electricity generation. The cost of electricity generation is the total cost of electricity generated by the power plant. So the chapter 4.3 suggests that the power generation cost of the coal-fired power plant is between 0.0375 USD/kWh-0.0746 USD/kWh; the power generation cost of the biogas power plant is between 0.0439 USD/kWh-0.0903 USD/kWh. Compared with the coal-fired power plant, the power generation cost of the biogas power plant is more expensive.
This paper makes the comprehensive comparison between the coal-fired power plant and the biogas power plant. It makes the technical comparison, environmental comparison and economical comparison. However, this paper mainly uses the secondary data to analyses the result especially in the part of environmental comparison, it only uses a few primary data to do the analysis. Then, using biogas power plant to replace coal-fired power plant would impact on society, but it’s a huge task and problem. There is no time and no enough information to analyses the social impact. It can be analyzed in the future.
6. Conclusion

As a form of energy, the market prospects of the biogas must be affected by the cost factors. The measure of competitiveness is the price of the unit calorific value, but the price of the biogas is so high in today’s production methods. As a renewable energy, its production methods, costs and environmental costs have not yet fully meet our expectations. However, compared with the fossil fuels, the sustainability outlook for biomass fuels is positive. As a source of the thermal power plant, the biogas is efficient and environmentally friendly. So, it's worth a great effort to develop.

In today's industrialized world of society, with the sustainable development of economy and society, resources including coal, oil, natural gas and other fossil fuels will eventually be exhausted. Therefore, it is a major strategic task for China's economic and social development to increase energy supply, ensure energy security, protect the ecological environment and promote sustainable economic and social development [19]. So to find clean, sustainable renewable energy and its conversion technology has become a top priority of China's current energy work. As is discussed in this thesis, the biogas is a type of clean, sustainable renewable energy. Using biogas power plant to replace the coal-fired power plant could relief the environment pollution in Henan province or even in China. So, the Chinese government should vigorously advocate and subsidize biomass power plants.
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