sustainability

Article

The Mechanism and Countermeasures of the Impact of State Subsidy Backslide on the Efficiency of Waste-to-Energy Enterprises—A Case Study in China

Huo-Gen Wang and Han Rao *

College of Economics and Management, Jiangxi Agriculture University, Nanchang 330045, China; whuogeng@163.com
* Correspondence: agochololate@outlook.com

Abstract: The scientific investment decision model of waste incineration power generation is helpful in providing a scientific basis for the government and environmental protection enterprises to formulate reasonable waste prices. The waste incineration power generation project revenue and cost composition framework, based on the project net present value of factors affecting causality analysis, the construction of a waste incineration power generation PPP project net present value system dynamics model, and the use of Vensim PLE software, version 7.3.5, combined with the garbage power generation of listed companies, was built, and we put into use the enterprise's financial data and the author's research of the case of the BOT (Build–Operate–Transfer) project data to examine the validity of the model test, simulation, and sensitivity analysis. The results show that the regression of a national subsidy does not necessarily lead to a price adjustment of the waste disposal fee, and when a change in tariff subsidy occurs, the loss brought by the reduction in a feed-in tariff can be compensated by increasing the income from carbon sinks, decreasing the intensity of investment through technological advancement, improving the coefficient of waste power generation through garbage classification, and increasing the utilization of production capacity through the treatment of multiple wastes in a single or a combination of ways.

Keywords: electricity tariff rebate; waste disposal fees; carbon emission reduction; system dynamics

Citation: Wang, H.-G.; Rao, H. The Mechanism and Countermeasures of the Impact of State Subsidy Backslide on the Efficiency of Waste-to-Energy Enterprises—A Case Study in China. *Sustainability* **2023**, *15*, 14190. https://doi.org/10.3390/su151914190

Academic Editors: Zakaria Solaiman, Shamim Mia and Md. Abdul Kader

Received: 25 July 2023
Revised: 19 September 2023
Accepted: 20 September 2023
Published: 26 September 2023

1. Introduction

China's rapidly growing economy and urbanization have led to a significant increase in household waste generated by the country's expanding urban population. By the end of 2020, the urban population reached 90.199 million, with an urbanization rate of 63.89%, representing a substantial increase from 19.4% in 1980. While landfilling and incineration are the predominant waste management options for domestic garbage, they present environmental challenges, such as land use, secondary pollution, and greenhouse gas emissions (source: China National Bureau of Statistics (http://www.stats.gov.cn/)). To address the issue of garbage encirclement and the need for a beautiful ecological environment, the Chinese Government has issued policy documents such as "Urban Household Waste Management Measures". These documents promote the adoption of incineration and power generation as potential solutions for waste reduction, non-harmful treatment, and resource utilization. The National Development and Reform Commission has also established encouragement policies, subsidies, and financial and tax incentives to stimulate market-oriented entities to participate in the market for household waste incineration and power generation. However, as the proportion of waste incineration increases, the subsidy policy of renewable energy power generation has encountered significant economic pressure, necessitating the withdrawal of subsidies.

The government–private social capital cooperation model, commonly referred to as the PPP (Public Private Partnership), is a long-term cooperation relationship established in the field of public services [1]. Originating in the United Kingdom in 1982, this model was initially introduced to tackle issues, such as an inadequate supply of public goods and inefficient management. In 2014, the State Council of China issued the "Guiding Opinions on Encouraging Social Capital Investment in Key Areas of Innovation", which emphasized the active promotion of the PPP model in the field of ecological protection. The PPP model entails consultation between the government and private social capital enterprises, culminating in an agreement to work together. Private enterprises are responsible for the design, construction, and operation work and receive reasonable investment returns in the form of either government payment or user payment. To ensure the public interest is served to the greatest extent possible, the government agency in charge is responsible for construction and operation conditions as well as quality supervision [2]. Various methods, such as O&M (Operations and Maintenance), BOT (Build–Operate–Transfer), BOO (Buy–Build–Operate), and BBO (Build–Own–Operate), are included [3]. According to the theory of public goods, domestic waste disposal is a public service with the attributes of a public good [4] (Figure 1).

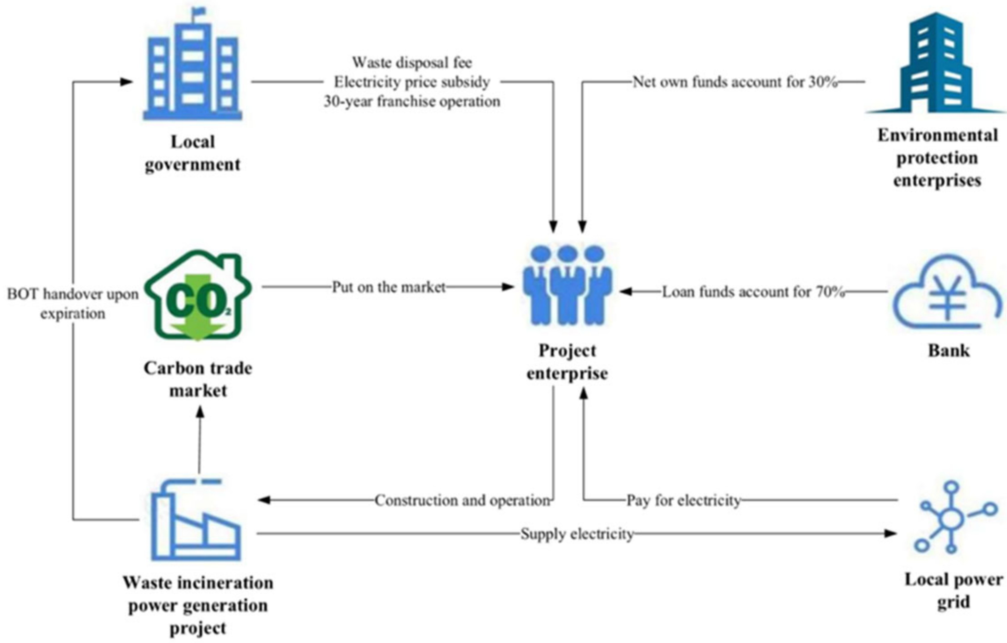

Figure 1. BOT operation mode of waste incineration power generation project.

The BOT model is commonly employed by the government to attract social capital or environmental protection companies to invest in incineration projects due to its public welfare, positive externalities, and high investment intensity. In the context of negotiations for BOT waste incineration power projects, the investment cost and return are critical decision-making factors for both project investors and government entities. The waste disposal price, in particular, serves as a key bidding factor and substantially impacts the project's operational efficiency in the long run. Various factors influence the efficiency of waste incineration power projects, including the concession period [5], waste supply [6], variations in waste combustion calorific value [7], waste disposal fees [8], grid-connected power prices [9], operating costs [10], capital structure [11], and tax incentives [12]. Chunling S [13] constructed a system dynamics model of natural gas PPP project revenues, combined with the completed model, and put into use the Northwest gas refueling station as a study case. They carried out a model validity test, simulation and sensitivity analysis, and proposed a method to improve the revenue compensation mechanism of waste incineration power generation. Yu Y, Zhao R [14] explored the behavioral strategy changes of a government–enterprise–public system by constructing a risk-perception-driven multi-interested subject dynamic game model using system dynamics simulation.

Waste-to-Energy (WTE) supply chain technologies, which have been developed by academics and industry, have been recognized as a highly effective way to reduce carbon footprints and improve resource management efficiency [15]. WTE is a functional energy supply network consisting of primary energy utilization, energy production, multi-network transmission, and waste recycling with biomass as the core. The whole network connects the forward supply chain of energy production–consumption–waste generation and the reverse supply chain of waste recycling–treatment–energy production through coupling, forming a closed-loop and interactive waste-to-energy recycling chain, realizing the transformation of the traditional unidirectional energy flow mode to the cyclic flow mode of efficient energy utilization [16]. It helps to solve the three major problems of waste management, energy demand, and environmental protection at the same time and realize the sustainable development of the economy, society, and the environment [17].

2. Theoretical Bases

2.1. Waste Incineration Power Generation Process

First, the local sanitation department or community property collects the waste and transports it to the waste transfer station. After compression and packaging at the transfer station, the waste is delivered to the waste power generation enterprise in a dedicated garbage truck. The waste is then weighed and dropped into the waste pool, where it ferments for 5–7 days. The settled filtrate is processed through a filtrate treatment system and discharged into the pipe network, with the remaining portion returning to the cooling unit as the cooling water for the engine. Next, the waste is lifted into the feed bin by a grab crane and is then slid into the incinerator through a chute, where it is dried, heated, and sent to the furnace for combustion. The heat generated from the incinerator is then used to generate steam to drive a steam turbine generator. The electricity produced is transmitted to the power grid after being increased in pressure, with a portion being used by the factory. The flue gas is subjected to a thorough desulfurization reaction in the tower, where acidic substances react with atomized lime slurry droplets. The resulting flue gas is emitted through chimneys that are 80 to 100 m high. Finally, the ash that is produced is transported to a comprehensive treatment unit for comprehensive utilization. The fly ash is solidified, subjected to leaching toxicity testing, and transported to a safe landfill site using a specialized, sealed transport device after passing the tests (Figure 2).

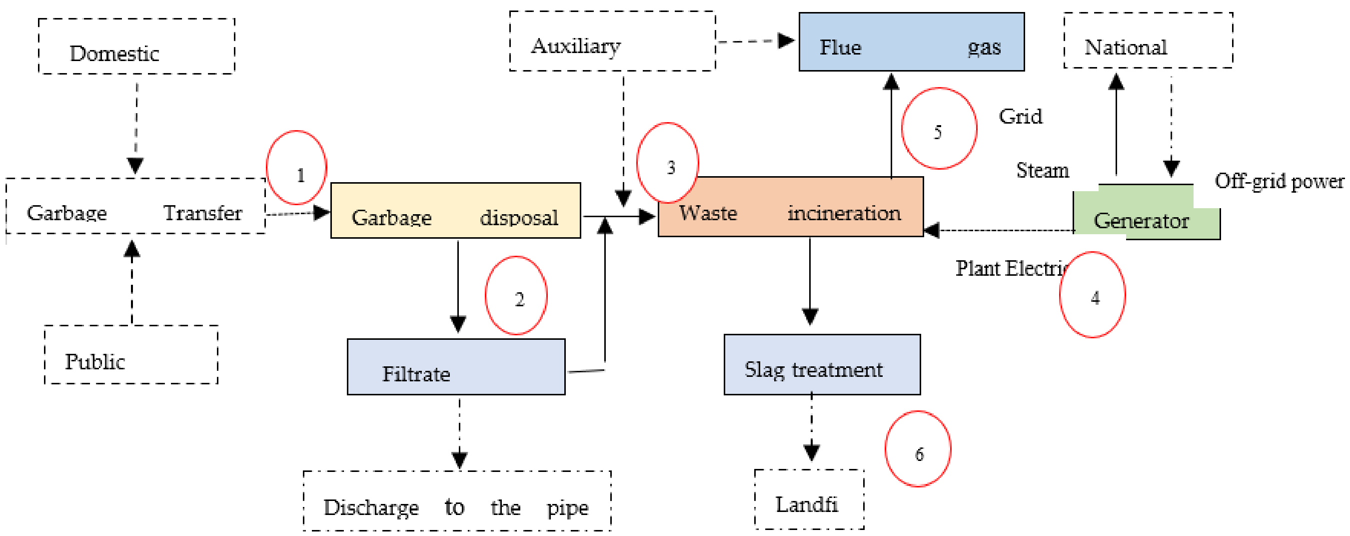

Figure 2. Waste incineration process and the main greenhouse gases produced (source: Green Dynamic Environmental Group Co.).

2.2. Cost–Benefit Analysis

The method of Cost–Benefit Analysis (CBA) is widely used to assess the investment value of a project by evaluating its overall costs and monetary benefits. In this study, the investment cost and benefit situation of a waste-to-energy project are analyzed for each year of the concession period, using a net present value (NPV) analysis in CBA. The sum of the net present value of benefits for each year determines the scale of investment, waste disposal, disposal fee, concession operating period, and other relevant factors.

2.2.1. Sales Revenue

Compared with landfill, waste incineration power generation can transform waste into carbon dioxide and heat energy in a relatively short period of time, which can not only avoid methane emissions in the landfill process but also replace fossil fuels through heat recovery and power generation to reduce greenhouse gas emissions, and it has the double carbon emission reduction effect of "controlling methane emission + replacing power generation". According to the "Carbon Emission Trading Management Rules", domestic waste incineration power generation projects belong to the field that can apply for the issuance of China's certified voluntary emission reductions (CCERs). The revenue from waste incineration power generation mainly comes from three areas: (1) Providing electricity to the national grid and obtaining electricity revenue, which is related to the amount of waste treated, the calorific value of waste combustion, and the feed-in tariff. (2) Waste disposal fees collected from local governments for providing waste incineration services, which are related to the amount of waste disposed of and the price per unit of waste disposed of. (3) Carbon emission reduction CCER revenue, which depends on the amount of carbon emission reduction from waste-to-energy generation and the price in the carbon trading market. Of course, there are some other aspects, such as providing steam services to other enterprises and residents.

2.2.2. Total Cost

The total cost of a waste incineration power generation company over a given period encompasses expenses related to preliminary research, bidding and construction, production, and ongoing operations during waste incineration power generation. The production cost can be further segmented into energy and power expenses, employee salaries and benefits, and maintenance and repair expenses. Period expenses primarily comprise management, financial, and sales expenses.

(1) Energy and power expenses. The enterprise sources its primary raw material, rubbish, from the government sanitation department at no cost. During downtime or maintenance of the incineration power plant, the enterprise depends on the national power grid for electricity to meet production and office use. Circulation water for the cooling tower and drinking water during the production process are sourced from the water supply system. Light diesel is added as an auxiliary and ignition fuel in the combustion process. To meet environmental protection and emission control standards, auxiliary materials, such as activated carbon, lime, chelating agents, and ammonia water, are procured externally to treat the filtrate and purify the flue gas during the treatment of the three wastes.

(2) Employee salaries and benefits. In various stages of waste-to-energy operations, including furnace operation, turbine operation, electrical operation, leachate workshop operation, garbage grab operation, ash crane control room, laboratory technicians, fly ash solidification, and other positions, a certain number of production employees are required. Most labor expenses consist of salaries and benefits.

(3) Maintenance and repair costs. In terms of maintenance and repair costs, the cost of purchasing repair materials and labor fees for routine maintenance and routine significant repairs of structures, machinery and equipment, and dust removal facilities form most expenses. Waste-to-energy facilities that use household waste as raw material require more complex equipment than conventional coal-fired power plants, such as increased dust

treatment equipment and leachate treatment equipment. This leads to higher building prices as well as operation and maintenance expenses.

(4) Management costs. As a BOT project, this project includes fixed assets within its intangible assets category, which are generally amortized using the straight-line technique as management costs over the operational period. Fixed asset depreciation follows the average life technique, with an average depreciation life of 28 years for houses, buildings, and machinery and equipment with no residual value.

(5) Financial expenses. The project's financial expenses are primarily composed of interest payments on loans during the building phase. Typically, waste incineration operations that generate electricity require investments ranging from CNY 300,000 to 500,000 (USD 41,118 to 68,531) per ton of garbage. As most companies require financing from the capital market, the project's constant cash flow after entering the operational period is highly favored by banks and other financial institutions. However, different equity investment ratios and finance costs can significantly impact the project's return rate and net present value.

(6) Sales expenses. Regarding the sales department's position dealing with the electricity department, management staff can handle this role, which can be largely disregarded.

2.2.3. Sales Revenue

The tax liabilities of waste-to-energy enterprises primarily comprise corporate income tax and value-added tax. As per tax and finance policy [2015] No. 78, "Preferential Policy on Value-Added Tax for Certain Comprehensive Utilization of Resources Products", the value-added tax policy "as collected, as refunded" is implemented for waste-to-energy operations, while the policy of "70% as collected, as refunded" is implemented for waste disposal labor. Additionally, a policy of "100% as collected, as refunded" is established for the electricity and heat generated from the incineration of urban household waste.

Based on the above analysis, the NPV of the waste-to-energy enterprise is derived as the following equation:

$$NPV = -I_0 - \frac{I_1}{1+r} + \sum_{t=2}^{n} e^{-rt}[365 \times \eta_t \times Q \times (P_1 + \lambda_2 P_2 + \lambda_3 P_3) - TC_t - Tax_t] \quad (1)$$

The project investment is divided into 2 years, the investment amount in the first year is I_0, the investment amount in the second year is I_1, the market necessary rate of return is r, n is the concession period, Q is the design waste treatment capacity, η_t is the waste capacity utilization rate in the first period, t is the waste capacity utilization rate in the first period, P_1 is the waste treatment price, P_2 is the waste on-grid power tariff, P_3 is the carbon sink price, λ_2 is the waste power feed-in tariff, λ_3 the waste carbon emission reduction, TC_t is the total cost in period t, and Tax_t is the government tax in period t.

When $NPV \geq 0$, the investment plan is accepted, and the larger the value of NPV, the higher the return of the project and the more worthy of investment.

When $NPV < 0$, the investment plan is rejected, implying that the investment project does not achieve the expected rate of return.

3. System Dynamics Modeling

Upon analyzing the factors that impact the net present value of waste incineration power generation production projects, it was observed that there exists a mutual influence between these factors, and their behavior demonstrates nonlinear and dynamic changes. These characteristics render the analysis and testing of the project with general models quite challenging. System dynamics is a quantitative technique that is well suited for investigating complex information feedback systems. It enables the description of the structure and feedback mechanism of the system. Utilizing the fundamental principles of system dynamics, a causal relationship diagram that depicts the price impact can be constructed, and the essential influential elements in the system and their price formation mechanism can be identified. This will serve as a basis for constructing a pricing model.

3.1. Cause-and-Effect Diagrams

According to the process flow and calculation principles of the garbage incineration power generation project (Equation (1)), a causal loop diagram of the net present value of the project is drawn (see Figure 3). The "+" sign indicates that an increase in the data of one variable will result in an increase in the data of another variable, while the "−" sign indicates that an increase in the value of one variable will result in a decrease in the value of another variable.

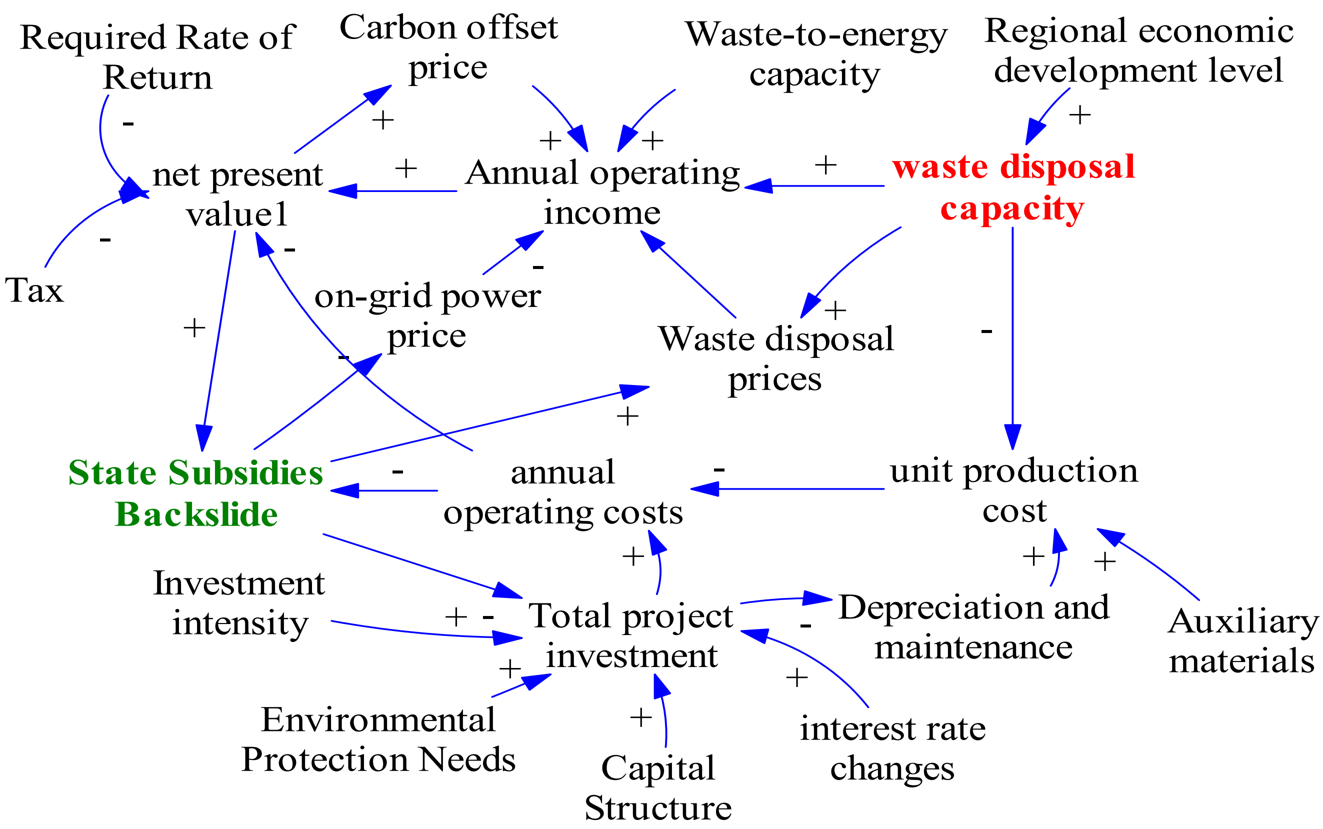

Figure 3. Cost–benefit cause-and-effect cycle of waste-to-energy BOT projects.

From Figure 3, the following four feedback loops can be seen.

(1) Decline in grid electricity price (−) → decrease in yearly operating income (−) → decrease in net present value (−) → increase in garbage disposal price (+) → increase in annual operating income (+) → increase in net present value (+) → decline in grid electricity price.

(2) Decline in grid electricity price (−) → decrease in annual operating income (−) → decrease in net present value (−) → decrease investment intensity or decrease in production cost (−) → increase in net present value (+) → decline in grid electricity price.

(3) Decline in grid electricity price (−) → decrease in annual operating income (−) → decrease in net present value (−) → rise in garbage disposal volume or rise in garbage combustion heat value (+) → increase in annual operating income (+) → increase in net present value (+) → decline in grid electricity price.

(4) Decline in grid electricity price (−) → decrease in annual operating income (−) → decrease in net present value (−) → increase in carbon offset income (+) → increase in annual operating income (+) → increase in net present value (+) → decline in grid electricity price.

Based on a causal feedback analysis, it has been revealed that the net present value of WTE projects is influenced by six key factors: garbage handling capacity, garbage power generation capacity, unit investment intensity, operating costs, grid-connected electricity prices, and carbon offset prices. Of these, the decrease in grid-connected electricity prices, combined with the other five significant factors, creates four price feedback loops, which ultimately determine the level of garbage disposal prices for WTE projects operating under a BOT model.

3.2. Flow and Stock Analysis of System Models

Drawing upon the interdependent relationships and feedback causality diagrams among the variables within the BOT waste incineration power project, as illustrated in Figure 3, the Vensim DDS software is applied to establish a framework of the flow and stock alterations of the impact factors on the net present value in the project, as presented in Figure 4.

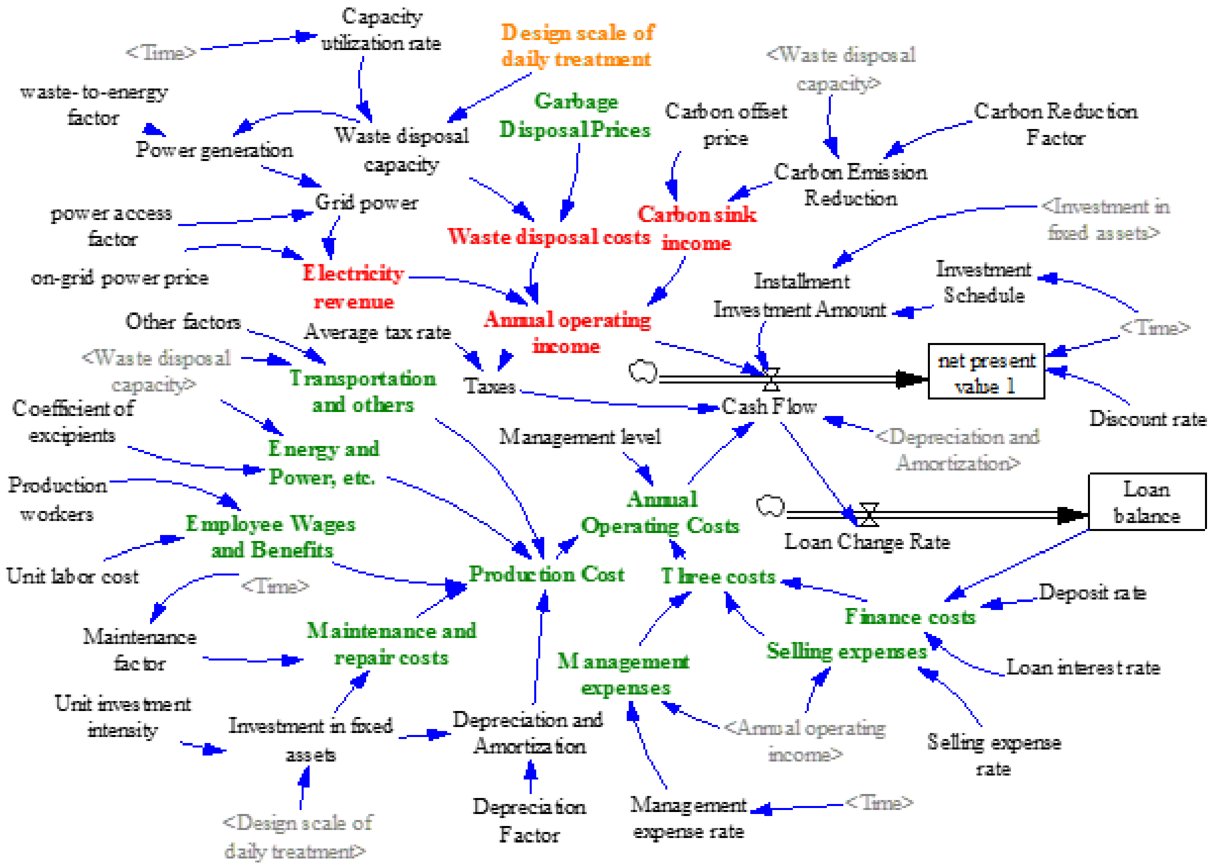

Figure 4. Stock flow diagram of price influencing factors for waste-to-energy BOT projects.

3.3. Construction of Simulation Equations

The inherent value of the system dynamics model lies not in its ability to forecast future outcomes but, rather, in its ability to offer a more comprehensive understanding of the interrelationships among variables within the examined system. Utilizing the flow and stock diagram presented in Figure 4, a system dynamics modeling equation for a garbage incineration power enterprise is developed. In this study, a total of 40 variables, which included 2 state variables, 2 rate variables, 22 auxiliary variables, and 14 constants, were chosen for the model. Detailed descriptions of the specific variable equations and parameters are presented in Tables 1 and 2.

Table 1. System dynamics modeling equations and parameters for the waste-to-energy enterprise.

Variable Type	Variable Name	Units	Equation and Parameters
State variable	Net Present Value(NPV)	million	INTEG (+ cash flow × EXP(−discount rate × Time))
	Loan balance	million	−10,000 + INTEG(−loan change rate)
Rate variable	Cash flow	million	annual operating revenue-annual operating costs-installment investment-taxes-amount of amortized investment + depreciation and amortization
	Loan variation rate	million	Cash flow
Auxiliary variables	Total project investment	million	investment intensity × daily treatment design scale
	Annual waste treatment capacity	10,000 tons	capacity utilization rate × design scale of daily treatment × 365/10,000
	Power generation	million KW	annual waste treatment capacity × waste generation coefficient
	On-grid power	million KW	on-grid coefficient × Power generation capacity
	Annual operating income	million	waste treatment fee income + electricity income + carbon sink income
	Electricity revenue	million	on-grid coefficient × power generation capacity × waste generation coefficient × on-grid tariff
	Garbage disposal fee	million	regional economic development level × waste disposal price × waste disposal volume
	Certified carbon emission reduction (CCER)	million	electricity generation × carbon emission reduction coefficient
	Carbon sink income	million	carbon emission reduction volume × carbon sink price
	Annual operating costs	million	production cost + three costs
	Production costs million	million	employee wages and benefits + maintenance and repair costs + energy and power, etc.
	Employee wages and benefits	million	unit labor cost × production workers garbage disposal volume × auxiliary material coefficient
	Energy and power, etc.	million	waste disposal volume × other factors garbage disposal volume × auxiliary material coefficient
	Transportation and others	million	waste disposal volume × other factors
	Maintenance and repair costs	million	fixed asset investment × maintenance factor
	Taxes	million	sales revenue × average tax rate
	Three expenses	million	management expenses + financial expenses + selling expenses
	Management expenses	million	administrative expense rate × sales revenue + depreciation and amortization
	Selling expenses	million	Selling expense ratio × sales revenue
	Depreciation and amortization	million	investment in fixed assets × depreciation factor
	Finance costs	million	IF THEN ELSE (loan balance < 0,—loan interest rate × loan balance,—deposit interest rate × loan balance)
	Amount of amortized investment	million	investment in fixed assets × investment schedule

To comprehensively comprehend the investment and production data of waste power enterprises of various scales and regions and to minimize the model's prediction error, this study examined the prospectus and financial statements data of five stable waste power enterprises from 2009 to 2021. These enterprises include China Guangdong Environmental Co., Ltd. (Guangdong Environmental), Green Dynamic Environmental Group Co., Ltd. (Green Dynamic), Zhejiang Weiming Environmental Protection Co., Ltd. (Weiming Environmental), Chongqing Sanfeng Environmental Group Co., Ltd. (Sanfeng Environmental), Fujian Shengyuan Environmental Protection Co., Ltd. (Shengyuan Environmental), and 2021 on-site survey data from Guangda Environmental Energy (Yingtan) Co., Ltd. The data were screened and averaged to obtain 14 initial constants, which are presented in Table 2.

Table 2. Main technical parameters of waste-to-energy projects.

Variable	Unit	Parameter	Description
Waste CO_2 emission reduction		0.35	IPCC Guidelines 2006, Polaris Power Network (https://www.bjx.com.cn/, 12 May 2019)
Unit waste-to-energy		350	Polaris Environmental Protection Network (https://huanbao.bjx.com.cn/special/?id=913209, 22 August 2019), Shengyuan Environmental Protection
Investment intensity	million/t (USD)	5.49	Based on data published across China
Power generation grid access rate	%	80	Shengyuan Environmental Protection Co., Ltd., Green Dynamic Environmental Group Co., Ltd. Prospectus
Production employees	person	50	Guangda Environmental Energy (Yingtan) Co., Ltd.
Employee wages and benefits	million/person (USD)	1.37	Based on the average of each enterprise
Depreciation rate of fixed assets	%	3.571	Depreciated on an average straight-line basis over 28 years
Coefficient of auxiliary materials	USD/t	2.74	Shengyuan Environmental Protection Co., Ltd., Green Dynamic Environmental Group Co., Ltd. Prospectus
Other coefficients	USD/t	2.06	Shengyuan Environmental Protection Co., Ltd., Green Dynamic Environmental Group Co., Ltd. Prospectus
Financing rate	%	6	Average of financing of various waste-to-energy companies
Overhead rate	%	3.5	Ratio to sales revenue
Selling fee rate	%	0	Shengyuan Environmental Protection Co., Ltd.
Deposit rate	%	3	
Average tax rate	%	3	Shengyuan Environmental Protection Co., Ltd., Green Dynamic Environmental Group Co., Ltd. Financial Annual Report

4. Model Simulation and Analysis of Results

4.1. Scenario Assumption

The present study sets up a simulated project in a metropolis that has a population of approximately 5 million individuals situated in the central region. The waste disposal scale of the project is 1000 t/d, and the production process employs a mature furnace-range furnace incineration power generation technology. The project comprises two incineration lines, each with a capacity of 500 t/d, and is equipped with 15 + 9 MW condensing steam turbine generator units. The annual generation time for the project is roughly 7500 h. Innovative technologies such as "semi-dry technique + activated carbon injection + bag dust removal" are used for flue gas treatment. The total investment required for the project is approximately CNY 400 million (USD 548,248), where the construction engineering expenses account for around 25%, equipment and installation engineering costs account for about 55%, and other expenses make up the remaining 20%. The project complies with the national requirement of no less than 20% self-owned capital, and the financing source is obtained through bank financing of CNY 300 million (USD 411,186) at an annual interest rate of 6% for a loan term of 2 years. The franchising operation for the project is 30 years, and the project will reach 100% of its designed capacity in the third year. Further fundamental technical parameters can be found in Table 3.

Table 3. Test of simulated and actual values for projects of different treatment sizes (2018).

Details	Unit	Nan'an Shengyuan		Jiangsu Shengyuan	
		Simulated Value	**Actual Value**	**Simulated Value**	**Actual Value**
Installed capacity of power generation	MW	30	30	15	15
Daily treatment capacity	ton	1300	1300	1000	1000
Investment amount	Million (USD)	6239.10	5285.27	4799.31	4583.20
Grid power	million/kw	13,312	14,016	10,220	11,756
Average grid power price	USD	0.09	0.08	0.09	0.08
Revenue from electricity sales	Million (USD)	1186.53	1073.54	910.91	671.77
Waste treatment capacity	10,000 tons	47.45	53.49	36.5	44.01
Capacity utilization rate	%	100%	108%	100%	
Waste treatment price	USD/ton	7.95	8.91	7.95	7.40
Waste treatment fee	Million (USD)	377.36	477.19	290.30	267.94
Annual operating income	Million (USD)	1560.87	1550.72	1201.20	939.84
Depreciation and amortization	Million (USD)	222.69	186.62	171.27	168.25
Labour costs	Million (USD)	106.96	109.42	82.27	77.61
Energy and power	Million (USD)	162.63	170.58	125.06	109.01
Transportation and others	Million (USD)	65.13	59.65	50.05	85.43
Maintenance and repair	Million (USD)	124.78	126.02	95.99	101.20
Cost of main business	Million (USD)	682.19	652.43	524.77	542.05

4.2. Pricing Simulation

Utilizing the system dynamics modeling equation (Table 1), the key technical parameters (Table 2), and the flowchart of an existing waste incineration power-generating project (Figure 4), the model was simulated.

The results indicate that a daily processing scale of 1000 t/d, with a unit investment intensity of 400,000 CNY/t (54,824.8 USD/t), a required return on investment of 8%, a franchise operating time of 30 years, a waste on-grid electricity price of 0.65 CNY/kW (0.0891 USD/kW), a carbon offset price of 0, a waste power generation of 350 kW/t, and a grid-connected rate of 80%, yields a calculated waste disposal price of approximately 76 CNY/t (10.42 USD/t).

However, data from more than 10 waste power generation projects, based on the prospectus released by Shengyuan Environmental Protection Co., Ltd. in 2020, suggest that the total investment for a daily processing scale of 1000 t is approximately CNY 36,000 million (USD 49,342,320), with a unit investment intensity ranging from 300,000 to 360,000 CNY/t (41,118.6–49,342 USD/t), which is CNY 4000 million (USD 548,248) less than the theoretical value. The model recalculates a waste disposal price of 58 CNY/t (7.95 USD/t) under the same conditions. If the daily waste processing volume in newly established projects cannot reach the design standard for capacity utilization and cannot fully subsidize the grid-connected electricity, a reasonable waste disposal price of 65–75 CNY/t (8.90–10.28 USD/t) is expected in the first five years. This aligns with the conclusion of 65 CNY/t (8.90 USD/t) calculated by E20 Research Institute and Bain and Company Enterprise Consulting (China) Co., Ltd. for domestic waste incineration power generation projects. Additional details can be found in Table 4.

Table 4. Measure of state subsidy withdrawal on waste disposal fee.

	Benchmark	Pessimistic	Neutral	Optimistic
Unit investment intensity (million/t)	36	36	36	36
Waste generation coefficient (kw/t)	350	350	350	350
Average grid power price (USD/kw)	0.09	0.05	0.07	0.09
Unit price of waste treatment (USD/t)	7.95	17.55	13.71	9.87
Impact of each 0.1-USD downward adjustment on waste treatment price		−3.84		

The comparison between the simulated and actual revenue and cost values of garbage power generation projects presented in Table 4 reveals a high level of consistency between the results obtained from the system dynamics-based decision-making model and the empirical data. This finding attests to the soundness and feasibility of the pricing model developed in this study and its ability to facilitate the evaluation of the effects of policy mechanisms on the benefits of garbage incineration power generation companies in the context of grid-connected electricity price subsidies.

4.3. Analysis of the Impacts of National Subsidy Reduction on Waste Treatment Fees

Three potential options for decreasing the grid electricity price subsidies are identified in the waste management sector, namely, modifying the benchmark electricity price, altering national subsidies to provincial subsidies, or addressing the treatment fee via market means. To evaluate the impacts of these options, a study was conducted considering a benchmark of CNY 360,000 (USD 49,342) per unit investment intensity per ton and a waste power generation coefficient of 350 kW/t. Three scenarios were analyzed, including a pessimistic scenario, where subsidies are removed and treatment fees are resolved by the market, a neutral scenario with provincial subsidies of CNY 0.1 (USD 0.01), and an optimistic scenario with an average electricity price of CNY 0.6 (USD 0.08). The outcomes of these scenarios are presented in Table 5.

Table 5. Multi-factor sensitivity analysis of waste treatment fee for waste-to-energy projects.

Original Assumptions and Changes	Investment Intensity		Capacity Utilization Rate		Waste Generation Factor		Carbon Sink Income	
	Numerical Value (USD)	Waste Price (USD)	Numerical Value	Waste Price (USD)	Numerical Value (USD)	Waste Price (USD)	Numerical Value (USD)	Waste Price (USD)
Improvement of 30%	3.84	4.39	130%	8.50	62.39	5.48	8.91	10.97
Improvement of 20%	4.39	6.86	120%	9.60	57.59	7.68	8.22	11.24
Improvement of 10%	4.94	9.32	110%	10.70	52.79	9.74	7.54	11.51
Original assumptions	5.48	11.80	100%	11.72	47.99	11.72	6.85	11.79
Deterioration of 10%	6.03	14.26	90%	12.89	43.19	13.85	6.17	12.06
Deterioration of 20%	6.58	16.73	80%	13.99	38.39	15.91	5.48	12.34
Deterioration of 30%	7.13	19.20	70%	15.08	33.60	17.96	4.80	12.62
Elasticity	−2.74		−1.10		−2.06		−0.27	

Note: Capacity utilization rate refers to the first 10 years, and the last 20 years are produced according to the original design.

Based on the results presented in Table 5 and under certain assumptions, such as a benchmark loan rate of 6%, a required return on investment of 8%, a unit investment intensity of CNY 350,000 (USD 47,971.7) per ton, and a waste-to-energy ratio of 350 kW per ton, it is observed that the household waste treatment price is approximately CNY 128 per ton when the grid-connected electricity price subsidies are canceled, leading to a reduction in the grid-connected electricity price to 0.40 CNY/kw (0.05 USD/kw). In contrast, when only the provincial subsidies are set at CNY 0.1 (0.01 USD) and the grid-connected electricity price is reduced to 0.50 CNY/kw (0.69 USD/kw), the household waste treatment price is CNY 100 per ton. Furthermore, if the current 15-year subsidies are maintained, resulting in an increase in the average grid-connected electricity price to 0.60 CNY/kw (0.08 USD/kw), the household waste treatment price decreases to CNY 72 (USD 9.87) per ton. The observed elasticity of the household waste treatment price to the grid-connected electricity price is approximately −280, indicating that a decrease of CNY 0.1 (USD 0.01) per unit of grid-connected electricity price results in an increase of CNY 28 (USD 3.84) in the household waste treatment fee.

4.4. Sensitivity Analysis of Other Factors on Waste Disposal Costs

In this study, we conducted an analysis to investigate the influence of investment amount, utilization rate, production cost, and carbon credit price on waste disposal fees, under the conditions of a unit investment intensity of 400,000 CNY/t (54,824.8 USD/t), a waste-to-energy conversion factor of 350 kw/t, a utilization rate of 100%, a production cost of 130 CNY/t (17.82 USD/t), a carbon credit price of 50 CNY/t (6.85 USD/t), and an average grid electricity price of 0.55 CNY/kw (0.08 USD/kw). The results of this analysis are presented in Table 6.

Table 6. Comprehensive regulation scheme of state subsidy backslides.

	Basic Scenario	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Average grid power price (USD/kw)	0.08	0.07	0.07	0.05	0.05
Unit investment intensity (million/t)	40	34	34	32	36
Waste-to-energy coefficient (kw/t)	350	385	350	385	385
Capacity utilization rate	100%	100%	110%	110%	100%
CCER price	0	0	0	0	100
Unit price of waste treatment (USD/t)	10.42	10.42	10.28	9.87	9.74

Based on the calculations presented in Table 6, we observe that various factors impact the waste disposal fees for a scenario with a unit investment intensity of 400,000 CNY/t (54,824.8 USD/t), a waste-to-energy conversion factor of 350 kw/t, a utilization rate of 100%, a production cost of 130 CNY/t (17.82 USD/t), a carbon credit price of 50 CNY/t (6.85 USD/t), and an average grid electricity price of 0.55 CNY/kw. Our findings indicate that a 10% decrease in unit investment intensity can lead to a CNY 18 (USD 2.47) reduction in the waste disposal fee, while a 10% increase in the capacity utilization rate can lower the fee by CNY 8. A 10% increase in the waste-to-energy conversion ratio results in a CNY 15 (USD 2.06) reduction in the waste disposal fee, and a 10% increase in the carbon credit price can reduce the fee by CNY 2 (USD 0.27). Given that the current overseas price of carbon credits is higher than the domestic price, there is potential for future growth. Specifically, a 100% increase in the carbon credit price can reduce the waste disposal fee by CNY 20 (USD 2.74). Therefore, the factors that influence waste disposal prices can be ordered as follows: carbon credit price > investment intensity > waste-to-energy conversion ratio > capacity utilization rate.

4.5. Measurement of the Cost of Waste Treatment through Integrated Regulation

Considering the aforementioned factors and their elastic impact on the waste disposal price, this study proposes four comprehensive regulatory measures to address the elimination of online power price subsidies.

Plan 1 entails reducing the unit investment intensity and increasing the garbage power generation coefficient through garbage classification to offset the impact caused by the decrease in the online electricity price when the national subsidy is completely canceled.

Plan 2 suggests mitigating the impact of the fall in the online energy price by decreasing the unit investment intensity and improving the capacity utilization rate under the same condition.

Plan 3 involves reducing the unit investment intensity, increasing the garbage power generation coefficient, and improving the utilization rate of capacity when all subsidies are canceled to offset the impact caused by the decrease in the online electricity price.

Plan 4, on the other hand, proposes a reduction in the unit investment intensity and garbage power generation coefficient while relying on the sale of carbon emission rights to offset the impact of online electricity price subsidy cancellation as carbon neutralization continues to develop. Detailed information on these plans is presented in Table 6.

5. Concluding Remarks and Suggestions

This study is centered on the income and cost structure of waste-to-energy incineration projects and employs Vensim PLE software to construct a dynamic net present value model for BOT (Build–Operate–Transfer) waste-to-energy incineration projects based on a causal relationship analysis of the factors impacting net present value. The model's reliability is evaluated through the use of financial data from publicly traded waste-to-energy businesses and case studies of BOT projects investigated by the researcher. Subsequently, the model is subjected to simulation and sensitivity analyses.

5.1. Conclusions

(1) For a waste incineration power generation project with a daily processing capacity of 1000 t, the required rate of return on investment is 8%, and the operating time is set at 30 years. Other parameters include a waste-to-energy conversion factor of 350 kw/t, a utilization rate of 100%, and an on-grid rate of 80%. Under these conditions, the price of waste to energy is 0.65 CNY/kw (0.09 USD/kw), and the carbon offset price is assumed to be zero. The calculated price of household waste disposal is 76 CNY/t (10.42 USD/t) at a unit investment intensity of 360,000 CNY/t (49,342.3 USD/t) and 58 CNY/t (7.95 USD/t) at a unit investment intensity of 360,000 CNY/t (49,342.3 USD/t)

(2) A reduction of CNY 0.1 (USD 0.01) per kilowatt hour in the on-grid price corresponds to an approximate increase of CNY 28 (USD 3.84) in the price of household waste disposal. When the on-grid power price subsidy is completely canceled, and the on-grid power price is lowered to 0.40 yuan/kw, the price of household waste disposal is expected to increase to 128 yuan/t (17.54 USD/t). If the national subsidy is canceled and only the provincial subsidy of CNY 0.1 is applied, the on-grid power price should be lowered to 0.50 CNY/kw (0.07 USD/kw) to maintain the price of household waste disposal at 100 CNY/t (13.71 USD/t). Conversely, if the current 15-year subsidy is maintained, and the on-grid power price is raised to 0.60 CNY/kw (0.08 USD/kw). The price of household waste disposal is expected to decrease to 72 CNY/t (9.87 USD/t).

(3) Based on the results, reducing the unit investment intensity by 10% can lead to a CNY 18 reduction in waste disposal fees, while increasing the capacity utilization rate by 10% can reduce waste disposal fees by CNY 8 (USD 1.10). Similarly, increasing the waste-to-energy coefficient by 10% can reduce waste disposal fees by CNY 15 (USD 2.06), while increasing the price of carbon sink by 100% can reduce waste disposal fees by CNY 20 (USD 2.74). The order of waste disposal cost components is as follows: price of carbon sink > investment intensity > waste-to-energy coefficient > capacity utilization rate.

(4) The study suggests that subsidies and reductions at the national level do not necessarily result in adjustments to waste disposal fees. Instead, risk-sharing principles should be followed, and changes in electric price subsidies should be offset by increasing carbon sink revenue, reducing investment intensity through technological progress, increasing the waste-to-energy coefficient through waste classification, and increasing the capacity utilization rate by processing various types of waste.

5.2. Recommendations

(1) Initiating the verification process for the issuance of Certified Emission Reductions (CCERs) at the earliest opportunity is imperative. With a carbon trading price of CNY 50 (USD 6.85), the revenue gained through CCER trading for every ton of garbage converted

by the enterprise is approximately CNY 20 (USD 2.74). The implementation of the CCER mechanism will significantly mitigate the negative impact of the government's subsidy reduction. Therefore, it is recommended that the verification process for CCERs and waste-to-energy CCER projects commences promptly.

(2) Emphasis should be placed on scientific design and industrial coordination. Adequate preliminary research and extensive planning should be conducted to select a suitable site for the waste-to-energy plant. Furthermore, efficient waste heat utilization, processing of different waste types, and high parameter combination technology should be adopted to reduce the unit investment intensity.

(3) It is beneficial for waste-to-energy enterprises to reduce production costs through technological innovation and strengthened operation management while extending their non-core business activities. They can rely on the main business of waste incineration power generation and carry out heat supply and steam supply business in the park at the same time to increase other incomes.

(4) Managing carbon assets to lower financing costs is a viable option for enterprises. As carbon assets can be traded on the carbon market, this allows for the creation of various financing tools, such as carbon bonds, quota pledge loans, and repurchase financing, etc. By leveraging these financing instruments, enterprises can obtain green financial credit and minimize their loan interest rates.

Author Contributions: Conceptualization, H.-G.W.; Software, H.R.; Formal analysis, H.R.; Investigation, H.R.; Resources, H.-G.W.; Writing—original draft, H.-G.W. All authors have read and agreed to the published version of the manuscript.

Funding: This study belongs to the Jiangxi Provincial Social Science Planning Project with project number 22GL11, and is funded by the National Natural Science Foundation of China with project numbers 71963018 and 71663030.

Institutional Review Board Statement: Not applicable. This article does not involve any ethical research.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data sources that can currently be displayed have been annotated in this article, including links to the Chinese government's official website and enterprise data sources. The remaining data is due to government and corporate data privacy regulations, it is not possible to disclose this data. However, we will supply the relevant data in response to reasonable requests If necessary.

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

References

1. Petersen, O.H. Public-private Partnerships as Converging or Diverging Trends in Public Management? A Comparative Analysis of PPP policy and Regulation in Denmark and Ireland. *Int. Public Manag. Rev.* **2011**, *12*, 11–37.
2. Liao, Z.; Jia, L.; Luo, J. On the Survey of Public-Private Partnerships—A Literature Review. *Financ. Econ.* **2018**, 80–92.
3. Yu, W.; Sector, F.S. China's PPP projects:Status Quo and Problems. *J. Shanghai Univ. (Soc. Sci. Ed.)* **2017**, *34*, 94–105. [CrossRef]
4. Zhang, Y.; Sun, Y.; Fu, Y.; Lu, D. Research on preparation of budget standard for quasipublic goods project—A case study of budget quota for collection, transportation and treatment of domestic waste in a city. *Ref. Econ. Res.* **2015**, 48–56.
5. Song, J.B.; Song, D.R.; Tan, C.M. A Decision-Making Model of Concession Period for Refuse-Incineration Power Generation BOT Projects. *Chin. J. Manag. Sci.* **2013**, *21*, 86–93.
6. Song, J.; Song, D.; Fu, Y. System dynamics model for the benefit of waste-to-energy incineration BOT project. *Manag. Rev.* **2015**, *27*, 67–74.
7. Zhikun, Z.; Guangtian, S. Study on method of estimating power generation during operation for a BOT project of refuse-incineration power generation. *Heilongjiang Electr. Power* **2008**, 125–127. [CrossRef]
8. Su-Dong, Y.E. Payment Mechanisms for BOT Project of Municipal Solid Waste Incineration Power Plants in China. *J. Beijing Jiaotong Univ. (Soc. Sci. Ed.)* **2014**, *13*, 25–30+74.
9. Ke-Jing, F.; Zu-Hong, X.; Min, L.U.; Fang-Hua, G.; Ji-Qing, L. System Dynamics Model for Economic Analysis of Waste Incineration Power Plant Based on LCA. *Adv. New Renew. Energy* **2017**, *5*, 365–370.
10. Wenxiong, H.; Wenlong, X.; Zhiyun, Q.; Song, Y.U. Price Component and Adjustment Mechanism of BOT Projects for Waste Incineration-power Generation. *Environ. Sanit. Eng.* **2011**, *19*, 1–4.

11. Shi, S.; Ye, X.; Zhang, D.; Liu, L. The influence of capital structure on the value stability of PPP projects: A case study of waste incineration power generation projects. *J. Financ. Account.* **2020**, 21–27. [CrossRef]
12. Wu, F.; Wang, Z. Environmental income measurement based on material flow cost accounting: A case study of solid waste incineration power plant in HY City. *Financ. Account. Mon.* **2018**, 91–97. [CrossRef]
13. Chunling, S.; Fei, R.; Mengxiao, Z. System Dynamic Analysis on Revenue for PPP Projects: A Case of Gas Projects. *Forum Sci. Technol. China* **2016**, 131–137. [CrossRef]
14. Yu, Y.; Zhao, R.; Huang, Y.; Yang, L. An Evolutionary Game Theoretical Analysis to Conflicts among Stakeholders Involved in the Operation of Municipal Waste Incineration. *Complexity* **2020**, *2020*, 8825284. [CrossRef]
15. Lam, H.L.; Ng, W.P.; Ng, R.T.; Ng, E.H.; Aziz, M.K.A.; Ng, D.K. Green strategy for sustainable waste-to-energy supply chain. *Energy* **2013**, *57*, 4–16. [CrossRef]
16. Fu, X.; Zhou, Y.; Sun, H.; Wang, Y. Park-level agricultural energy internet: Concept, characteristic and applicationvalue. *Trans. Chin. Soc. Agric. Eng. (Trans. CSAE)* **2020**, *36*, 152–161, (In Chinese with English abstract).
17. Sharma, S.; Basu, S.; Shetti, N.P.; Aminabhavi, T.M. Waste-to-energy nexus for circular economy and environmental protection: Recent trends in hydrogen energy. *Sci. Total Environ.* **2020**, *713*, 136633.