energies

Article

An Economic and Technology Analysis of a New High-Efficiency Biomass Cogeneration System: A Case Study in DC County, China

Hui Huang [1], Xiaoli Yan [1,*], Shizhong Song [2,*], Yingying Du [1] and Yanlei Guo [1]

1 School of Management, China University of Mining & Technology, Beijing 100083, China; hh@cumtb.edu.cn (H.H.); sqt1800501007@student.cumtb.edu.cn (Y.D.); bqt1900502012@student.cumtb.edu.cn (Y.G.)
2 Collaborative Innovation Research Office, Science and Technology Innovation Research Center, Beijing 100012, China
* Correspondence: sqt1700501016@student.cumtb.edu.cn (X.Y.); ssz777777@163.com (S.S.); Tel.: +86-188-0012-1979 (X.Y.); +86-185-1881-5727 (S.S.)

Received: 17 June 2020; Accepted: 29 July 2020; Published: 1 August 2020

Abstract: Biomass is the fourth largest energy source in the world; it is easy to store and can be converted into various kinds of renewable energies. The biomass cogeneration system is an important way to utilize biomass energy, especially in northern China. At present, there are many problems in biomass power plants in China, such as high latent heat loss of chimney and cooling towers, low power generation efficiency, and thermal efficiency. In order to solve this problem, this paper introduces low vacuum circulating water heating technology in the biomass cogeneration system, and expounds the differences between China and Western countries in biomass power plants. Based on this background, the technology is redesigned and reformed to make it more suitable for the biomass fuel varieties in the power plant location, and realize the localization of technology and the expansion of scale. The application of this improved technology in China's biomass cogeneration project is analyzed. Based on the biomass cogeneration project in the DC County of China, the analysis confirms that the designed low vacuum circulating water heating technology is suitable for biomass power generation projects with agricultural and forestry wastes as raw materials, and its application can greatly improve the heat utilization efficiency of the whole cogeneration system. At the same time, in order to estimate the possibility of profitable investment when the key financial parameters change, the financial risk is analyzed. The results show that the probability of 90% net present value (NPV) in 15 years is between 355.28 million RMB and 623.96 million RMB, and the internal rate of return can reach 17.7%.

Keywords: biomass energy; biomass cogeneration; heat transfer; heat recovery; technical and economic analysis

1. Introduction

Since China's reform, and opening up, the industrial economy has developed rapidly, and energy demand has increased dramatically. According to the BP World Energy Outlook 2019, China's energy demand is still growing. Although the growth rate is decreasing, it will drop to 1.1% per year by 2040, which is lower than 1/5 of the average annual growth rate (5.9%) in the past 22 years, but China will still be the largest energy consumer by 2040 [1]. China is the largest coal production and consumption country in the world. The large-scale use of coal has produced a large number of mining waste, resulting in serious environmental pollution [2]. By the end of 2018, the reserve production ratio of coal, oil, and natural gas was 132, 50, and 50.9, respectively. Studies have also shown that by the end of 2050, the global energy gap will exceed 1000 EJ, which shows that the world is facing severe energy shortages [3].

The resulting carbon dioxide emissions are also high. According to the World Energy Outlook 2018, released by the International Energy Agency (IEA) in 2017, global carbon dioxide emissions—due to energy consumption—increased by 1.6%, breaking the three-year steady state [4]. In addition, the BP Statistical Review of World Energy 2019 report shows that in 2018, the global CO_2 emission growth rate was 2%, reaching the peak of nearly seven years. China's growth rate is 2.2%—slowing down, but still higher than the global growth rate—and the emissions are in a climbing trend [5]. To cope with global warming and energy shortages, as well as the requirements of all sectors in the world, China has been committed to the control and utilization of fossil energy, and the development and utilization of clean energy in recent years. At the Paris Climate Change Conference in 2015, China announced its goal of increasing the share of non-fossil energy in basic energy consumption to about 20% by 2030 [6]. China is a country with a large population. As early as 2004, the domestic waste produced by China ranked first in the world—and the growth rate is also the fastest. It is predicted that China's domestic waste output will be twice that of the United States in 2030 [7]. In order to avoid the occurrence of garbage siege, domestic garbage must be properly treated scientifically. This requires China to accelerate the development of clean energy, such as nuclear and renewable energy.

1.1. China Biomass Energy and Biomass Power Generation

Biomass energy is the fourth largest energy source in the world. In 2018, the Annual Report on Renewable Energy 2018, released by the IEA, showed that in 2017, the global available bioenergy reached four times the total amount of wind and solar energy. Renewable energy provides 50% of the energy. In the next five years, biomass energy is expected to become the global leader in renewable energy [8]. Biomass energy is not only convenient for storage, but can also be converted into various energy forms, including thermal energy, electric energy, transportation fuel, etc. It can manufacture all carbon-based products to replace some products and services based on fossil energy [9]. Using biomass to produce low carbon energy is considered an important goal of sustainable development [10]. China is a large agricultural country with a total of approximately 460 million tons of standard coal available as energy resources each year. By 2015, biomass energy utilization was about 35 million tons of standard coal; only 7.6% of biomass resources were utilized [11]. A large number of agricultural and forestry resources have been discarded, and corn straw—burning on the spot in some areas—has caused serious air pollution (and even fire damage) [12]. In particular, in Jilin Province, Heilongjiang Province, Liaoning Province, and other agricultural provinces in China, large-scale burning of crop straw and other waste in the field have caused serious air pollution [13–15]. These unreasonable treatment methods have caused some seriously economic deficit. At the same time, they are not conducive to the ecological environment and sustainable development of agriculture. Therefore, problems related to the rational disposal of agricultural and forestry wastes need to be solved urgently.

In the new era, facing the new situation, the state puts forward a scientific and reasonable energy development policy: "saving, cleaning and safety", which also provides direction and compliance for the healthy development of the power industry [16]. The Guidance Catalogue for Industrial Structure Adjustment (2019 version) encourages biomass engineering projects and equipment manufacturing [17]. At the World Low Carbon Cities Alliance Conference and Low Carbon City Development Forum in 2019, academician Ni Weidou once pointed out that it is unrealistic to shut down all coal power directly from the perspective of China's situation, and the energy reform of China's power can be realized through the gradual transition from "coal reduction" to "coal removal". Based on this, he proposed that, in the transition period, large-scale coal-fired plants with good conditions could use coal biomass coupling power generation to gradually turn into biomass power plants [18]. Biomass power generation originated from the global energy crisis in 1973 is currently the most mature and largest-scale biomass energy utilization technology. The biomass power generation technology in western countries such as the United States, Denmark, and Finland has developed quite well. However, most of the biomass power plants in China have low thermal efficiency. Waste heat is lost in boiler flue gas, cooling towers, and other links, resulting in waste of resources. Therefore, some Chinese scholars and industry experts began to pay attention to the waste heat recovery and utilization of biomass power plants. Wu Sheng, Xia Yu, and others, have studied the economic and environmental benefits of using the recovered heat to heat tap water in the water storage tank and then sell the hot water by focusing on the waste heat sources, such as the tail gas of the boiler, the continuous blowdown flash tank, and the oxygen exhaust valve of the deaerator. The results show that the economic, social, and environmental benefits of the enterprise are gradually improved [19]. With the application of energy-saving and efficient technology of biomass power generation, the use of waste heat generated by power generation for heating is also favored by many power plants. The development of biomass cogeneration has provided possibilities and effective ways for clean heating and sustainable environmental development. Research by Shi Yuanchun et al. showed that, from the perspective of carbon emission rates, biomass power generation is lower than that of hydropower, photovoltaic, wind power, and other renewable energy generation—only 23 g $CO_{2/}$kWh [20]. According to the Clean Heating Plan for Winter in the Northern Region (2017–2021), by 2019, the clean heating rate in the northern region will reach 50%, replacing 74 million tons of bulk coal, and the current clean heating rate is less than 20% [21]. In this regard, Zhang Dayong, the Secretary General of China Biomass Energy Industry Promotion Association, believes that China's power generation based biomass energy utilization mode will have a significant change. Biomass cogeneration is an inevitable trend of biomass energy utilization. Clean biomass heating is an important starting point to replace coal burning in counties in the future, especially to replace loose coal in rural areas [22].

China's Renewable Energy Law has clarified the status of renewable energy, including biomass energy, and has issued a series of policies to support it. According to the latest market forecast of the International Energy Agency (IEA), modern bioenergy will become the largest growth of renewable energy in 2018–2023. It is expected that bioenergy will meet about 3% of the global electricity demand in 2023 and China is expected to account for 37% of the Global Bioenergy [23]. According to the 13th Five-Year Plan for the Development of Biomass Energy by the National Energy Administration, by 2020, biomass energy will be commercialized and utilized on a large scale. The annual utilization of biomass energy is about 58 million tons of standard coal. The total installed capacity of biomass power generation will be up to 15 million kilowatts with an annual power generation capacity of 90 billion kilowatt hour [11]. According to statistics, at the end of 2018, there were 902 biomass power plants in my country. The cumulative installed capacity of all biomass power plants is 17.845 million KW, and it can generate 90.68 billion kWh per year, which has reached the national planning value ahead of schedule. Of this, 77.2 billion kWh were incorporated into the national grid. Waste incineration power generation accounts for 51%, more than half of the total biomass installed capacity. The second is agricultural and forestry biomass power plants, accounting for 45%, which is the second time that waste incineration power generation exceeds agricultural and forestry power generation. Biogas power generation accounted for 4%, the smallest proportion [24].

1.2. Cogeneration System and Biomass Cogeneration

The combined heat and power system is a comprehensive energy system that realizes heating (while supplying power to users) [25]. For now, coal and natural gas are the core energy sources for heating methods in Chinese cities. The technology of the cogeneration system is mature at home and abroad. As early as 2004, Denmark already had 10 biomass cogeneration plants and 10 research and development projects in operation. Sweden has about 15 biomass cogeneration plants connected to the central heating network. For Finland, they also built more than 10 biomass cogeneration plants [26]. In 2005, China's thermal power cogeneration units, of more than 6 MW, reached 7×10^7 kW, accounting for 15% of China's total installed capacity, nearly 80.5% of China's industrial heating capacity, and 26% of civil heating capacity [27]. In 2013, the heating capacity of 6 MW and above power plants reached to 3.24×10^6 TJ. The total installed heating capacity reached to 2.52×10^5MW. Moreover, the total heating area of the country reached to 57.17×10^8 m^2 [28]. In recent years, the Chinese government has vigorously supported the development of cogeneration technology. The 13th Five-Year Plan for Electric

Power Development proposed that, by 2020, the flexibility transformation scale of cogeneration units and conventional coal-fired power will reach 133 million kilowatts and 86 million kilowatts, respectively, and strive to achieve a cogeneration central heating rate of more than 60% in large and medium-sized cities in the north, and gradually eliminates the small coal-fired heating boilers within the coverage of pipe networks [29]. All of these show that the application of combined heat and power technology is feasible and effective. It is also the energy-saving and economic efficiency of this technology that makes its development at home and abroad more mature. However, the application areas are mostly concentrated in coal-fired power plants, such as coal power. There are relatively few applications in the field of biomass energy. Yefei et al. evaluated and analyzed the economy of biomass coal coupled power generation. The results showed that biomass coupled power generation enjoyed the benefits of coal-fired unit cogeneration. The coupling power generation is large, the power generation income is good, and the coupling advantage is obvious [30] The realization of cogeneration and clean heating is not only the basic attribute of straw power generation industry, but also an effective way to solve the problem of agricultural and forestry waste. Cogeneration is recognized as an important energy-saving technology for power generation, and its steam has no cold source loss. Biomass cogeneration is a hot topic studied by scholars at home and abroad. Andiappan, et al. designed a system decision analysis method of a biomass cogeneration system [31]. Tagliaferri et al. analyzed and evaluated the life cycle of biomass cogeneration power plants in the UK through a case study. The results show that the use of biomass can reduce greenhouse gas emissions [32]. Hailong Li et al. analyzed the factors that affect the efficiency of biomass cogeneration, and found that flue gas quenching (FgQ) plays an important role in combined heat and power (CHP) plants based on biomass or waste. When the flue gas condenser (FGC) is running, increasing the flow rate and reducing the temperature of circulating water will reduce the total energy efficiency [33]. Celebi, et al. Compared the performance of cogeneration system with oil, natural gas, and wood boilers, and found that a cogeneration system can avoid fossil carbon emissions and may generate negative heat price [34–36]. Previous research studies have shown that the thermal efficiency of biomass cogeneration can be increased to about 85%, which is about 45% higher than large condensing units [37].

China's biomass cogeneration has been introduced and developed since 2005. With the change of industrial policy from 2011 to 2012, the state stipulates that all biomass should be developed in the direction of cogeneration. The national development and Reform Commission and the National Energy Administration issued the notice on the guidance on promoting the development of biomass heating. According to the document, by 2020, the installed capacity of biomass cogeneration will exceed 12 million kilowatts [38–41]. In order to solve the problem of coal-fired pollution in rural areas, the comprehensive Department of the National Energy Administration issued the notice on carrying out the construction of a biomass cogeneration county clean heating demonstration project. It opened up a new way for the governance of the county's bulk coal, especially rural bulk coal, and provided a basis for exploring the comprehensive transformation of biomass power generation to cogeneration, and improving the biomass cogeneration policy [42,43]. The issuance of these notices is to give full play to the inherent economics and green and low-carbon environmental characteristics of biomass energy in county-level clean heating, and form an industrial pattern that replaces county-level coal burning, especially in rural areas. The state has repeatedly issued policies to promote the development of biomass power generation towards biomass cogeneration. However, the proportion of cogeneration projects is still very small. By the end of 2018, there are 137 agricultural and forestry biomass cogeneration projects in China, accounting for only 15% of the national biomass power generation projects [24]. This is related to China's actual situation. On the one hand, the raw materials of foreign biomass thermal power plants mainly use sawdust, while China's sawdust is insufficient, and the fuels are mainly agricultural and forestry wastes, straw, construction waste, and wood waste. On the other hand, foreign biomass power plants are close to the fuel producing areas, and are mainly used for township level heating, and their unit power is generally relatively small (most of them are 10 MW). However, most biomass power plants in China have an installed capacity of 30 MW (i.e., 30,000 kWh), and even 35,000 MW in the southern Shandong Province. Therefore, in order to realize the waste heat utilization of the biomass power plant and better promote the development of biomass cogeneration industry, it is necessary to design and adapt the imported technologies.

Therefore, it is of great significance to study the application of cogeneration technology in the field of biomass energy. It cannot only effectively utilize waste straw and consume forestry waste, but also reduce the emission of carbon dioxide. At the same time, compared with the decentralized heating and coal-fired heating in northern China, it can also reduce the emission of pollutants, such as sulfide and nitrogen compounds, to protect the environment. In addition, China is currently in the critical period of poverty alleviation. In many poor areas, heating cannot meet standard requirements. The biomass cogeneration project can be used as a poverty alleviation project, which cannot only improve the local living standards, but also increase the social identity of local residents for power plants, and solve the problem of integration between enterprises and surrounding people.

1.3. Conventional Biomass Energy Direct-Fired Cogeneration System

At present, most biomass cogeneration systems are biomass direct-fired cogeneration. The operation process is shown in Figure 1. The biomass is pulverized and then sent to the fluidized bed boiler to produce steam driven steam turbine and drive the generator to generate electricity. The steam turbine unit is used to extract steam and realize cogeneration [44].

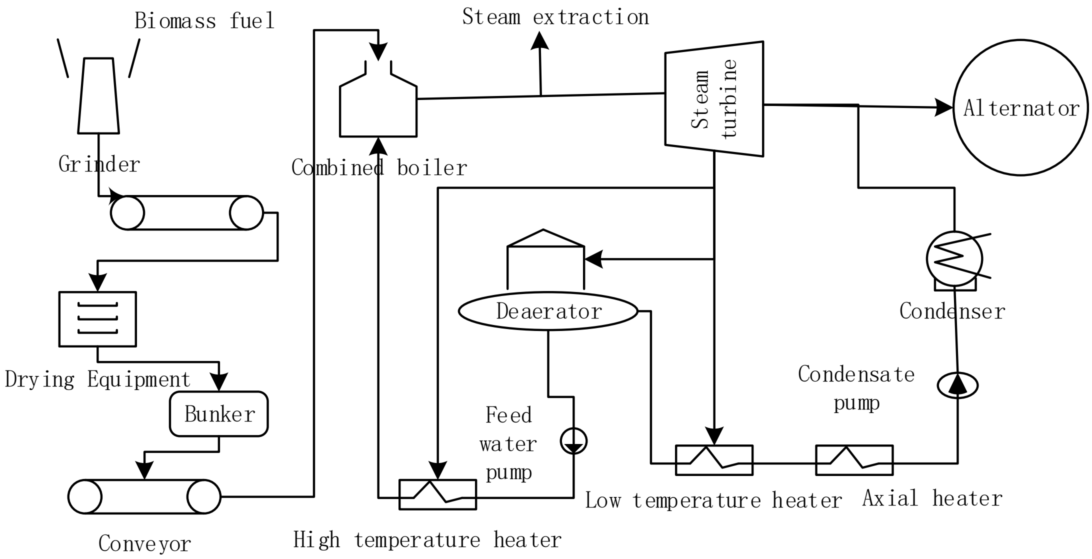

Figure 1. Flow chart of conventional biomass direct fired cogeneration system.

1.4. Principle and Key Technology of Biomass Cogeneration

To achieve biomass cogeneration, a circulating heating system is required and the backwater heating system is an auxiliary system of a thermal power plant consisting of a condenser and multiple heaters. The working principle of the heater is as follows: the flue gas after the combustion of biomass fuel passes through the steam turbine and enters the condenser, which is cooled to form a condensate. The condensate pump draws out the drain water in the low-pressure heater and pressurizes it to the return water heating system as the circulating cooling water of the low-pressure heater. The circulating cooling water passes through a plurality of heaters in sequence and heat exchange occurs between the extraction steam from the turbine and the circulating water. The extraction steam is cooled to be hydrophobic and the circulating water absorbs heat to form a higher temperature circulating cooling water. The circulating cooling water enters the deaerator and merges with the drainage water. The water is pumped out and boosted by the water pump to form the cooling water of the high-pressure heater. As shown in Figure 2, a return water heating system including 8 heaters [45,46]. To sum up, the return water heating system uses the extraction steam of the steam turbine to heat the water supply improve the thermal efficiency of the power plant and save fuel.

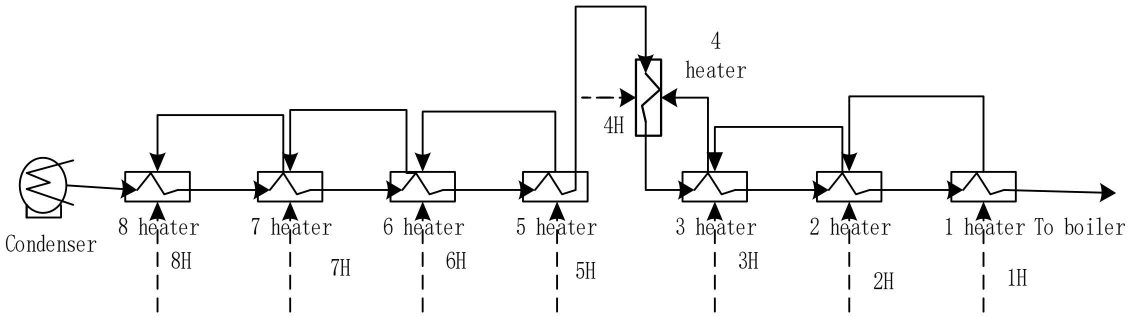

Figure 2. Flow chart of return water heating.

Return water heating is a necessary link to realize heat supply and low vacuum operation of steam turbines is the key technology to realize heat supply and improve efficiency in the biomass thermal power industry at present. This technology is mainly to increase the exhaust pressure to 0.059–0.078 MPa through the variable condition operation of steam turbine, and increase the outlet temperature of circulating water in condenser from 20–45 °C to 60–70 °C, and then heating users with the circulating water [47]. When generating electricity the steam with higher temperature and pressure will be generated. After working in the steam turbine, it will generate exhaust steam with a large amount of residual temperature. After that, use this exhaust steam to provide heating for users, as shown in Figure 3.

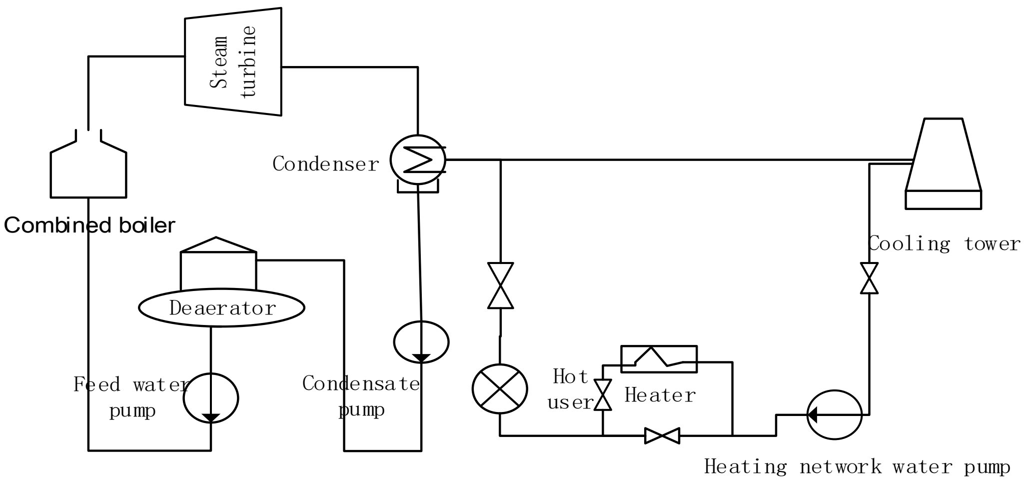

Figure 3. Schematic diagram of low-vacuum circulating water heating technology.

Its heating mechanism: in the conventional pure condensing operation unit, a part of the steam enthalpy is converted into electric energy by doing work in the turbine, and most of the rest (60–70%) is lost through the cooling tower. When the steam turbine is operating under low vacuum, the steam exhaust pressure and steam temperature of the steam turbine are increased. The temperature of the circulating water is increased and the temperature requirements for heating of the residents are met. Moreover, the exhaust condensation heat originally lost at the cold source is recovered for heating. In different periods, the operating principles are:

(1) during the heating period, the low-vacuum circulating water heating mode is used to operate the cooling tower and the circulating water pump out of operation. The circulating water system of the condenser is switched to a circulating water circuit composed of a heating network circulating pump, hot water pipe network, etc. To form a new "exhaust steam waste heat-heat network circulating water"

heat exchange system, the condenser becomes a return water heater and users become a cooling tower, forming a complete circulating water circuit. The cold source loss of the unit is reduced to zero, and the cycle heat efficiency is increased to more than 80%;

(2) during the non-heating period, the unit resumes pure condensing mode operation. The heating network circulation pump and heating network heater are out of operation. The original circulating water pump and cooling tower resume operation. That is, through the energy cascade, utilization improved the thermal energy utilization efficiency of the entire power plant.

1.5. Application and Improvement of Technology

The generation and development of biomass power generation technology originated in Western countries. So far, biomass power generation technology has become mature. China's biomass power generation mostly introduces foreign technology to operate power plants. Through the previous article, we have known that there are some differences between the biomass power generation industry in China and foreign countries, including the diversity of biomass raw materials and the larger scale of biomass power plants. This often leads to such things as Chimneys and cooling towers have large latent heat losses, low power generation efficiency, and low thermal efficiency. Therefore, for the biomass power generation, heating, and other technologies imported from abroad, special attention should be paid to the local actual situation of the power plant in the technology application link. If necessary, technology needs to be redesigned and improved accordingly, to promote localization of the technology, and expand the application benefits of the technology.

In order to change the current situation of biomass power plants using high-temperature and ultra-high pressure once reheat technology, which is high cost and not suitable for small unit power plants—to improve steam parameters and thermal efficiency, and to better apply low-vacuum circulating water heating technology in biomass power plants, make the local biomass fuel varieties play a greater role, improve the thermal efficiency of biomass power plants, and realize the localization of technology and the expansion of application scale—the technology has been adaptively designed and micro-renovated:

(1) the condenser is used as the first stage heater with basic heat load, and the peak heater is set for adjustment according to the air temperature to ensure the continuity of heating and heating effect;
(2) for the design of steam turbine, the pressure bearing capacity of water side should reach 0.5MPa. The design of last stage blade of steam turbine should consider the safety and economy of low vacuum operation, as well as the safety and thermal efficiency under pure condensing condition in summer. Considering the function of primary heater of condenser, the maximum exhaust pressure is 25KPa–35KPa;
(3) set a safety valve on the return water main pipe to prevent the return water pressure from exceeding the maximum pressure that the condenser can bear;
(4) in order to prevent the condenser tube from scaling, the chemical treated softened water is used in the circulating water of the heat supply network, and an on-line cleaning device for the condenser copper pipe is installed;
(5) when heating in low vacuum operation, the unit capacity, and heat load should be reasonably matched. If low vacuum circulating water heating is used for 30MW units, the heating area should be controlled within 600000–1500000 m^2.

2. Materials and Methods

2.1. Overview of Biomass Cogeneration System in DC County, China

Based on the biomass cogeneration project in DC County of China, the economic evaluation and risk evaluation of low vacuum operation circulating water heating technology of cogeneration are carried out in this paper. Moreover, studies the feasibility and benefit of cogeneration technology. The cogeneration project is planned in the local modern manufacturing industrial park, focusing on the development of biomass energy, the production, sales of clean electricity and heat energy. The plant area is mainly equipped with 2 × 30 MW steam turbine generator units, 2 × 130 t vapor/h high temperature, and high-pressure combined grate boilers. It will support auxiliary projects, such as straw collection, storage and transportation, crushing, and heating infrastructure and pipe network.

The fuel for the project comes from the agricultural and forestry wastes of the county and surrounding counties, mainly including corn straw, cotton stem, branches and bark, etc. The transportation radius is within 80 km. The annual purchase capacity is 350000–400000 tons of bark, 300,000 tons of corn and wheat straw, 30,000 tons of cotton straw, 100,000 tons of corncob, tree root, and waste fuel. The materials that meet the requirements are transported to the material shed by vehicles, and the top of the dry material shed is equipped with a grab crane for feeding equipment, which is then sent to the boiler for combustion by means of mechanical feeding.

Straw direct combustion power generation technology is adopted for combustion. The direct combustion power generation technology does not require strict raw materials, and is widely used with good stability. In order to be more suitable for all kinds of local agricultural and forestry biomass, combined with the patented boiler technology of the power plant, the project adopts the combined grate boiler. During the combustion process, the water preheated by desalting and deoxidizing will be heated into steam, which will be sent to the steam turbine for power generation. At the same time, the high-temperature flue gas generated by combustion continuously exchanges heat with the water wall around the furnace and the super-heater in the water-cooled cavity. After leaving the super-heaters at all levels, the flue gas enters the economizer and flue gas cooler tower at the tail. The flue gas in the tower successively exchanges heat with the economizer and flue gas cooler pipe row. After leaving the last flue gas cooler, the flue gas completes all the heat exchange in the boiler.

The project uses agricultural straw and forestry waste as fuel. The flue gas pollutants produced after combustion are mainly smoke, sulfur dioxide and nitrogen oxides. To reduce environmental pollution, low nitrogen combustion + Selective non catalytic reduction (SNCR) + cyclone dust removal + pulse bag Dust collector + lime-gypsum desulfurization forms the flue gas after it reaches the standard and is discharged through a 120 m high chimney.

This cogeneration project is the main heat supply source for local parks and county resident living and industrial parks. It uses low-vacuum circulating water heating technology. The condenser is used as the primary heater and the exhaust condensation heat is used to heat the circulating water to make use of the exhaust condensation heat. During the heating period, circulating water is pumped from the heating network to each heat user. The circulating water supply temperature is 62 degrees and the return water temperature is 47 degrees. In this way, the heat users in the heat network play the role of cooling tower in the circulating a cooling system. It will solve the problem of large latent heat loss of cooling tower, and realize waste heat recovery. In order to obtain a better research effect, the relevant indicators of economic evaluation, such as power generation and heating of the power plant were actually investigated, and Table 1 was obtained.

Table 1. Cogeneration power and energy output of the plant.

Item	Amount	Unit
Factory available quantity	7000	h/year
Annual generation capacity	4.56×10^8	kWh
Plant power consumption rate	12.35%	—
Annual power supply	4×10^8	kWh
Heating supply	7687.7×10^4	kWh

2.2. Evaluation and Risk Evaluation Methods

In order to evaluate the profitability of the technology after adaptive design and transformation in the biomass power plant, this paper takes the biomass power plant in DC County of China as the basis. It uses the office software Excel 2010 to carry out economic evaluation on the economic evaluation indexes of net present value (NPV), internal rate of return (IRR), and investment payback period (Pt), and sensitivity analysis. At the same time, in order to estimate the possibility of profitable investment when the key financial parameters change, the commercial software @risk7.6 (palisade Corporation, Ithaca, NY, USA) based on the Monte Carlo method was used for sensitivity analysis [48].

The article adopts the dynamic economic analysis method to evaluate the economic feasibility of the project from the perspective of the project operation enterprise. It mainly analyzes the three indicators of NPV, IRR and Pt, and analyzes the sensitivity of the uncertainty parameters to estimate the possibility of profitable investment when Pt the key financial parameters change. Index calculation definition and calculation method are as follows.

NPV is the sum of the present value of cash flows in and out of the project throughout its life cycle, which is calculated according to the following formula:

$$NPV = \sum_{t=0}^{n} (CI - CO)(1+i)^{-t} \tag{1}$$

IRR is the discount rate that makes the present value of each year in the life cycle equal to zero, and it reflects the income level of the project, which can be expressed as the following equation:

$$\sum_{t=0}^{n} (CI - CO)_t (1+IRR)^{-t} = 0 \tag{2}$$

Pt is the time required to recover the funds from investment expenditures and reflects the investment recovery capacity, which could be calculated as the following equation:

$$\sum_{t=0}^{p_t} (CI - CO)_t (1+i)^{-t} = 0 \tag{3}$$

In Equations (1)–(3), CI is the annual income; CO is the annual cost; i is the discount rate and t is the time of the project.

2.3. Economic Evaluation Model

The core of this work is economic evaluation. The relevant economic index data of the evaluation comes from the actual survey results. Moreover, the determination of electricity price and heat price is calculated according to the relevant regulations of the country's biomass power generation and heating, to ensure the validity and reliability of the economic analysis process and results have the following economic hypothesis.

2.3.1. General Assumptions

Assumed that the construction period of the project is one year, the service life is 15 years, and the inflation rate is 2%. The cost and price are calculated according to the annual increase. Moreover, the amortization period is 10 years with the amortization rate is 10%. The power consumption rate of the plant is 12.35%, the discount rate is 10%, and the default IRR is 10%. The tax is based on China's current national fiscal levy with a tax rate of 25%. NPV, IRR and Pt are used to evaluate its economic feasibility. Detailed project data is shown in Table 2.

Table 2. Major economic assumptions.

Item	Amount
Plant operation life (year)	15
Amortization period (year)	10
Amortization rate	10%
Plant power consumption rate	12.35%
Discount rate	10%
Inflation rate	2%
Tax rate	25%

2.3.2. Costs

The project cost is considered from the aspects of project investment, operation, and production cost. Operating costs is determined by the sum of fuel, plant operation, maintenance, management, and taxes, which including personnel, power consumption, maintenance materials, consumables, waste treatment, and by-product management. The specific cost items are shown in Table 3.

Table 3. List of investment and operating costs.

Item	Cost
Power investment (ten thousand RMB)	52,000
Heating investment (ten thousand RMB)	13,000
Fuel cost (ten thousand RMB/year)	11,200
Management expenses (ten thousand RMB/year)	1800
Manufacturing cost (ten thousand RMB/year)	3500
Financial expenses (ten thousand RMB/year)	2000
Annual cash outflow (ten thousand RMB/year)	18,500

2.3.3. Revenues

The revenue includes electricity generation, electricity sales, and heating. The biomass cogeneration project is an environmentally friendly renewable energy project and it can utilize some relevant national preferential electricity price policies. The subsidy price for biomass power generation is 0.75 RMB/kWh. The electricity self-use rate is 12.35% and the tax rate is 25%. For Table 4, it lists the power and heat output of thermal power plants to estimate income.

Table 4. Technical and economic indicators and annual income statement.

Item	Amount	Unit
Electricity price	0.75	RMB/kWh
Heat price	0.26	RMB/kWh
Power supply revenue	2.8×10^4	ten thousand RMB
Heating revenue	2000	ten thousand RMB
Total annual operating revenue	3.01×10^4	ten thousand RMB

3. Results

In this section, the economic analysis and sensitivity analysis are mainly carried out for the thermal power plant to consider the impact of uncertain factors such as biomass price, electricity price, and plant availability on the economic performance of the project, and comprehensively observe the project economy.

3.1. Economic Results

The economic evaluation is based on the cash flow model. The accumulated cash flow within the life of the project is analyzed as shown in Figure 4. The accumulated cash flow chart is calculated for the expenditure and income of each year and accumulated with the profit of last year. It can be seen from the figure that the static investment payback period is 6 years.

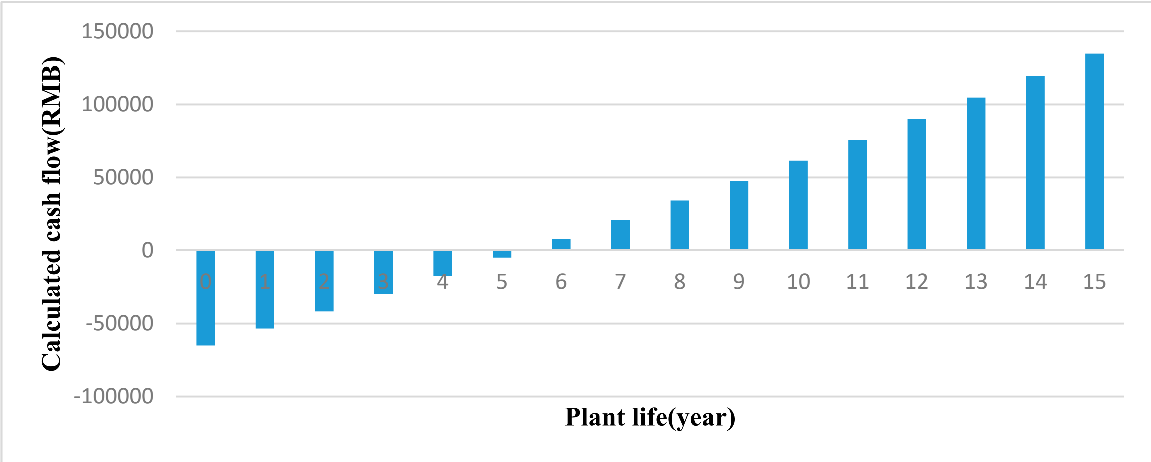

Figure 4. Cumulative cash flow chart.

Other major economic performance indicators are summarized in Table 5. According to the data in Table 5, annual total operating income is 3.01 million RMB and the annual cash outflow is 18.85 million RMB. The power consumption is calculated by multiplying the annual power generation of the plant by the plant electricity rate. After that, the power consumption cost is calculated based on the general electricity price of Hebei Province that calculated according to the economic evaluation index in Section 2.2. For the next part, the net present value is 32.973 million RMB with the internal rate of return is 17.7% and the dynamic investment recovery period is 7.4 years which indicating the project showed good economic performance.

Table 5. Results of main economic indicators.

Item	Amount
Dynamic investment payback period (year)	7.4
Static investment payback period(year)	6
Net present value (ten thousand RMB)	32,917.3
Internal rate of return (%)	17.7

3.2. Comprehensive Benefit Evaluation

From the above analysis, as a result the NPV, IRR, and Pt of the project are respectively 329.173 million RMB with 17.7% in 7.4 years. All economic indicators are reasonable. The project shows good economic effect and is feasible. At the same time, the analysis results of risk assessment also confirmed the good results of economic assessment. The results of the sensitivity analysis more clearly define the relationship and sensitivity between the economic benefits of the project and the influencing factors. In this situation, the sensitivity to the availability factor of the plant is relatively high, which should be the key control point of the project operation.

In addition, the project has obvious environmental benefits. The low-vacuum circulating water heating technology enables the waste heat of the biomass power generation process to be used instead of coal power and coal heating to achieve clean energy heating and power supply. It will save about 180,000 tons of standard coal per year. At the same time, it reduced greenhouse gas emissions by 260,000 tons, as well as smoke and dust emissions by about 68 tons, which stay with the national sustainable development and green development orientation. It truly contributes to the environmental protection of the region and the country, and benefits citizens and the society.

3.3. Risk Assessment

This section will evaluate the impact of changes in investment costs and operating costs and risk factors on benefits, and observe the possibility of project profitability. Considering the range of ±10% of investment cost and operation cost, respectively, and simulate the impact on NPV. The principle is based on the Monte Carlo simulation method. By replacing the value range (probability distribution) as a factor with internal uncertainty, the numerical results are obtained by repeated random sampling and then the results are calculated repeatedly. Each time, using a different set of random values in the distribution function, recalculate 100,000 times according to each case, and finally generate a distribution of possible result values.

In Figures 5 and 6, it can be seen that within ±10% of the change in investment cost, NPV changes are normally distributed and the probability of NPV falling between 254.99–403.36 million, RMB is 90%. The probability of NPV falling within 370.22–609.53 million RMB corresponding to the change range of operation cost is the same.

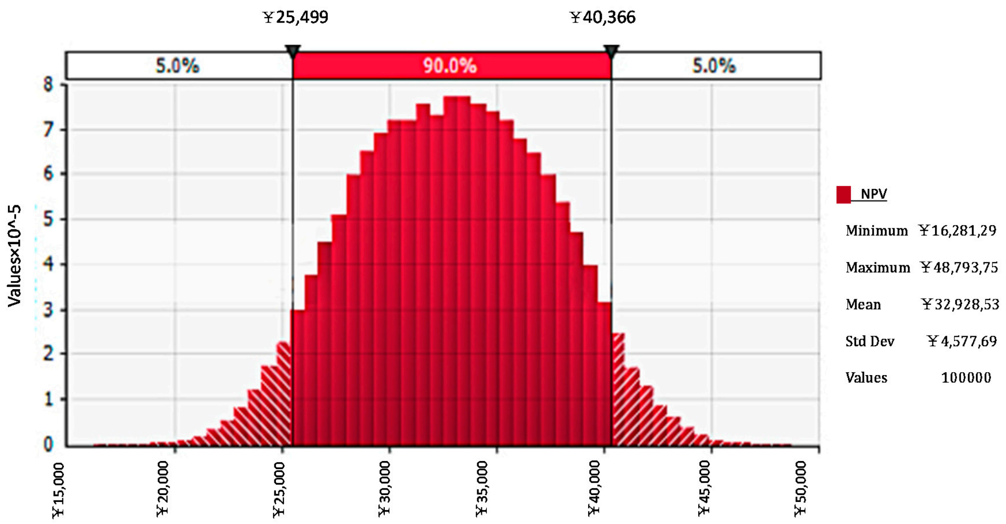

Figure 5. Impact of capital cost on changes in net present value (NPV).

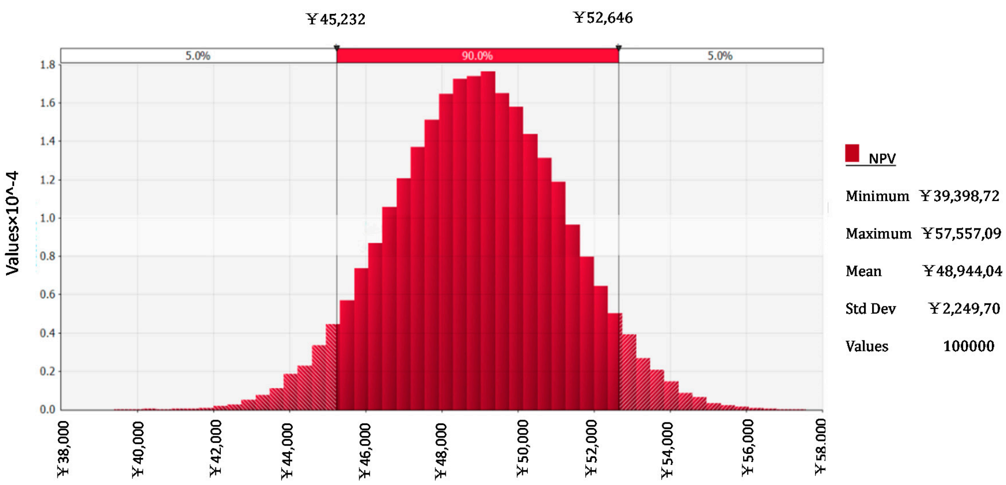

Figure 6. Impact of operating costs on NPV.

It can be seen from Figure 7 that in the 15-year life cycle of the thermal power plant, the probability of NPV of 355.28–623.96 million RMB is 90%, and the median value is 489.42 million RMB. It can be seen that the thermal power plant project based on the low vacuum operation of the steam turbine with circulating water heating has investment value, which has a high probability that can gain profits.

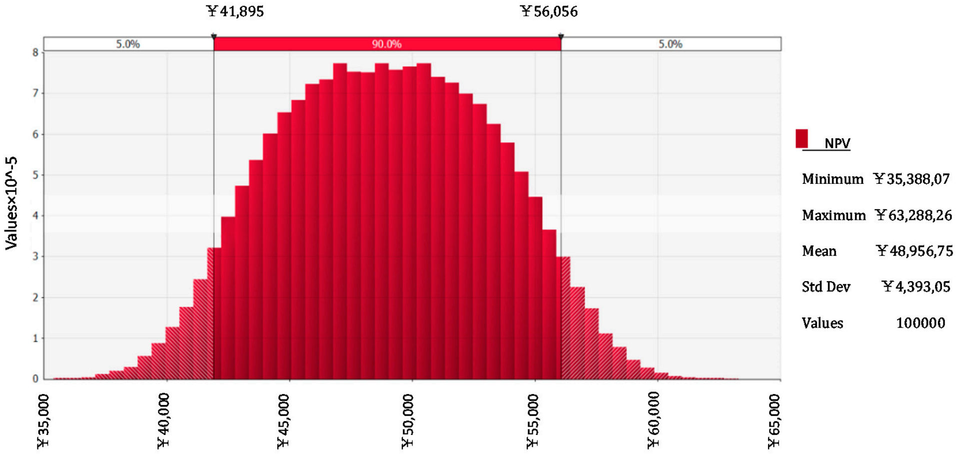

Figure 7. Comprehensive impact of changes in investment and operating costs on NPV.

4. Discussion

Based on the above economic evaluation and financial risk analysis, it can be seen that the application of this technology can obtain good benefits. The probability of NPV of 355.28-623.96 million RMB is 90% and the median value is 489.42 million RMB in the 15-year life cycle of the thermal power plant. Moreover, considering the uncertainty of biomass fuel price, power generation price, and plant availability, a single factor sensitivity analysis is carried out to discuss the factors affecting NPV and IRR and their critical points.

First of all, biomass fuel is the main source of cost for biomass thermal power plants. The current price of biomass fuel is 250 RMB/t and the annual fuel consumption is 500,000 tons. From the relevant market, the price of biomass fuel used in the power plant varies from 250–300 RMB/t. Therefore, the price is set in the range of 250–300 RMB/t. The potential impact on NPV and IRR is analyzed and discussed. The following analysis is shown in Figure 8.

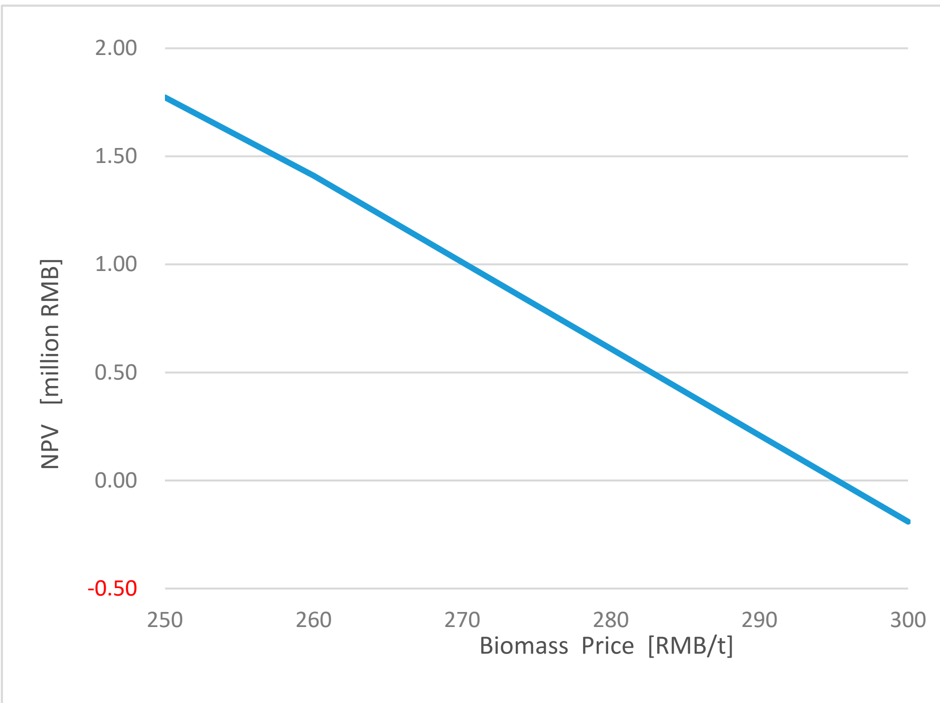

Figure 8. Functional relationship between biomass price and NPV.

The analysis shows that, under the condition that other conditions remain unchanged, the relationship between biomass fuel price and NPV is a linear positive correlation function, and the break-even point is slightly higher than 295 RMB/t, as long as the price of biomass fuel is less than 295 RMB/t and the net present value is positive. The application of this technology will enhance the competitive advantage of biomass power plant. For the price of biomass fuel, lower will be better, otherwise it will lead to losses. Even if the price falls to 295 RMB/t, the IRR at this time is 10.02%, which is still greater than the preset internal rate of return in our overall economic assumption and can still achieve profitable operation. However, it can only achieve continuous operation, and the power plant ash is in the situation of poor operation.

Secondly, the sale of biomass power is the main source of income for biomass thermal power plants. The direct impact on the income of electricity is the electricity price and power supply. The amount of power supply depends on the construction of thermal power plant, the configuration of machinery, equipment, plant availability, and other hard conditions. The construction of power plant, machinery and equipment, and other hardware facilities will generally make decisions through financial budget and feasibility analysis of the project. Once completed, there will be no change unless the expansion is completed. Therefore, the NPV analysis of power supply will be studied in the following paper for the availability of power plant. In this paper, other variables are fixed, and the price fluctuation range is set to analyze the impact of price change on NPV of biomass power plant.

Due to China's policy preference for biomass thermal power plants, the analysis of the potential impact of power generation prices on economic indicators in this paper mainly considers the decline and increase issue of government subsidies. At present, the price of biomass power generation is 0.75 RMB/kWh with a change range of ±10%. That is the sensitivity analysis of the price in the range of 0.675–0.825 RMB/kWh is conducted and the function of price and NPV is obtained. From Figure 9, there is a linear positive correlation function between the state subsidized biomass electricity price and the net present value, and the critical value is 0.692 RMB/kWh. That is, under the condition that other conditions remain unchanged, when the biomass power generation price is lower than 0.692 RMB/kWh, the investment will no longer benefit the project, and the technology will no longer be competitive. Only when the national subsidy biological electricity price is greater than 0.692 RMB/kWh, the investment can benefit.

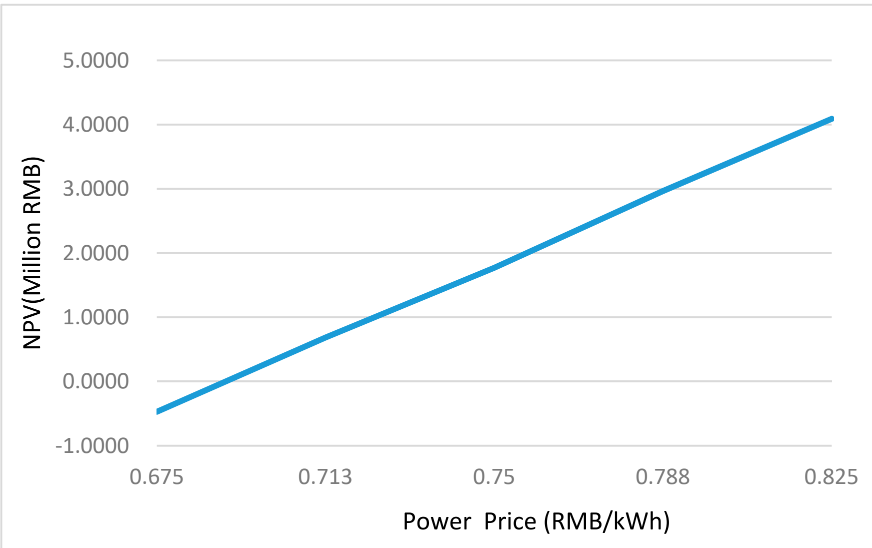

Figure 9. Electricity price as a function of NPV.

Therefore, under the current market situation, the states need to keep support, and supporting policies, for the biomass thermal power industry. It will take time and continuous improvement of technology to simply rely on the biomass thermal power plant reducing costs and survive. However, there is no need to worry too much about biomass thermal power plants. At the end of 2018, the National Energy Administration of China promised to maintain the intensity of renewable energy subsidies for 20 years. With policy support, the current development of the biomass thermal power industry has been guaranteed.

In this paper, the main economic evaluation of the improvement and application of low vacuum circulating water heating technology in biomass power plant is carried out. Therefore, it is necessary to study and analyze the impact of the change of heating price on NPV. The current local heating price is 0.26RMB/kWh, considering the variation range of ±15%, that is, the sensitivity analysis of the heating price in the range of 0.221–0.229 RMB/kWh, and the relationship between the heating price and the net present value is obtained, as can be seen from Figure 10. There is a linear positive correlation between the heating price of biomass power plant and NPV. After the improvement and application of low vacuum circulating water heating technology, under the condition that other variable factors remain unchanged, even if the heat price is within ± 15% of the current price, the heating will bring benefits to the power plant, and the net present value of heating income is at least 150 million RMB, which is competitive.

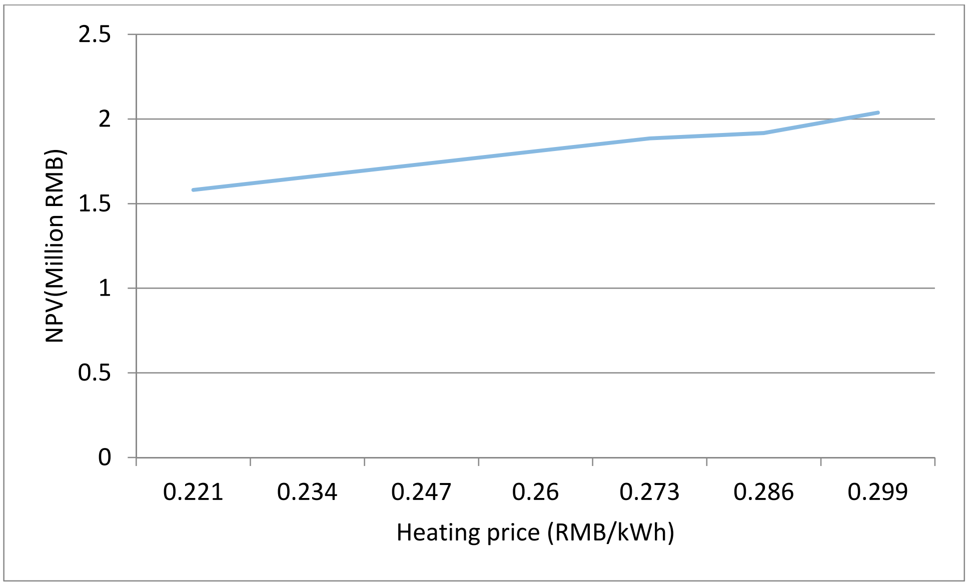

Figure 10. Heating price as a function of NPV.

The availability of the plant determines the operation and output of the biomass thermal power plant will directly benefits the biomass thermal power plant. To a certain extent, the greater the availability of a plant and the longer its life cycle, the greater the possibility that it can generate benefits for the power plant. By stabilizing other variable parameters, only the availability of biomass power plants can be changed, and the profitability of biomass power plants can be observed. The current set of unit operating hours is 7000 h/year. Assume that the change range is ±10%, i.e., 6300–7700 h/year. The sensitivity analysis is carried out to observe its impact on NPV. The functional relationship between the two is shown in Figure 11. Through the analysis, there is a linear positive correlation between NPV and availability of power plant, so that the critical point of available hours of plant, where technology application investment can obtain benefits, appears at 6444 h/year—that is, when other conditions do not change, when the available hours of the plant is less than 6444 h/year, the NPV is negative in the life cycle of the power plant. When it is profitable and reaches 6300 h/year, the NPV is −46.98 million RMB, and the IRR is also reduced to 9%, which is lower than the internal rate of return set in the hypothesis. The improved technology will no longer be competitive when applied to power plants. Only when the annual utilization hours of the power plant is greater than 6444 h/year, the NPV of the power plant is positive and increases with the increase of the available hours of the power plant.

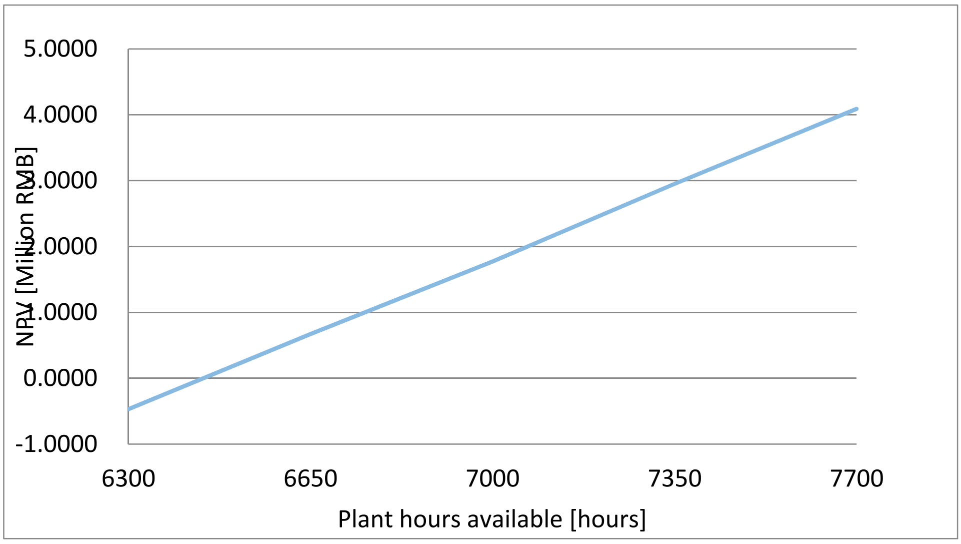

Figure 11. Plant availability as a function of NPV.

At the same time, the impact of changes in uncertain factors on the IRR is analyzed and a sensitivity analysis chart is drawn. As can be seen from Figure 12, the change direction of fuel price is opposite to that of internal rate of return. Other influencing factors, such as electricity price, heating price, and availability of the power plant, have the same direction and different degrees of influence on IRR. The influence of the power plant availability and electricity price on internal rate of return is basically the same, and the project is highly sensitive to these two variables. In the whole life cycle of the project—especially the availability of equipment—is the factor that the equipment can self-regulate and control. In order to ensure the economic benefits of the thermal power plant, the maintenance of mechanical equipment is an important part of daily work. The change of heating price has little impact on the IRR of the biomass power plant, which is basically the same as the current heating price effect. When the change reaches nearly 7.5%, that is, when the heating price is 0.28RMB/kWh, the IRR has increased significantly, which is more than 15%. It can be seen that using the low vacuum circulating water heating technology to recover the waste heat of the power plant is profitable for the project, and the benefit of increasing income is stable.

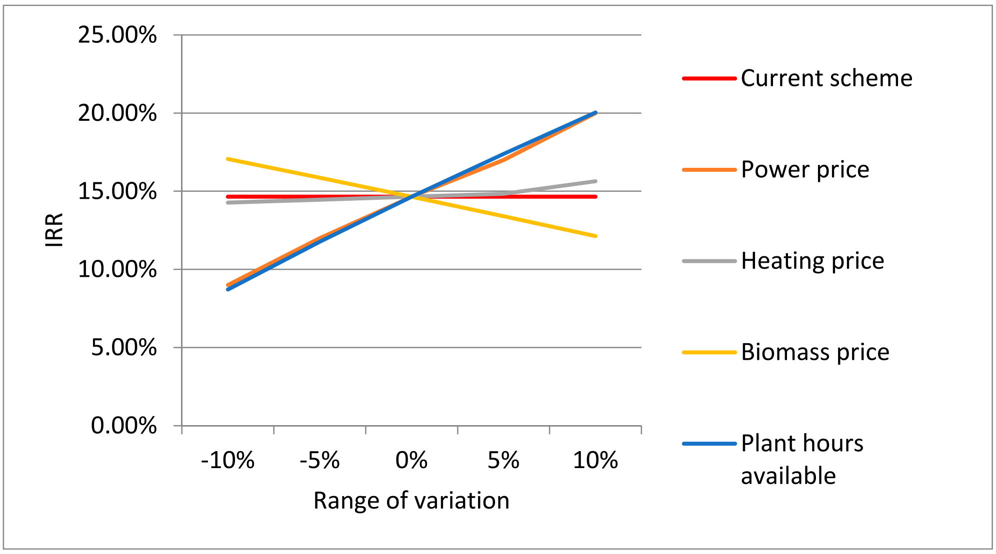

Figure 12. Sensitivity analysis chart.

In short, through sensitivity analysis, it can be seen that through the design and utilization of low vacuum circulating water heating technology, waste heat recovery of the biomass power plant, solving the problem of waste heat dissipation, and increasing heating projects, can improve the enterprise income. At present, the heating price in this area is 0.26 RMB/kWh; even if it changes in the range of ± 15% (0.221–0.229 RMB/kWh), it can still increase revenue. The impact of electricity price and annual utilization hours of power plant on NPV and IRR is the same, and the degree is similar. The change of the two has a greater impact on NPV and IRR, which is worthy of attention. Fuel is the basis of the power plant power supply and heating, and its price change trend is opposite to that of power plant income, and has a great impact. The price of biomass fuel should not be higher than 295 RMB/t, otherwise, even if the technology is used for waste heat recovery and heating, it will no longer have a competitive advantage.

5. Conclusions

This article introduces the low-vacuum circulating water heating technology, which is the current key technology in the biomass cogeneration system and operation of biomass cogeneration in China. In view of the differences between biomass power generation in China and those in western countries, such as the types of biomass raw materials and the scale of biomass power plants, this paper redesigns and improves the technology, especially the design of facilities and equipment and the process design of cleaning devices. It is based on the biomass power plant project in DC County of China with the redesigned and improved low vacuum circulating water heating technology. This paper analyzes the economic rationality and feasibility of the technology from the aspects of NPV, IRR, and Pt. As a result, the problem of large latent heat loss of cooling tower and chimney, low power generation efficiency, and thermal efficiency of most biomass power plants in China has been solved. The waste heat recovery has been realized and the thermal efficiency of biomass power plant has been improved. Moreover, it makes the waste heat of biomass power generation process based on local agricultural and forestry wastes be utilized to replace more than 20 coal heating boilers for heating, and no new heating boilers are built in the park to realize clean energy heating and power centralized supply, saving about 180,000 tons of fossil energy annually, reducing 260,000 tons of greenhouse gas emissions and 1000 tons of sulfur Emissions, 68 tons of smoke, and dust emissions at the same time. The comprehensive environmental benefit is obvious; at the same time, it can also provide central heating and increase farmers' income by more than 60 million RMB every year, so it is highly praised by the surrounding residents. According to the survey, 85% of the local residents are very supportive and satisfied with the project. Compared with the common waste heat recovery project of biomass power plant, the design and application of waste heat heating technology with waste heat is obvious. Wu Sheng and Xia Yu mentioned above recycled the waste heat from the boiler tail gas of biomass power plant, continuous blowdown flash tank and deaerator oxygen exhaust valve to heat tap water in water storage tank and then sell hot water, and make economic and environmental benefits. Finally, the results show that after the implementation of the project, 3000 t of standard coal can be saved, 8000 t of CO_2 emission will be reduced, 25.5 t of SO_2 emission, and 22.2 t of NOx emission will be reduced, the annual profit is more than 600,000 RMB. By comparison, it can be seen that through the design of low vacuum circulating water heating technology, which is suitable for local biomass fuel and power plant scale, can achieve better comprehensive benefits than ordinary waste heat recovery project.

In the perspective of economy, the net present value, internal rate of return, and investment recovery period, etc., analyzes the economic rationality and feasibility of this technology by several indicators. The results show that the NPV is 329.173 million RMB, the IRR is 17.7%, the static Pt is 6 years, and the dynamic Pt is 7.4 years. It shows that the designed low-vacuum circulating water heating technology of biomass cogeneration is a feasible choice, and is suitable for biomass power generation projects using agricultural and forestry wastes as raw materials in northern China, its application can improve the thermal efficiency of biomass power plants.

At the same time, considering the uncertainty of some factors in the process of economic analysis the sensitivity analysis is carried out by selecting the parameters, such as the price of biomass fuel, the price of electricity, and the availability of the plant. The results show that the availability of the plant and the price of electricity have a high sensitivity impact on the economic benefits of the project. In particular, the current electricity price includes government subsidies. Once the subsidy policy is cancelled or the subsidy price drops to 0.692 RMB/kWh the NPV is negative and it will no longer have good economic benefits. Therefore, the biomass thermal power industry should strive to reduce operating costs, expand power supply, and heating to ensure the sustainable development of the biomass thermal power industry.

In addition, financial risk assessment is carried out for the two parameters of investment cost and operation cost, and the results confirm the competitiveness of the technology designed under the condition of unpredictable changes of the two parameters. Under the condition of ± 10% change of both, the probability of NPV falling in the range of 355.28–623.96 million RMB in 15 years' life cycle is 90%.

Author Contributions: Conceptualization, H.H. and S.S.; methodology, H.H. and S.S.; software, X.Y.; validation, X.Y.; formal analysis, X.Y.; investigation, H.H., X.Y., Y.D., and Y.G.; resources, H.H. and S.S.; data curation, X.Y.; writing—original draft preparation, X.Y.; writing—review and editing, X.Y., H.H. and S.S.; visualization, X.Y. and H.H.; supervision, H.H.; project administration, H.H.; funding acquisition, H.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the basic scientific research fee of Central Universitym, grant number [2010QG01], and the APC was funded by [School of Management, China University of Mining & Technology, Beijing].

Acknowledgments: The author would like to thank China's DC County Biomass Cogeneration Power Plant for its support and cooperation in this investigation and study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. BP. *World Energy Outlook 2019*; BP: Beijing, China, 2019.
2. Liu, H.B.; Liu, Z.L. Recycling utilization patterns of coal mining waste in China. *Resour. Conserv. Recy.* **2010**, *54*, 1331–1340.
3. Moriarty, P.; Honnery, D. What is the global potential for renewable energy? *Renew. Sustain. Energy Rev.* **2012**, *16*, 244–252. [CrossRef]
4. International Energy Agency. *World Energy Outlook 2018*; IEA: Paris, France, 2018.
5. BP. *Statistical Review of World Energy 2019*; BP: London, UK, 2019.
6. Xi Jinping's Speech at the Opening Ceremony of the Paris Climate Change Conference. 2015. Available online: http://news.xinhuanet.com/fortune/2015-12/01/c_.htm (accessed on 9 May 2019).
7. World Bank. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Available online: https://www.worldbank.org/en/news/infographic/2018/09/20/what-a-waste-20-a-global-snapshot-of-solid-waste-management-to-2050 (accessed on 11 May 2019).
8. International Energy Agency. Renewables 2018, Market Analysis and Forecast from 2018 to 2013 on Renewable Energy and Technologies. 2018. Available online: http://www.iea.org/rene-wables2018/ (accessed on 11 May 2019).
9. Henrich, E.; Dahmen, N.; Dinjus, E.; Sauer, J. The role of biomass in a future world without fossil fuels. *Chem. Ing. Tech.* **2015**, *87*, 1667–1685. [CrossRef]
10. Widholm, J.; Nagata, T. *Biotechnology in Agriculture and Forestry*; Springer: Heidelberg, Germany, 2010.
11. National Energy Administration of the People's Republic of China. The 13th Five-Year-Plan of Biomass Energy Development. Available online: http://www.gov.cn/xinwen/2016-12/05/content_5143612.htm (accessed on 3 May 2019).
12. Jiang, D. Strengthen the implementation of effective improvement plan for heavy pollution weather. *China Emerg. Manag.* **2015**, *11*, 43–45.

13. National Energy Administration of the People's Republic of China. The 12th Five-Year-Plan of Biomass Energy Development. Available online: http://www.gov.cn/zwgk/2012-12/28/content_2301176.htm (accessed on 28 April 2019).
14. Chen, J.; Zheng, W.; Gao, H.; Shao, J.; Liu, C. Estimation method of straw burned area based on multi-source satellite remote sensing. *Trans. Chin. Soc. Agric. Eng.* **2015**, *3*, 207–214.
15. Li, R.; Zhang, S.; Wang, Y.; Zhang, X.; Zhao, H.; Zhou, Q.; Chen, W. Mass concentration of atmospheric fine particulates in crop harvesting period in Sanjiang Plain, northeast China. *China Env. Sci.* **2015**, *3*, 676–682.
16. National Development and Reform Commission, National Energy Administration. The 13th Five Year Plan for Energy Development. National Energy Administration. Available online: http://www.nea.gov.cn/2017-01/17/c_135989417.htm (accessed on 20 April 2019).
17. People's Government of the People's Republic of China. Development and Reform Commission. Guiding Catalogue of Industrial Restructuring. 2019. Available online: http://www.gov.cn/xinwen/2019-11/06/content_5449440.htm (accessed on 16 December 2019).
18. Ni, W.D. Speech on the Paris Agreement and the way of low carbon transformation of coal power at the processsing. In Proceedings of the World Low Carbon Cities Alliance Conference and Low Carbon City Development Forum, Lishui, China, 27 July 2019.
19. Wu, S.; Xia, Y. Application of waste heat recovery and reconstruction project in biomass power plant. *Energy Sav.* **2019**, *38*, 94–96.
20. Shi, Y.C.; Cheng, X.; Zhu, W.B. Some strategic thinking on the development of biomass energy in China. *Sci. Technol. Guide* **2019**, *20*, 6–11.
21. National development and Reform Commission of the people's Republic of China. Planning for Winter Clean heating in Northern China (2017–2021). 2017. Available online: http://www.nea.gov.cn/2017-12/27/c_136854721.htm (accessed on 11 May 2019).
22. Feng, Y.J. Transformation from Biomass Power Generation to Cogeneration. *China Electric Power News*. February 2018. Available online: http://www.xinhuanet.com/power/2018-02/05/c_.htm (accessed on 9 May 2019).
23. International Energy Agency. *World Energy Outlook 2017*; IEA: Paris, France, 2017.
24. Biomass Industry Promotion Association. *Ranking Report of China's Biomass Power Generation Industry*; Biomass Industry Promotion Association: Beijing, China, 2019.
25. Werner, S. Ecoheatcool: European Heating and Cooling Market Study, Ecoheatcool Work Package 1. Technical Report, Euroheat & Power. 2006. Available online: https://www.euroheat.org/wp-content/uploads/2016/02/Ecoheatcool_WP1_Web.pdf (accessed on 9 May 2019).
26. Hu, X.J.; Zhang, X.M.; Cai, L.Y. Research progress of CCHP optimization. *Energy Res. Manag.* **2010**, *2*, 13–16.
27. Gao, H.Y.; Xiao, N. Development trend of CHP industry in China. *Power Gener. Equip.* **2010**, *6*, 467–469.
28. Editorial Committee of China. *China Electric Power Yearbook*; China Electric Power Press: Beijing, China, 2014.
29. National Development and Reform Commission, National Energy Administration. 13th Five Year Plan for Electric Power Development. Fujian Regulatory Office of National Energy Administration. Available online: http://fjb.nea.gov.cn/news_view.aspx?id=27538 (accessed on 11 May 2019).
30. Ye, F.; Zhao, H.S.; Lin, H.Y. Economic analysis of the coupling of biomass gasification and coal-fired cogeneration units. *Jilin Electr. Power* **2018**, *46*, 5–8.
31. Ling, W.C.; Andiappan, V.; Wan, Y.K.; Ng, D.K.S. A systematic decision analysis approach to design biomass combined heat and power systems. *Chem. Eng. Res. Des.* **2018**, *137*, 221–234. [CrossRef]
32. Tagliaferri, C.; Evangelisti, S.; Clift, R.; Lettieri, P. Life cycle assessment of a biomass CHP plant in UK: The Heathrow energy centre case. *Chem. Eng. Res. Des.* **2018**, *133*, 210–221. [CrossRef]
33. Li, H.L.; Wang, B.; Yan, J.Y.; Salman, C.A.; Thorin, E.; Schwede, S. Performance of flue gas quench and its influence on biomass fueled CHP. *Energy* **2019**, *180*, 934–945. [CrossRef]
34. Liu, X.; Zhou, X.; Zhu, B.; He, K.; Wang, P. Measuring the maturity of carbon market in china: An entropy-based TOPSIS approach. *J. Clean. Prod.* **2019**, *229*, 94–103. [CrossRef]
35. Wang, G.; Yao, Y.; Chen, Z.; Hu, P. Thermodynamic and optical analyses of a hybrid solar CPV/T system with high solar concentrating uniformity based on spectral beam splitting technology. *Energy* **2019**, *166*, 256–266. [CrossRef]
36. Celebi, A.D.; Sharma, S.; Ensinas, A.V.; Maréchal, F. Next generation cogeneration system for industry—Combined heat and fuel plant using biomass resources. *Chem. Eng. Sci.* **2019**, *204*. [CrossRef]

37. Zang, X.F.; Jiang, X.; Sa, T.Y. Prospects and main problems of biomass cogeneration. *Sci. Technol. Inf.* **2013**, *23*, 395.
38. National Development and Reform Commission, Energy Administration. Guidance on Promoting the Development of Biomass Heating. Available online: http://zfxxgk.nea.gov.cn/auto87/201712/t20171228_3085.htm (accessed on 11 May 2019).
39. Wang, G.; Wang, F.; Shen, F.; Jiang, T.; Chen, Z.; Hu, P. Experimental and optical performances of a solar CPV device using a linear Fresnel reflector concentrator. *Renew. Energy* **2020**, *146*, 2351–2361. [CrossRef]
40. Wang, P.; Li, J.; Bai, F.; Liu, D.; Xu, C.; Zhao, L.; Wang, Z. Experimental and theoretical evaluation on the thermal performance of a windowed volumetric solar receiver. *Energy* **2017**, *119*, 652–661. [CrossRef]
41. Zhang, L.; Shu, H.; Zhang, L.; Jia, Y. Gas modified pyrolysis coke for in-situ catalytic cracking of coal tar. *ACS Omega* **2020**, *5*, 14911–14923.
42. Yao, H. Biomass cogeneration governance Lixian coal pollution. *Electr. Ind.* **2017**, *10*, 67–69.
43. National Energy Administration of the People's Republic of China. Notice on Carrying out "Hundred Cities and Towns" Biomass Cogeneration County Clean Heating Demonstration Project Construction. Available online: http://zfxxgk.nea.gov.cn/auto87/201802/t20180211_3116.htm (accessed on 11 May 2019).
44. Chen, D.M.; Liu, F.; Yang, Q. Energy consumption analysis and greenhouse gas emission of biomass direct combustion system. *J. Sol. Energ.* **2016**, *37*, 553–558.
45. Wang, G.F. Modeling of Return Water Heating System and Research on Coordinated Intelligent Control of Unit. Ph.D. Thesis, Xi'an University of Architecture and Technology, Xi'an, China, 2005.
46. Zhu, B.; Ye, S.; Jiang, M.; Wang, P.; Wu, Z.; Xie, R.; Chevallier, J.; Wei, Y. Achieving the carbon intensity target of china: A least squares support vector machine with mixture kernel function approach. *Appl. Energ.* **2019**, *233*, 196–207. [CrossRef]
47. Zheng, J. Application of circulating water heating technology in low vacuum operation of steam turbine. *Energy Sav. Technol.* **2006**, *24*, 380–382.
48. Palisade Corporation. *@RISK User's Guide—Risk Analysis and Simulation Add-In for Microsoft®Excel*; Palisade Corporation: Ithaca, NY, USA, 2015.