

Article

A System Dynamics Model to Assess the Effectiveness of Governmental Support Policies for Renewable Electricity

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Abstract: China's support policy for renewable electricity belongs to a feed-in tariffs scheme. With the rapid development of renewable electricity industries, this set of policies brought about a heavy fiscal burden for the government. The exploration of whether current support policy provided excessive subsidies for renewable electricity is of great practical significance. We hold an idea that the internalization of positive externality is the only criterion for the government to support the development of a renewable electricity industry. The problem of whether the current policy provides excessive subsidies for renewable electricity industry can be solved by assessing whether its positive externality is internalized, as renewable electricity industry has a characteristic of externality. Our study object is an assumed biomass power plant in Jingning County, Gansu Province. A system dynamics model was built. Applying the environmental cost accounting method and net present value analysis method, we connected the techno-economic analysis of the biomass power plant with the measurement of positive externality of biomass power generation together. In this system dynamics model, we developed an indicator to reveal whether the subsidies provided by governmental policies can compensate the positive externality generated by the assumed biomass power plant. This study mainly draws the following conclusions: Firstly, China's current support policy does provide excessive subsidies for the renewable power industry. The subsidies received by biomass power plants from the government are higher than the positive externality generated by them; secondly, the positive externality measurement of the biomass power industry is influenced by many regional factors; thirdly, without governmental policy support, biomass power plants cannot compete with traditional power companies; fourthly, as biomass power generation is concerned, the current price subsidy intensity is about US\$0.0132 higher per kWh than a reasonable level. Furthermore, the parameters frequently applied in the calculation of the prices of pollutant emission reduction in Chinese research papers are relatively small, which is only half of their actual values. Jingning County, situated in inland west-northern China, lacks typicality. There is a limitation in judging whether the government's support policy for renewable electricity is reasonable through a feasibility analysis of investment in a biomass power generation project. This may be the main drawback of this study.

Keywords: biomass power generation; positive externalities; support policy; apple branches; Jingning

1. Introduction

1.1. Background and Literature Review

In order to expand the market share of renewable electricity, many countries in the world have implemented policies to encourage the development of renewable energy industries [1,2]. Price-based feed-in tariff (FIT) and market-based renewable portfolio standards (RPSs) schemes are the two most frequently-used support schemes [3,4]. Countries which have implemented FIT schemes include Germany, Denmark, and Spain; they set fixed prices or a price premium over the market price of electricity for a specified time period [5]. The RPS scheme is represented by the UK, the US, and Australia, which require electricity producers to acquire a certain percentage of renewable electricity. Tradable green certificates (TGCs) are issued for all renewable electricity produced.

At present, renewable electricity production in China is supported by the FIT scheme. Under this scheme, the installed renewable energy capacity has significantly increased. The portion of the FIT higher than the market price coming from the Renewable Energy Development Fund (introduced by the government) has created a great financial burden on the government [6]. According to the relevant research, the financial gap of the Renewable Energy Development Fund had reached US\$18.13 billion by 2018 [7].

According to the Chinese government plan [8], China's renewable energy policy will ultimately transform from an FIT scheme to an RPS scheme, which means that the subsidy funds that renewable electricity producers had received from the government before will mainly come from the TGC market in the future.

It is known that the reason that the FIT scheme for renewable energy has brought a heavy fiscal burden on to China's government is the higher subsidy intensity. Thus, a question has arisen: What kind of subsidy intensity is rational?

The current theoretical research related to the FIT focuses on assessing its effectiveness. Scholars have usually discussed effectiveness from the aspects of social welfare, technological innovation, and installation growth of renewable energy [9]. Scholars have seldom paid attention to the rationality and accuracy of the FIT subsidy intensity.

Compared with traditional fossil energy, renewable energy is conducive to environmental protection and resource conservation—namely, it has positive externalities. Positive externality refers to the beneficial effects of economic activities of one economic entity on other economic entities; the recipients of positive externalities do not need to pay any cost [10]. The internalization of positive externality transforms the external benefits generated by the positive externality maker into private benefits of the positive externality maker in different ways [11]. It can solve the social optimal supply shortage caused by a lack of incentives, thus overcoming the efficiency loss caused by positive externalities and re-achieving the Pareto optimality [10]. Compared with traditional power, renewable electricity has positive externalities. It can increase social benefits and reduce pollutant emissions. According to the principle of modern economics, there is a phenomenon of insufficient resource allocation in industries with positive externalities. The internalization of positive externalities is the fundamental way to solve this type of problem. That the government formulates policies to support the development of renewable electricity is a form of the internalization of positive externality.

The positive externality of renewable electricity is the main reason why the government provides a subsidy to encourage its development. Biomass power generation is a classic type of renewable energy, for convenience, we take it as an example to demonstrate our research route.

Generally speaking, biomass power generation can be viewed as a type of agricultural circular economy [12]. The question of how to scientifically determine the subsidy intensity of biomass power generation is equivalent to the question of how to regulate the development of a circular economy accurately.

A circular economy has obvious positive externalities [13,14]. Despite the academic disagreement over the impact of the development of a recycling economy on the performance of a business, most

scholars approve of the viewpoint that the development of a circular economy needs the support of the government [15,16]. Many countries have begun to pay more attention to the role of the circular economy in achieving sustainable development [17,18].

The internalization of externalities is an effective way to promote the sustainable development of industries with external characteristics. Therefore, whether the externalities have been compensated for can provide a reference standard for evaluating the effect of regional transformation from a traditional economy to a circular economy, and can provide a quantitative standard for evaluating the developmental performance of a regional circular economy, as long as the externality of the circular economy can be monetized. After decades of attempts, scholars have successfully established a method for an environmental economic loss assessment, based on the market value approach; although the assessment of environmental losses is a very difficult problem [11,19]. The application of environmental loss assessment techniques and methods has led to the development of relevant empirical studies [20,21]. Research on the measurement of economic losses caused by environmental pollution in China has also achieved rich results [22,23].

At present, scholars in the field of environmental management have studied the rationality and optimization of industrial policies from the perspective of the quantitative measurement of externalities [24,25]. For example, Ding et al. (2008) [26] proposed a reverse logistics investment valuation model to calculate the number of subsidies the government needs in order to provide theoretical guidance and a decision-making basis for the government to regulate and control an enterprise's investment in environmental protection projects or technologies through the implementation of incentive policies. Ding et al. (2014) [13] built a quantitative assessment model of the internalization of externalities with a life cycle assessment and net present value analysis to explore the reasonable subsidy space and promote the development of new energy vehicles.

Relatively speaking, there have been few achievements in the study of the internalization of externalities from the perspective of green products or enterprises. This type of study is in its infancy.

Present studies have paid attention to the negative environmental externalities of economic activities, while few scholars have focused on the positive externalities of a circular economy in the social and environmental fields.

China supports the development of a circular economy, but its support for a circular economy lacks a scientific standard of judgment [9]. In the field of biomass power generation, China has formulated detailed supportive policies, including tax breaks and price subsidies. However, whether the government's support policy for biomass power generation is reasonable is a problem to which few scholars have paid close attention.

1.2. Comprehensive Utilization of Agricultural By-Products

An important component of the development of an agricultural circular economy is to comprehensively utilize agricultural by-products. According to estimates, the dry weight of apple tree branches pruned per hectare ranges from 2.4 to 6.6 tons every year [27,28]. For primary apple production areas, an apple tree branch is an important type of agricultural by-product; the total production of apple tree branches is quite substantial, and has considerable potential utilization value. However, in practice, the resource utilization of apple tree branches has not caught people's attention. Currently, apple tree branches are used mainly as firewood for cooking or heating (as is the case for straw, also), which not only produces waste but also pollutes the environment. In some apple production areas, apple tree branches are smashed and bagged to produce edible fungus [29,30]. Few apple production regions use apple tree branches as feedstock for biomass power generation. These regions are apt to obtain a type of clean energy named biogas, by building methane-generating pits and constructing an industrial circular economy chain, named "grass-livestock-biogas-fruit," centered on biogas [31,32]. In rural areas, biogas is an important kind of clean energy, which generally uses livestock excrement as feedstock. This is the reason why the development of biogas utilization typically accompanies the development of livestock breeding industries. The sustainable utilization

of biogas cannot be separated from livestock excrement (having a high heating value) as the fill for a methane-generating pit. Both apple orchard management and livestock breeding belong to a labor-intensive industry; however, it is difficult for an orchard operator to undertake the dual work of both managing orchards and caring for livestock, as rural labor is insufficient when viewed against the backdrop of rapid urbanization. For instance, the areas of apple tree cultivation in Jingning County of the Gansu Province account for 68.7% of the total area of arable lands, reaching 707 km² in 2016, which was the largest area of such cultivation in China [33]. The agricultural distribution pattern in Jingning County is divided into the south, mainly the apple orchard industry, and the north, which is primarily the grain growing industry [34]. In the southern part of the county, most farmed arable lands are used to plant apple trees, and it is difficult for the owners of livestock to breed livestock due to the lack of crop straw as fodder. There are almost no large livestock operations among the local fruit farming communities.

In 2015, we conducted a questionnaire survey of over 500 local fruit farmers. The results indicated that 66.5% of the households of the respondents did not breed any large livestock, such as pigs, cattle, and sheep; 32% of them had methane-generating pits; and 40% of the respondents thought that the main factor that hampered the improvement of biogas utilization efficiency was the lack of feedstock with a high heating value, such as cattle excrement. The survey results are in accordance with the research conclusions of local scholars. For example, Wang and Yan (2015) pointed out that, with an increase in the number of rural migrant farmers who had left for urban jobs, rural areas were dominated by the remaining elders and children, with a lack of skilled young and post-adolescent laborers. Meanwhile, with the promotion of industrial products, such as electric cookers in rural areas, the advantage of biogas in cooking has continuously weakened, and most people have begun to ignore the management and maintenance required for methane-generating pits. Thus, the utilization rate of biogas has decreased yearly [35].

In summary, there are two aspects to the problem of comprehensive utilization of agricultural by-products in the main apple tree production areas. On the one hand, influenced by many factors (such as insufficient manpower), small-scale livestock breeding and management are out of place, and the utilization rate of methane-generating pits is low. Enthusiasm for the building of new methane-generating pits is not high, and the circular economy model of “grass-livestock-biogas-fruit” does not work well in primary apple production areas. On the other hand, affected by traditional habits and development concepts, a large number of apple tree branches are treated as firewood and are burned directly for heating and cooking, which wastes resources and contaminates the environment.

This study explores the feasibility of generating power using apple tree branches as fuel inputs to replace biogas in the primary apple production areas using a case study in Jingning County, Gansu Province. We analyze the economic and environmental benefits, in order to provide theoretical guidance for the promotion of a circular economy model of “apple-biomass power generation-organic fertilizer” in the primary apple production areas and evaluate the reasonableness of the governmental support policy, based on an assessment of the positive externality of biomass power generation. Meanwhile, this study also builds a dynamic system model which can help to ascertain more accurately the subsidy intensity conducive to improving the efficiency of governmental support policies for the development of industries with positive externalities.

1.3. Basic Conditions of Jingning County

Located in the northern latitudes 35°01′~35°45′ and eastern longitudes 105°20′~105°05′, Jingning County belongs to a typical hilly-gully area in the Loess Plateau and is one of 18 arid counties in the central Gansu Province with an annual rainfall of only 423.6 mm. The total population of Jingning County is 48.78 million, and it has an arable land area of approximately 98,000 hm², where 93% of the ploughed land is located on the slope of a hill or ditch [36]. Jingning County has 22.4 million poor people in rural areas. The poverty rate, which is the proportion of poor people to all people in the rural areas, reached 59.6% in 1986 [37]. Based on the concept of poverty alleviation through agricultural

industrialization, Jingning County's poverty alleviation plan prioritized the development of apple cultivation supplemented by grain planting from 1986 to 2002, and the county gradually formed a spatial production pattern of "north grain and south apple" [34]. As of 2015, the total area of apple orchards in the entire county reached 707 km² (of which, fruiting orchards accounted for nearly 50%), the total weight of apple products reached 0.6 million tons, and the total earnings reached US\$0.3778 billion. The income from apple sales accounts for 80% of the rural per capita net income in Jingning County. By 2018, the poverty rate in Jingning County had dropped to 13.32% [38].

The samples of apple tree branches used in this study, which cover the main apple varieties in Jingning County, were collected from the towns of Chengchuan and Weirong. All samples were first dried and smashed, and then the heating values of the dry weights were measured through a microcomputer oxygen bomb calorimeter. The measurement process of every sample was repeated three times. The ash content was measured with a dry ash method. The ash-free heating value equals the heating value of dry weight/(1-ash content). The mathematical analysis adopted the *t*-test. Compared with crop straw and other high-energy plants, apple tree branches have obvious advantages with regards to the heating value of the dry weight and the ash-free heating value (see Table 1).

Table 1. Comparison of heating values of apple tree branches with other biomass fuels.

Index	Unit	Apple Tree Branches	Wheat Straw	Maize Straw	Reed
Dry weight heating value	MJ/kg	17.78	16.89	16.56	17.22
Ash content	%	2.47	4.21	6.07	7.89
Ash-free heating value	MJ/kg	18.23	17.63	17.63	18.72

Data source: The heating value of apple branches was sourced from the laboratory data and other values were sourced from the relevant research literature [39,40].

The ash-free heating value of apple tree branches in Jingning County reaches 18.23 MJ/kg, which is higher than the average value for terrestrial plants globally (17.79 MJ/kg) [41]. Compared with wheat, maize, and other crop straws, apple tree branches have the characteristics of higher heating values and lower ash contents. Research has shown that there is a significant correlation between the ash content and heating value of the dry weight [41]. Under the fixed conditions of the generating efficiency of a biomass power generation plant, apple tree branches are one of the most desired feedstocks.

The total area of apple cultivation in Jingning County was 707 km² in 2016. We calculated that the range of the annual total amount of apple branches is from 0.16 to 0.47 million tons. With an increase in the age of the apple tree, the annual total production of apple tree branches will reach its peak value, of more than 0.4 million tons, in approximately 10 years. Meanwhile, Jingning County also has many straw resources; their output reached 0.55 million tons in 2012, of which maize straw accounted for 66.30% and wheat straw accounted for 23.15% [42].

In the eastern developed regions of China, the biomass fuel cost of a biomass power plant is approximately US\$0.068/kWh, which accounts for nearly 70% of the total cost [43]. In 2013, the biomass power generation capacity in China reached 7790.02 MW, of which the total scale of Eastern China, Central China, and South China accounted for 77.65% [44].

For economically developed regions in China, biomass resources are relatively rare, and the price of biomass feedstock is boosted when biomass power plants compete for the purchase of biomass fuel. At present, the purchase price of biomass fuel is basically between 30.22–52.89 US\$ per ton, but the price in Jingning County was between 30.22–45.34 US\$ per ton in 2012, which is obviously lower than that of China's eastern regions; additionally, the biomass feedstock sold in rural markets accounts for only 4% of the total production [23].

The results of the questionnaire given to fruit farmers in Jingning County in 2015 showed that over 95% of the respondent fruit farmers used apple tree branches—pruned down in the process of managing orchards—for heating and cooking; only very few fruit farmers directly burned them. In summary, the biomass feedstock market in Jingning County has not yet been exploited at present.

2. Methodology

2.1. Positive Externalities of Biomass Power Generation

An externality is an activity that imposes involuntary costs or benefits on others or an activity whose effects are not completely reflected in its market price [45]. According to this definition, the positive externality of a circular economy, which does not include the economic benefits of a circular economy because it can be reflected in the market price of the production, is embodied primarily in positive environmental and social benefits. We calculated the externality produced by biomass power generation as Equation (1):

$$E_t = E_{st} + E_{et}, \quad (1)$$

where E_t is the positive externality produced by biomass power generation in t year, E_{st} is the social benefits in t year, and E_{et} is the positive environmental externality in t year.

2.1.1. The Calculation of Social Benefits

Social benefits include two components. One component is the benefits of an employment increase, and another component is farmers' increased incomes from biomass sales. The other is increased income from biomass sales.

The construction and operation of biomass power plants can create jobs, thus transforming some farmers into workers. In China, the income level of industrial workers is higher than that of farmers. Compared with farmers' income levels, the fact that the project of building biomass power plants increases jobs is equal to the increase of social income.

In Jingning County, fruit farmers often use apple branches for heating or cooking. We assumed that this part of the energy consumption gap is supplemented by electricity after the peasants sell their apple branches, which means that the fruit farmers must purchase the same amount of energy (electricity) to satisfy their cooking and heating needs, and this part of the payment in the past has not been a requirement. Therefore, fruit farmers' incomes from biomass sales should be subtracted from this portion of the expenditure, leaving the remainder as a part of the positive externalities of biomass power generation.

Social benefits can be calculated by Equation (2):

$$E_{st} = E_{bst} + E_{eit}, \quad (2)$$

where E_{bst} is the increased income from biomass sales in t year, E_{eit} is the benefits of an employment increase in t year, and these two indicators can be calculated by Equations (3) and (4):

$$E_{bst} = C * P_1 - C * L * E / 3.6 * P_2, \quad (3)$$

$$E_{eit} = N(W - (I * R + i * (1 - R))), \quad (4)$$

where W is the average wage of employees working in a biomass power plant; N is the number of employees employed by the biomass power plant; R is the urbanization rate of the study area; I is the average urban income; and i is the rural average income; C is the weight of biomass sold by a fruit farmer; P_1 is the price of the biomass; L is the lower heating value of the biomass; E is the combustion efficiency of a farmer's kitchen range; and P_2 is the price of rural electricity.

2.1.2. The Calculation of Positive Environmental Externality

Compared with coal-fired electricity, biomass power is cleaner; emissions of the major pollutant and greenhouse gases, such as SO_2 , NO_x , CO , and CO_2 , can be decreased drastically. Therefore, it can be said that the positive environmental externality of biomass power generation is the reduction of negative environmental externality; its measurement can be converted into a market price accounting

for the pollutants' emissions reduction. the positive environmental externality can be calculated by Equation (5):

$$E_{et} = \sum_{e=1}^n EM_e P_e, \quad (5)$$

where E_{et} is the positive environmental externality in t year, EM_e is the effective emission reduction of e th pollutants of biomass power generation compared with on-grid electricity, and P_e is the market price of the environmental loss generated by the e th pollutant. In this study, the main pollutants included four types: SO_2 , NO_x , CO, and CO_2 . The calculation of these pollutants' parameters is very complicated, and the process of these parameters' calculation is presented in detail in Sections 2.5.6–2.5.8.

2.2. Government's Fiscal Subsidy

China's feed-in tariff, similar to that of many nations in the world, has been enforced in the development of biomass power generation. At present, as far as biomass power generation is concerned, the unified purchase price of the State Grid Corporation of China is US\$0.1133/kWh, while that of desulfurized coal-fired electricity ranges approximately from US\$0.0408/kWh to US\$0.0710/kWh. As far as desulfurized coal-fired electricity in Gansu Province is concerned, the purchase price of the State Grid Corporation of China is about US\$0.0453/kWh, then the price subsidy intensity for biomass power generation is US\$0.068/kWh.

Meanwhile, judging by the "Catalogue of Preferential Value-added Tax Policies for Products and Labor Services Generated from the Comprehensive Utilization of Resources" published by the Ministry of Finance of the People's Republic of China and State Administration of Taxation in 2015, the tax rebate ratio of biomass power generation is 100%. According to the "Enforcement Regulations of Enterprise Income Tax Law of the People's Republic of China," published by the State Council of the People's Republic of China in 2007, the income tax on biomass power generation can be calculated as less than 10% because of the nature of the comprehensive utilization of resources; all corporate income taxes of corporations involved in biomass power generation are exempted in the first three years of their operational period, and 50% of corporate income taxes are exempted from the fourth to the sixth year. According to the support policy mentioned above and the gap between the prices in biomass power and desulfurized coal-fired electricity, the fiscal subsidy provided by the government can be calculated.

Therefore, besides the price subsidy, the subsidies obtained by biomass power generation plants because of the government's support policies is composed of two parts: Income tax exempted and value-added tax exempted. Because all the value-added tax has been exempted, the value-added tax exempted can be calculated by Equation (6):

$$V_t = T_o - T_i, \quad (6)$$

where V_t is the value-added tax exempted, T_o is the output tax, and T_i is the input tax.

Income tax exempted can be calculated by Equation (7):

$$I_t = a_t P_t * r * b_t + 0.1 * P_t, \quad (7)$$

where I_t is the income tax exempted in t year, P_t is the current year's profit of a biomass power plant, and a_t is a coefficient of the current year's profit, which is equal to 90% from 2019 to 2024 and 0% after 2024. r is the income tax rate, and b_t is a coefficient of the income tax rate, which is equal to 100% from 2019 to 2021, 50% from 2022 to 2024, and 0% after 2024.

In conclusion, the government's fiscal subsidies for biomass power generation are composed of three parts: The price subsidy, income tax exempted, and value-added tax exempted. It can be calculated by Equation (8):

$$FS_t = B_t P_S + V_t + I_t, \quad (8)$$

where FS_t is the government's fiscal subsidy in t year, B_t is the electricity generated by a biomass power plant in t year, P_t is the price subsidy of biomass power, and V_t and I_t are the value-added tax exempted and income tax exempted in t year.

2.3. The Method to Judge Whether the Positive Externality Has Been Internalized

The economic theory of the externality tells us that industries with positive externalities will be underdeveloped. To promote the development of industries with positive externalities, it is necessary for the government to provide some support policies for the purpose of eliminating their positive externalities and achieving the promotion of the development of these industries. The essence of this kind of behavior of the government is called the internalization of externalities. Theoretically, the government's support should be equivalent to the positive externalities. In sum, whether the government's fiscal subsidy has matched the positive externality of biomass power generation can be judged by Equation (9):

$$Q = \sum_{t=2019}^{2039} (E_{st} + E_{et} - FS_t), \quad (9)$$

where Q is the indicator of externality internalization, E_{et} is the positive environmental externalities of biomass power generation in t year, E_{st} is the social benefits in t year, and FS_t is the government's fiscal subsidy in t year. We can say that the positive externality of biomass power generation has been internalized when the value of Q is equal to zero in 2039. The degree of externality internalization depends on the difference between Q and zero.

2.4. Six Scenarios of Analysis

As far as a planned biomass power plant is concerned, its operational circumstances are not stable, the market price of biomass fuels will fluctuate, and the governmental support policy can be variable. Moreover, it is not known whether the planned biomass power plant can be absorbed into the project of Clean Development Mechanism (CDM), which is one of the three flexible mechanisms to achieve partial emission reduction commitments abroad under Kyoto Protocol. Registered as a CDM project in the UN CDM Executive Board, the CO₂ emission reductions generated by the project can be sold in the regional carbon trading market. Thus, our analysis was based on several scenarios (see Table 2) to simulate possible practical situations. We analyzed the conditions that made the biomass power plant project feasible for every scenario.

Table 2. Several scenarios for the operation of a biomass power plant.

Index	Scenario					
	I	II	III	IV	V	VI
Price of biomass fuel (US\$/ton)	variable	variable	variable	variable	variable	variable
Price of biomass power (US\$/kWh)	0.1133	0.1133	0.0453	0.0453	0.0453	0.0453
CDM	no	yes	no	yes	yes	no
Support policy	yes	yes	yes	yes	no	no

Every scenario depicts the specific management environment of a biomass power plant. By comparing the conditions that can maintain the normal operation of a biomass power plant without a loss, the rationality of the government's support policy based on the idea of internalizing the positive externality of biomass power generation can be discussed.

2.5. Biomass Power Generation Technologies in the Designed Project and its Parameters

2.5.1. Biomass Power Generation Technologies

Many commercially proven power generation technologies which can use biomass as a fuel input are available. These technologies can generally be classified into three types: Biomass combustion,

anaerobic digestion, and biomass gasification technologies [46]. Among these, the direct combustion of biomass for power generation is the most mature and common form of biomass power generation. Around the globe, over 90% of the biomass used for energy purposes goes through the combustion route. We did not consider anaerobic digestion as a feasible biomass generation technology, because the main biomass we used to generate power is composed of apple tree branches, which is not a feedstock used to produce biogas, in general. Although gasification technologies are commercially available, more work, such as R&D (Research and Development) and demonstrations, should be conducted to promote their widespread commercial use, as only approximately 373 MWth (megawatt-thermal) of the installed large-scale gasification capacity was in use in 2010, with only two additional projects totaling 29 MWth planned for the period up to 2016 [46]. The direct combustion of biomass is also a popular technology which has been adopted by China's biomass power generation plants. To discuss the economic and technological feasibility of biomass power generation using apple tree branches as a fuel input, a techno-economic analysis of a 30 MW biomass-fired power plant is provided.

2.5.2. Data Collection

Processing Equipment and Design Parameters of the 30 MW Biomass-Based Steam Power Plant

Currently, the main technologies for biomass power generation include water-cooled vibrating grate combustion technology and fluidized bed combustion technology. The former, which was developed by BWE—a famous corporation whose business is to produce industrial boiler in Denmark, adopts the grate-firing method in which the fuel can be diffused equally and burned with a vibrating grate, and the clinker is discharged at the terminal part of the boiler [47]. This method is an effective solution to inefficiency, and corrosive tail gas and clinker agglomeration. Thus, we assumed that the project of biomass power generation using apple tree branches as a fuel input would employ the water-cooled vibrating grate combustion technology.

To reduce the import cost of a water-cooled vibrating grate boiler, Chinese corporations have pursued domestically manufactured equipment by actively cooperating with BWE—a Danish boiler manufacturer. At present, many corporations, such as the Jinan Boiler Group Co., Ltd. and the Hangzhou Boiler Group Co., Ltd., manufacture their own water-cooled vibrating grate boilers and supply their products to domestic biomass power generation plants [48].

The operating principle of biomass direct combustion power generation technology can be depicted as follows: The biomass is sent directly into the boiler as a fuel input, after which high-temperature and high-pressure steam, produced by the boiler, pushes the steam turbine to drive a dynamo, which generates electricity. Table 3 lists the boiler and turbine data.

Table 3. Specifications of the boiler and turbine of the 30 MW plant.

Item	Value	Unit
Boiler capacity	130	t/h
Capacity of the turbine	30	MW
Steam requirement as per manufacturer	3.8	t/MWh
Steam required for full capacity (30 MW)	114	t/h
Pressure of steam	93	bar
Temperature of steam	540	°C
Heat required to produce 1 ton of steam at 93 bar and 540 °C	2.34	GJ/t
Boiler efficiency	92	%
Hours of operation	7000	h/y

Structure of the Total Investment and Financial Costs of the 30 MW Biomass Power Plant

The registered capital of the designed project, which accounts for 20% of the total investment, is approximately US\$9.10 million. The remaining 80% of the investment will be loaned from a bank whose lending rate is 5.94%. The long-term loan amount is US\$36.40 million with a repayment period

of 13 years, of which the grace period is 2 years, and the repayment method is the average capital plus interest. The operation period of the biomass power generation project is from 2019 to 2039.

2.5.3. Mathematical Equations Used to Evaluate the Requirement of Biomass Fuel

In this study, the available biomass fuels include apple tree branches, wheat straw, and maize straw. The former is designated as the main biomass fuel, while the other two types are auxiliary fuels, used only when apple tree branches cannot be sufficiently supplied.

The calorific value of the dry weight cannot be used to evaluate the biomass requirement under boiler conditions in the process of biomass power generation. Cheng Xuyun et al. (2013) found that the lower heating value (LHV) has an intimate relationship with the structure of biomass fuel, which involves the mass fractions of moisture, ash, volatile matter, and fixed carbon. The LHV can be estimated from industrial analysis indices as follows [49]:

$$LHV = 6.22 - 5.38M + 11.68V - 8.42A + 10.89C, \quad (10)$$

where M , V , A , and C are the percentages of moisture, volatile matter, ash, and fixed carbon, respectively, accounting for straw biomass based on industrial analysis conditions; the unit of LHV is KJ/g.

The annual biomass requirement is also influenced by the structure of the biomass fuel. The requirements of the biomass fuel vary with the fraction of the moisture content in the biomass and the system efficiency of the equipment used for biomass power generation. We assumed that the biomass would be processed before consumption, and its mass fraction of moisture content is in accordance with the conditions under which the LHV is estimated. The following equation is used to estimate the annual biomass requirement (M_f) [50]:

$$M_f = \frac{E \times 3.6}{LHV \times \eta}, \quad (11)$$

where M_f , E , LHV , and η indicate the annual biomass requirement, energy demand, lower heating value, and combustion efficiency, respectively.

2.5.4. Net Present Value (NPV)

The method of net present value (NPV) is employed to judge whether a project is economically feasible. The net cash flow, which is the basis of an analysis of the net present value, is computed according to the item structure of the cash flow of the construction project, as shown in Figure 1.

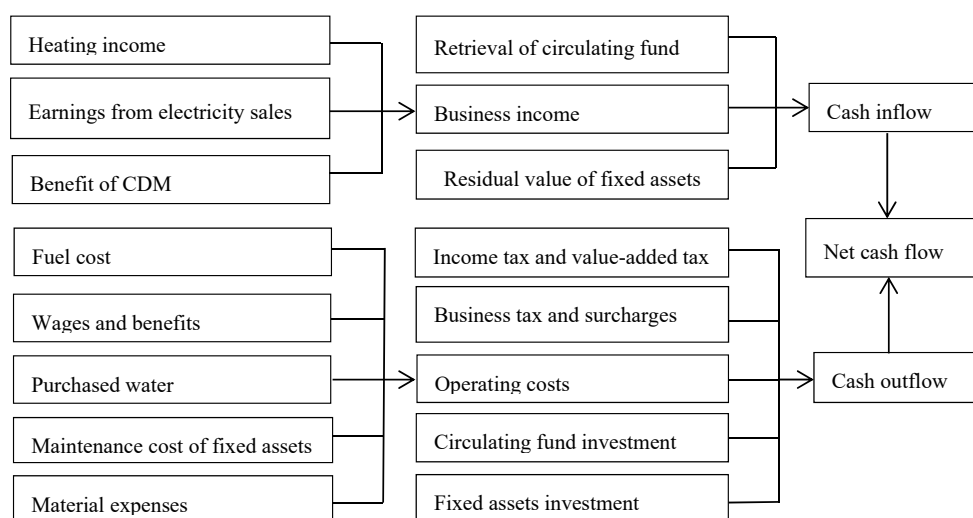


Figure 1. Item structure of the cash flow of a construction project [51].

The net earnings of each year in the lifetime of the project are discounted to year zero with the selected rate to satisfy the marginal average rate of return (MARR), and the investment is deducted from the sum of the present net earnings. This value of the *NPV* can be computed by the following equation [52]:

$$\begin{aligned} NPV &= -S + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \dots + \frac{CF_T}{(1+r)^T} \\ &= NPV = -S + \sum_{j=1}^T \frac{CF_j}{(1+r)^j}, \end{aligned} \quad (12)$$

where *S* is the initial investment, *CF* is the cash flow, *r* is the discount rate, and *T* is the economic life of the plant.

2.5.5. Internal Rate of Return (IRR) and Payback Period (PBP)

The definition the internal rate of return (IRR) is the discount rate that makes the *NPV* equal zero over the lifetime of the project, and it can be computed by Equation (13):

$$NPV = -S + \sum_{j=1}^T \frac{CF_j}{(1 + IRR)^j} = 0, \quad (13)$$

The payback period (PBP) is the number of years that the project takes to recover its total investment (TI) through earnings after interest and tax (*EAIT*). The PBP can be computed by Equation (14) [53]:

$$PBP = \frac{TI}{EAIT}. \quad (14)$$

2.5.6. Emission Reductions by Displaced Energy

Compared with a coal-fired power plant, biomass power generation is considered to be a cleaner energy source, which reduces emissions, such as CO_2 and SO_2 , as the biomass always releases these emissions during a biological degradation process, even though it is not used as biomass fuel to generate power. The amount of emissions that can be reduced by the displaced energy can be estimated as follows [54]:

$$ER_d = E \times (PC \times EF_C + PP \times EF_P + PN \times EF_g), \quad (15)$$

where ER_d is theoretical emission reduction of pollutants of biomass power generation compared with on-grid electricity, in fact the value of ER_d is equal to the pollutants' emission amount generated by traditional electricity's production; *E* is the amount of electricity generated by the biomass power plant; *PC* is the share of coal in China's primary energy consumption; *PP* and *PN* indicate the shares of petroleum and natural gas in China's primary energy consumption, respectively; and EF_c , EF_p , and EF_g indicate the emission factors of coal, petroleum oil, and natural gas, respectively. These emission factors are shown in Table 4.

Table 4. Emission factors of several fuels [52].

Fuels	Emission Factors (Unit: t/MWh)			
	CO ₂	SO ₂	NO _x	CO
Coal	1.1800	0.0190	0.0052	0.0002
Petroleum oil	0.8500	0.0164	0.0025	0.0002
Natural gas	0.5300	0.0005	0.0009	0.0005
Renewable	0	0	0	0

In China, the consumption structure of its primary energy has varied rapidly in recent years. The 2015 Chinese energy consumption share is shown in Table 5.

Table 5. Chinese energy consumption share in 2015 (unit: %).

Country	Coal Power	Petroleum Power	Gas Power	Renewable Power
China	64	18.1	5.9	12

2.5.7. Emissions from the Transportation of Biomass Raw Materials (ET)

Emissions from the transportation of biomass raw materials can be calculated using the following Equation (16):

$$ET = \frac{M \times D \times T \times EF}{TT}, \quad (16)$$

where ET is the total emissions from the transportation of biomass raw materials; M is the weight of biomass fuel that must be transported; D is the distance that the biomass fuel needs to be transported; T is the tortuous coefficient of country roads; EF is the emission factor of diesel-based transportation; and TT is the truck load per trip.

We assume that the transportation vehicles from rural households to temporary storage stations are light-duty vehicles and that the transportation vehicles from temporary storage stations to biomass power plants are heavy-duty vehicles. The overall average emission factors are shown in Table 6.

Table 6. Emission factors (EF) of diesel vehicles.

Pollutant	Unit	Emissions Standards	EF _t	
			Diesel Light-Duty Vehicles (Average Mass Lower Than 3.5 t)	Diesel Heavy-Duty Vehicles (Average Mass Higher Than 12 t)
CO ₂	t/km	EU III	0.356×10^{-3}	0.932×10^{-3}
NO _x	t/km	EU III	1.400×10^{-6}	8.400×10^{-6}
CO	t/km	EU III	0.700×10^{-6}	2.600×10^{-6}
SO ₂	t/km	EU III	0.100×10^{-6}	0.300×10^{-6}

Data source: Determination of emission factors from motor vehicles under different emission standards in China [55].

2.5.8. Effective Emissions Reduction from Biomass Power Plants

In reality, the biomass power generation can also bring about pollutant emissions which should be subtracted from ER_d . Thus, the effective emissions reduction from a biomass power plant (EM_e) can be evaluated using Equation (17):

$$EM_e = ER_d - E \times E_b - ET, \quad (17)$$

where EM_e is the effective emission reduction of biomass power generation, ER_d is the theoretical emission reduction of pollutants of biomass power generation compared with on-grid electricity; E is the amount of electricity generated by the biomass power plant; E_b is the emission factors of pollutants; and ET is the emissions from biomass transportation.

The life cycle GHG (greenhouse gas) emission intensity of biomass power is 0.045 kg CO₂ e/kWh [56]; the emission factors of other emissions of a biomass power plant, including CO, SO₂, and NO_x, are 0.0080332 kg/kWh, 0.0000228 kg/kWh, and 0.0008626 kg/kWh, respectively [57]; ET were calculated using Equation (16).

2.6. System Dynamics and the BEP-SD Model

The system dynamics method, which was first founded in the 1950s [58], was applied to construct a circular economy systemic analysis model. This method has been widely used in the study of many complex systems of the economy, society, and ecology [59,60], and is characterized by quantifiability and controllability. It can reveal the dynamic changes, feedback, delays, and other processes of a system. Thus, this method has an obvious advantage in analyzing, improving, and managing systems characterized by a long developmental cycle and complex feedback effects [61].

The system dynamics model is generally composed of three types of variables: Level variable, rate variable, and auxiliary variable. The level variable is a cumulative variable which is like a water pool, it represents the status of the system and is always put in a rectangle. The rate variable makes the level variable change, which represents the rate at which the level variable changes. The auxiliary variable is the intermediate variable used to describe the information transfer and transformation process between the level variable and rate variable in the decision-making process. In addition, a constant is also often used in building a system dynamics model. The arrow direction indicates the causal relationship between variables.

To distinguish whether the construction of a biomass power generation plant is economically feasible and whether the China biomass power generation support policy is rational, the bioenergy-effect-policy system dynamics (BEP-SD) model, which is centered around biomass power generation using apple branches as a fuel, is constructed to quantitatively simulate various flows in the agricultural circular economy system of Jingning County, simulate their effects and long-run trends, and detect the system defects before providing some suggestions to improve the final system performance. According to the logical framework narrated above, the causal loop of the BEP-SD model was designed, as shown in Figure 2.

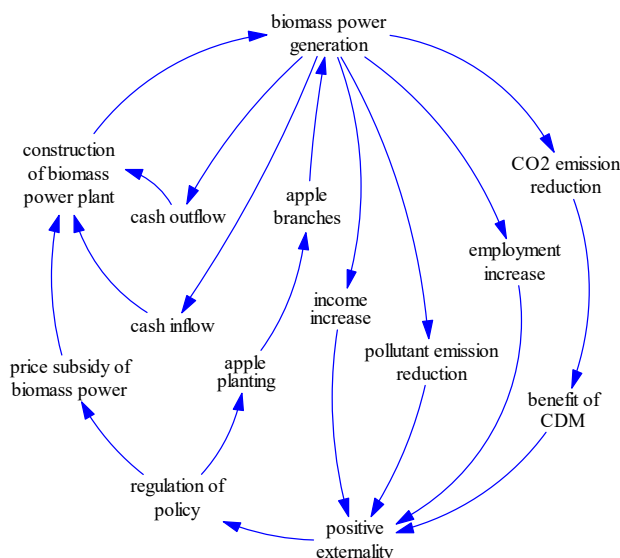


Figure 2. The causal loop of the bioenergy-effect-policy system dynamics (BEP-SD) model.

For the convenience of narration, we broke down the BEP-SD model into four subsystems: (1) Consumption of biomass fuel, (2) positive externalities, (3) fiscal subsidy, and (4) net present value. The consumption of a biomass fuel subsystem mainly includes one level variable, one rate variable, and 27 auxiliary variables. This subsystem simulates the growth process of the apple tree branches consumed by the biomass power generation plant and analyzes the cost of the biomass fuel (see Figure 3).

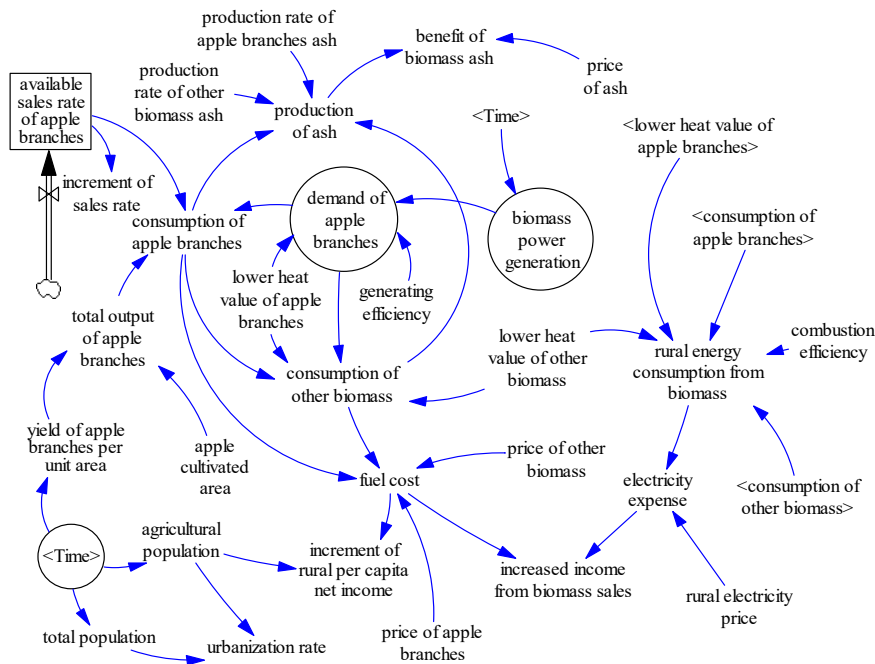


Figure 3. Subsystem of the consumption of biomass fuel.

The positive externalities subsystem involves one level variable, one rate variable, and 37 auxiliary variables. The operation of a biomass power generation plant generates some positive effects, such as economic growth, employment increases, and pollution reduction. This subsystem mainly analyses the positive environmental externalities relating to the environmental benefits generated by using biomass power to replace coal-fired power, such as emission reductions of CO₂, SO₂, NO_x, and CO. We mainly focus here on the environmental benefits generated by the emissions reductions of CO₂, SO₂, and NO_x (see Figure 4).

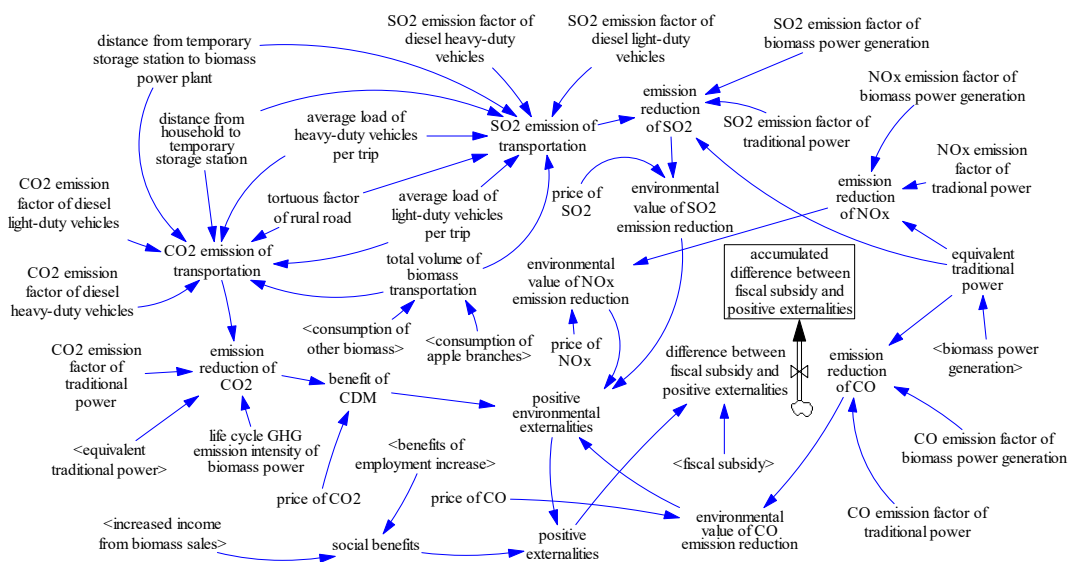


Figure 4. Subsystem of positive externalities.

The fiscal subsidy subsystem involves three level variables, four rate variables, and 45 auxiliary variables. This subsystem simulates the process of fiscal subsidy generation and depicts the gap between the fiscal subsidy and positive environmental externalities. It is used to judge the rationality of the governmental support policy for the development of biomass power (see Figure 5).

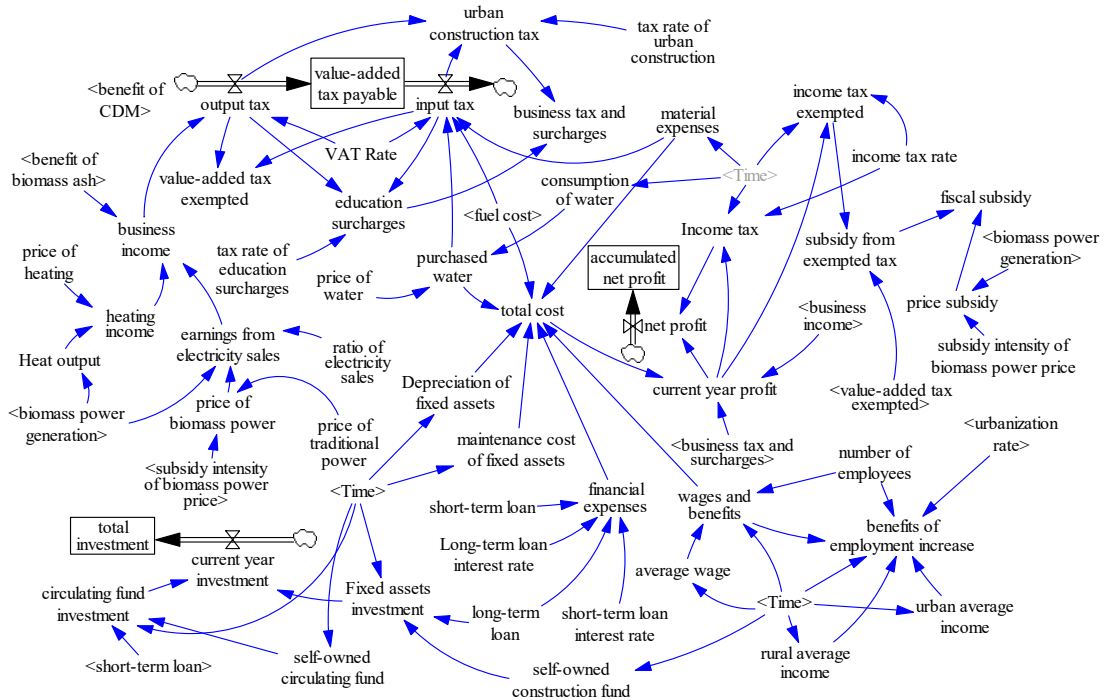


Figure 5. Subsystem of the fiscal subsidy.

The net present value subsystem involves two level variables, two rate variables and eight auxiliary variables. This subsystem is designed to compute the net present value of the project through which we judge whether the project of building a 30 MW biomass power plant using apple tree branches as biomass fuel is feasible (see Figure 6).

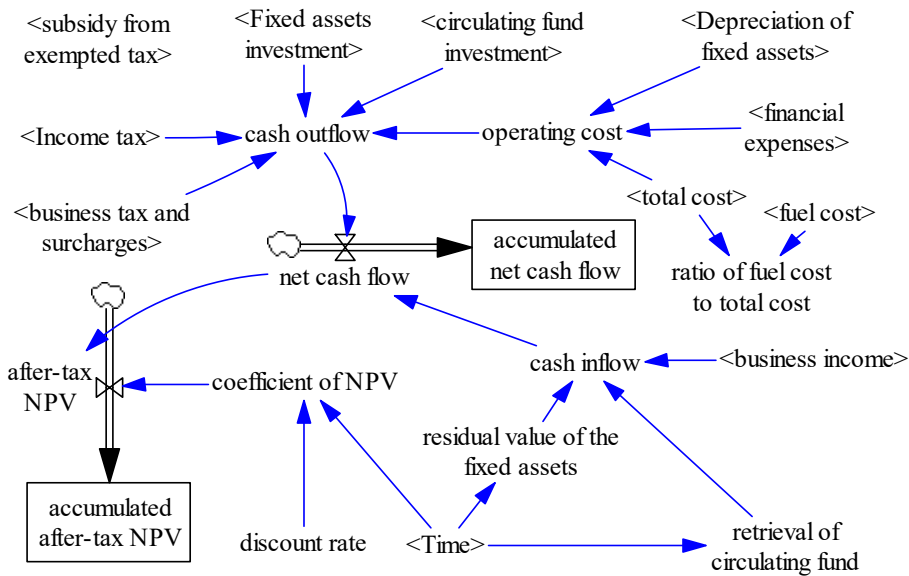


Figure 6. Subsystem of the net present value.

The BEP-SD is employed to analyze the interaction mechanisms among the different subsystems and the feedback relationships between the parameters of the model, thereby demonstrating and simulating the development of a biomass power plant quantitatively and dynamically.

In an allusion to the price fluctuations of biomass power and biomass fuel and the technological changes in biomass power generation, this study applied a scenario analysis to discuss the economic feasibility of a biomass power plant project. The project has positive externalities, and the

internalization of these externalities is the theoretical basis of the governmental support policy for the development of biomass power generation. At present, China's unified on-grid price for biomass power is US\$0.1133/kWh, which is approximately US\$0.0529/kWh higher than the desulphurization benchmarking feed-in tariff; this higher part of the price can be regarded as an approximate compensation for the externalities. This study explores the rational space of the biomass power support policy and proposes policy recommendations by comparing the positive externalities generated by biomass power generation and the governmental subsidies for the development of biomass power.

3. Results and Discussion

3.1. Demand Analysis of Biomass Fuel

We assume that 70% of the total apple tree branches in Jingning County can be purchased ultimately in the rural market accompanied by an increase in the availability of apple tree branches; this amount will be nearly 0.11 million tons in the next few years. With an increase in the age of the apple trees, the available apple tree branches will increase yearly, and the highest available amount will reach 0.28 million tons, plus approximately 0.38 million tons of crop straw every year. These biomass resources can ensure the required biomass fuel inputs for the planned biomass power generation plant.

Based on the assumption that the planned biomass power plant will operate with a full load, we simulated the consumption trends of the biomass fuel in the planned biomass power plant (see Figure 7). The requirements of the apple tree branches and other biomass are within the scope of the supply capacity of Jingning County. To illustrate the relationship between the biomass price and the economic feasibility of the assumed project, the biomass price is marked in the figure legend; for example, scenario I 49 indicates that all data presented in the figure are calculated based on an assumption that the biomass price is US\$49/ton in scenario I.

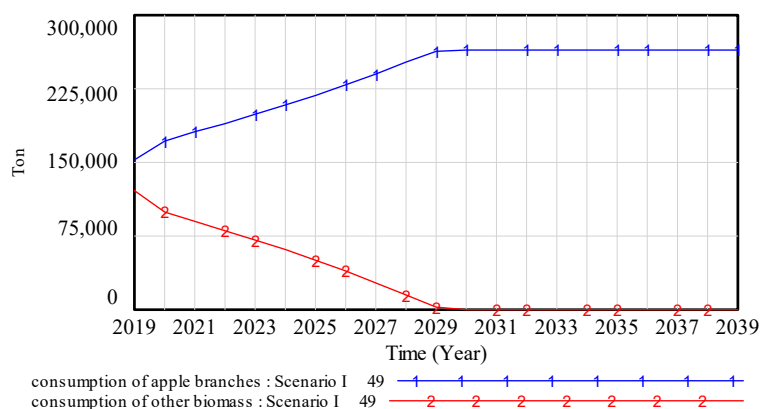


Figure 7. Consumption trends of biomass fuels in a biomass power plant.

Accompanied by an increase in the consumption of apple tree branches, the fuel cost of the project descends gradually as the LHV of apple branches is higher than for other biomasses, such as maize, wheat straw, and other crop straws. We made this conclusion under the assumption that the prices of apple branches and other biomass will not be raised with the building of the biomass power plant. As with biomass fuel, other crop straw biomass serve as substitutes for apple branches, and crop straw in the rural markets of Jingning County accounts for only 4% of the total scale; thus, this judgment is reliable.

3.2. Economic Feasibility Analysis of the Project of Building a 30 MW Biomass Power Plant

According to the NPV method, the project is economically feasible if the value of the NPV is larger than zero by the last year of its operation period. Thus, we can judge whether the planned project is

economically feasible by analyzing which price for the biomass fuel makes the NPV larger than zero by 2039 when the indices of the IRR, the price of biomass power, the generating efficiency of the biomass power plant, and the other conditions of a plant's normal operations are fixed (see Table 2). The NPV values would be less than zero and the assumed project will not be economically feasible if the prices of biomass fuel are larger than the prices listed in Table 7.

Table 7. Conditions that make the project economically feasible.

Index	Scenario					
	I	II	III	IV	V	VI
Price of biomass (US\$/ton)	49.2	54.7	1.3	6.8	−7.5	−13.0
PBP (year)	7.4	7.4	7.3	7.3	7.5	7.5
IRR (%)	14	14	14	14	14	14
NPV in 2039 (10 ³ US\$)	174.1	78.1	190.5	94.5	38.3	95.8

In the six scenarios, scenario I and scenario II are practical and feasible as the prices of crop straw (e.g., wheat and maize straw) were between US\$30.22 and US\$45.34 in 2012, which are less than those in scenario I and scenario II. The PBP is less than eight years, which is within the acceptable range, indicating that the planned biomass power plant is economically feasible (see Table 8).

Table 8. Two scenarios that can generate a higher economic efficiency.

Index	Scenario I			Scenario II		
Price of biomass (US dollars/ton)	30.2	37.8	45.3	30.2	45.3	52.9
PBP (year)	4.8	5.6	6.6	4.4	5.8	7.0
IRR (%)	14	14	14	14	14	14
NPV (10 ³ US\$)	29,505	17,773	6195	37,900	14,589	2857

As far as the cost of biomass power plant is concerned, the cost of biomass fuel accounts for about 60% of the total cost. So, to some extent, the price of biomass fuel seals the fate of biomass power plants. From scenario III to scenario VI, the prices of biomass fuels are far less than the prices that the market would accept (see Table 7), especially scenario V and scenario VI, whose prices are only US\$0.0453/kWh, and there are no support policies for the investors in biomass power to help them decrease the cost of biomass fuel. We conclude that the biomass power generation project is not economically feasible without a support policy for biomass power generation and higher prices compared with fossil-based power.

3.3. Sensitivity Analysis of Profitability of Biomass Power Generation Project

3.3.1. The Influence of the Fluctuation of Biomass Price

Biomass fuel cost accounts for about 60% of the total cost of the biomass power generation project (Figure 8), and the fluctuation of the biomass price exerts an important impact on the profitability of the biomass power generation project.

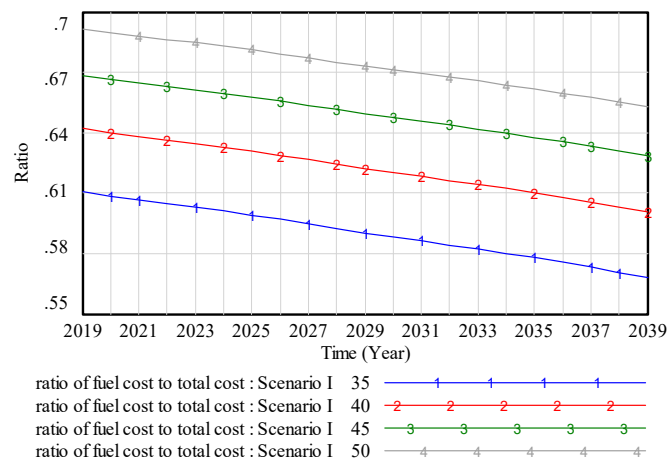


Figure 8. Ratio of fuel cost to total cost in scenario I.

According to the judgment standard of the net present value method, the project has investment value when the accumulated after-tax net present value is larger than zero at the end of the project. Obviously, in the project operation period, the earlier the accumulated after-tax NPV exceeds zero, the stronger the profitability of the project. In Figure 9, there is a trend that the profitability of the biomass power generation project declines together with the rise of the biomass fuel price under the backdrop of scenario I. When the price of biomass fuel is US\$35/ton, it needs less than nine years for the indicator value of the accumulated after-tax net present value to exceed zero; when the price of biomass fuel is US\$40/ton and US\$45/ton, this time will be shorter than 11 and 14 years, respectively; and when biomass fuel prices are above US\$50/ton, biomass power generation projects will lose investment attractiveness for industrial capital, as shown in Figure 9.

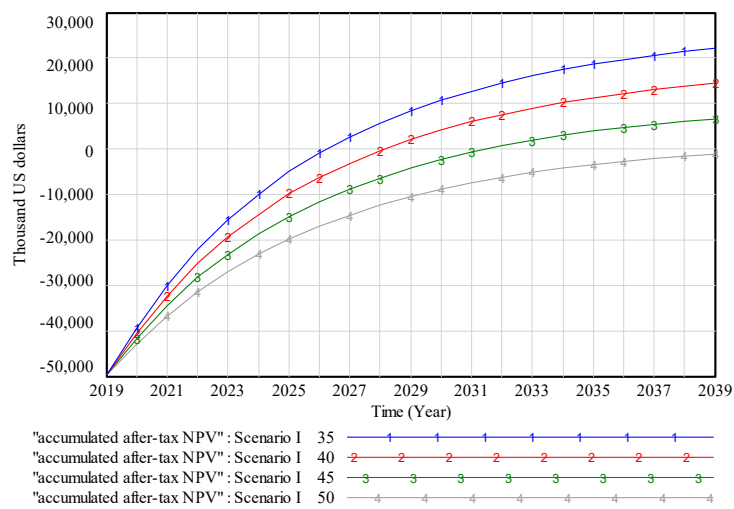


Figure 9. Sensitivity of profitability of the biomass power project to biomass price fluctuations.

3.3.2. The Influence of Governmental Price Subsidy Intensity

Among the policy tools that the government uses to support renewable electricity development, the price subsidy occupies a very important position, as shown in Figure 10.

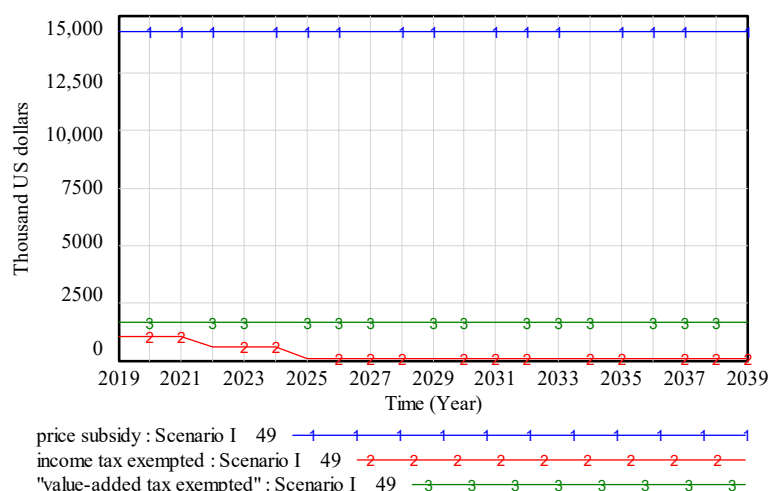


Figure 10. The structure of the governmental fiscal subsidy.

The governmental price subsidy intensity for the development of renewable electricity exerts an important impact on the profitability of the biomass power generation project. In Figure 11, scenario I40-1 means that the price of biomass is US\$40/ton, and governmental price subsidy intensity is US\$0.068/kWh; from scenario I40-2 to scenario I40-4, the prices of all types of biomass are US\$40/ton, but the governmental price subsidy intensity is US\$0.0604/kWh, US\$0.0529/kWh, and US\$0.0453/kWh, respectively.

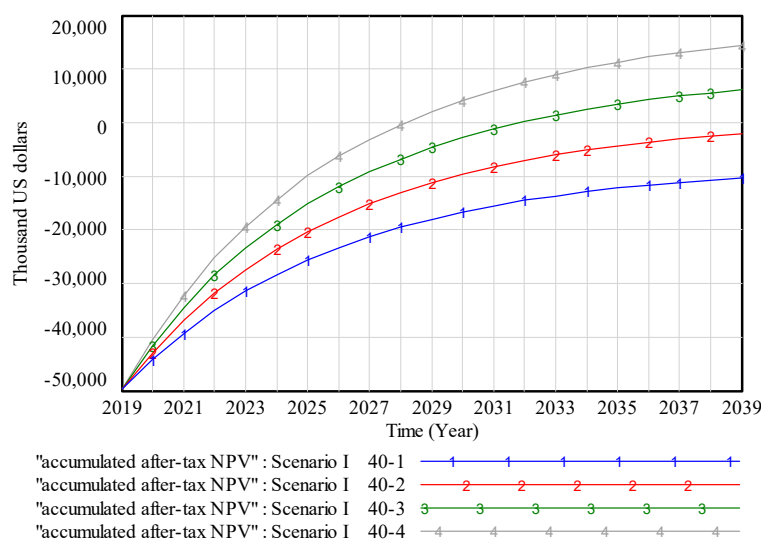


Figure 11. The influence of the governmental price subsidy intensity on the profitability of the project.

There is an obvious trend in Figure 11 that the profitability of the biomass power generation project declines rapidly together with the decline of the governmental price subsidy intensity. The indicator value of the accumulated after-tax net present value can be greater than zero in less than 11 years as the price subsidy intensity is US\$0.068/kWh; as the price subsidy intensity is US\$0.0604/kWh, it will take less than 14 years. However, as the subsidy intensity is US\$0.0529/kWh and US\$0.0453/kWh, the biomass power generation project loses its investment value.

3.4. Analysis of the Present Support Policy of Biomass Power Generation

3.4.1. To What Extent has the Positive Externality of Biomass Power Generation Been Internalized?

As mentioned before, the indicator value of Q (see Equation (9)) can help us judge whether the positive externality of biomass power generation has been internalized by the government's policy. For convenience, Q is replaced by another variable named the "accumulated difference between fiscal subsidy and positive externalities" in the system dynamics model, whose definition is the accumulated difference value that the fiscal subsidy is subtracted from the positive externality from 2019 to 2039.

The indicator value of the accumulated difference between the positive externalities and fiscal subsidy should be close to zero at the end of the project operation period if the positive externality was internalized completely. However, its values in scenario I49 and scenario II 54 in 2039 are US\$−140,729,000 and US\$−113,399,000, respectively, which are much lower than zero. Therefore, we can draw a conclusion that the subsidies provided by government policies far exceeds the positive externalities generated by the biomass power generation project.

The evolution trend of "difference between the fiscal subsidy and the positive externalities," which is far less than zero (see Figure 12), indicates that the fiscal subsidy far exceeds the positive externalities generated by biomass power generation. We can infer that the biomass power generation project is not economically feasible without the support of the government because the positive externalities of the biomass power generation project are not compensated.

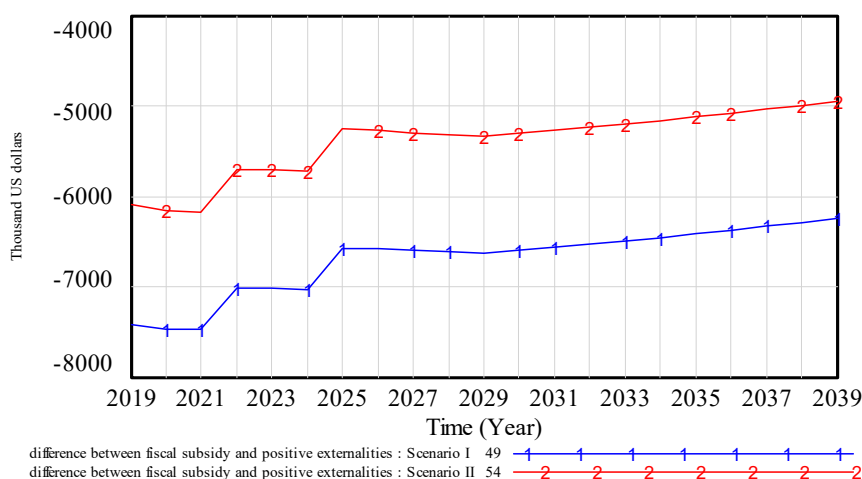


Figure 12. Difference between the fiscal subsidy and positive externalities in scenario I and scenario II.

The curves in Figure 12 present a similar developing trend, which indicates that the indicator's values are small from 2019 to 2024, and become bigger gradually after 2025. Because the value of positive externality of biomass power generation is relatively stable, the value of "difference between the fiscal subsidy and the positive externalities" mainly depends on the value of the fiscal subsidy. Therefore, the indicator curves in Figure 12 illustrate that the support intensity of the government's policy is larger in the first six years, and then its support intensity becomes weak, so the values of this indicator in the two scenarios will grow bigger and bigger.

3.4.2. Analysis of the Structure of Positive Externality and Fiscal Subsidy

The positive externality of biomass power generation mainly includes six items. According to their values by descending order, the list of these six items is the environmental value of SO_2 emission reduction, increased income from biomass sales, environmental value of NO_x emission reduction, benefit of CDM which is equal to the environmental value of CO_2 emission reduction, benefits of employment increase, and environmental value of CO emission reduction (see Figure 13).

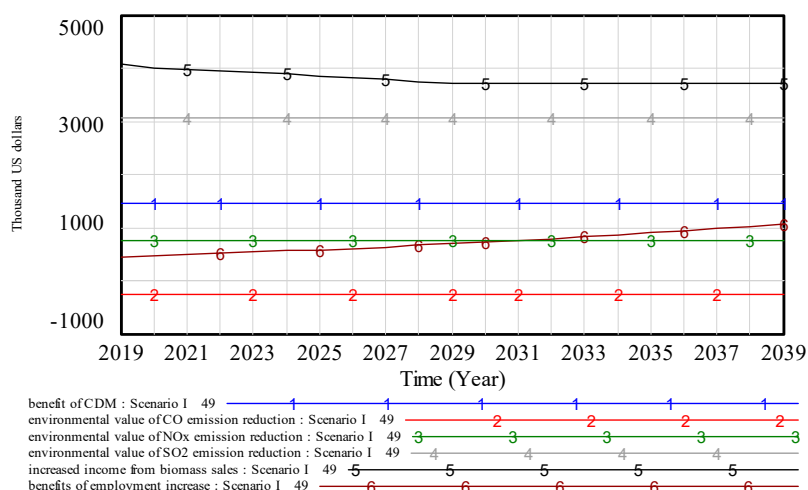


Figure 13. Items of positive externalities in scenario I.

Among them, the benefits of employment increase and increased income from biomass sales is a social benefit, which accounts for approximately 23% of the positive externality of biomass power generation.

In Figure 13, the environmental value of CO emission reduction is negative, which means that the emission level of CO for the biomass power plant is higher than traditional power.

Compared with the income tax exempted and value-added tax exempted, the price subsidy holds a large proportion of the government’s fiscal subsidy, which can explain why the biomass power plant cannot operate economically without it from scenario IV to scenario VI (see Figure 10).

3.4.3. The Reasonable Governmental Price Subsidy Intensity and Prices of Pollutant Emission Reduction

From the previous analysis, we know that biomass power generation has a positive external effect. According to the theory of externality, the internalization of externality is an effective tool for optimizing resource allocation. Therefore, the reasonable government subsidy intensity should ensure that the net present value of biomass power generation projects is exactly equal to zero. The rational price subsidy intensity, which is that value that can make the indicator value of accumulated after-tax NPV equal to zero, is easy to calculate when the biomass price is set.

We calculated the reasonable price subsidy intensity when the biomass price is US\$35, US\$40, and US\$45 per ton. The average value of the price subsidy intensity in these three scenarios is US\$0.0548/kWh, which is US\$0.0132 lower than the current price subsidy intensity. However, the values of accumulated after-tax NPV are still smaller than zero in these scenarios, as shown in Table 9.

Table 9. The reasonable governmental price subsidy intensity.

Indicators	Biomass Price (US\$/Ton)		
	35	40	45
Subsidy intensity (US\$/kWh)	0.0477	0.0548	0.0619
Accumulated after-tax NPV (10 ³ US\$)	25.297	25.649	25.978
Accumulated difference between fiscal subsidy and positive externalities (10 ³ US\$)	-161,026	-194,200	-227,373

What conclusion can we draw from this situation? Positive externality includes two parts, one is social benefits, and the other is positive environmental externalities. The indicator parameters, which are included in the calculation of social benefits, come from a market survey and are reliable. The quantities of the emission reduction of biomass power generation are reliable too. Thus, the only

points that can arouse our suspicion are the prices of pollutant emission reduction. A reasonable inference is that the values of these indicators are smaller than their actual values. In order to obtain the actual values of these indicators, we promoted their values in the same proportion. These parameters can be calculated by Equation (9), where E_{et} can be replaced by E'_{et} :

$$E'_{et} = E_{et}(1 + a) = \sum_{e=1}^n EM_e P_e ((1 + a)) \quad (18)$$

where E'_{et} is the positive environmental externality whose prices of the pollutant emission reduction are enhanced in the same proportion as a . The prices of the pollutant emission reduction that can make the value of the “accumulated difference between fiscal subsidy and positive externalities” close to zero are listed in Table 10 when the biomass price is US\$35, US\$40, and US\$45, respectively.

Table 10. Parameters that make the biomass power generation project economically feasible. (Equations and Parameters shows in Supplementary Materials).

Indicators	Biomass Price (US\$/Ton)		
	35	40	45
Price of CO ₂ (US\$)	14.74	15.00	15.21
Price of CO (US\$)	335.84	340.90	345.72
Price of NO _x (US\$)	2687.99	2727.22	2765.74
Price of SO ₂ (US\$)	2154.49	2181.78	2212.60
Subsidy intensity (US\$/kWh)	0.0477	0.0548	0.0619
Accumulated after-tax NPV (10 ³ US\$)	25.297	25.649	25.978
Accumulated difference between fiscal subsidy and positive externalities in 2039 (10 ³ US\$)	−15.8525	−7.2754	5.2422

The prices of the pollutant emission reduction listed in Table 6 are much larger than the corresponding values from scenario I to scenario VI. The latter is less than half of the former.

There is a huge controversy about the market value of pollutant emissions reduction. These indicators have a wide range of values. These parameters produced by our calculation may provide a useful reference for related research in the field of sustainability.

3.5. The Explanation of the Fiscal Burden Imposed by Renewable Electricity Policy

Renewable electricity subsidies are mainly derived from renewable energy surcharges for traditional power, which can be viewed as a type of Pigou tax. It was reported that the renewable electricity generated by biomass power plants reached US\$64.7 billion kWh. According to our research result that the current price subsidy intensity is US\$0.0132 higher than a reasonable level, among the governmental fiscal burden produced by its renewable electricity support policies, there is about US\$0.854 billion that can be attributed to an unreasonable price subsidy intensity in the field of biomass power generation, which accounts for 4.7% of the total amount [62], and is about two times the proportion that biomass power generation accounts for of the total installed capacity of renewable electricity. We can infer that the scale of the positive externality of renewable electricity we calculated is approximately accurate. As far as biomass power generation is concerned, the government’s financial burden imposed by renewable electricity policy should be partly attributed to the fact that the tax rate of renewable energy surcharges imposed on traditional power is relatively low.

3.6. The Limitation of this Research

3.6.1. The Uncertainty of this Research

In general, the generation efficiency of biomass power generation equipment will improve with the development of technological innovation, and its price will decline. These factors will reduce the total cost of the biomass power generation project, and thus improve the feasibility of the project.

It will also affect the governmental support policies for the development of renewable electricity. At the same time, along with socioeconomic development, the gap between urban and rural labor prices tends to narrow, and the negative environmental externalities of traditional power will also decline due to technological progress; these factors will lead to a reduction in the positive externalities of biomass power generation, which in turn will affect the governmental subsidy intensity for the development of renewable electricity, thereby reducing the investment feasibility of a biomass power generation project.

3.6.2. The Issue of Monetization Assessment of the Positive Environmental Externality

A monetization assessment of the positive environmental externality of biomass power generation is a complicated process. The value of the positive environmental externality depends on many parameters. Among these parameters, the most significant parameter is the market value of the environmental loss per unit of pollutant emission, namely the market price of pollutants. The value of this parameter varies greatly from region to region. The same is true for the calculation of social benefits of the positive externalities of biomass power generation. In comparison, the calculation process of the government's financial subsidies is relatively simple, and there are few different viewpoints on the calculation results. The degree of internalization of the positive externality of biomass power generation mainly depends on the accuracy of the positive externality's calculation results, which is the reason why a monetization assessment of the scale of positive externality is one of the hot spots of academic debate.

4. Conclusions

Based on our research and analysis, we conclude the following:

- (1) According to the established system dynamics model, the positive externalities of biomass power generation are influenced by many factors, such as the biomass market price, market price of pollutant emission reduction, labor wage, and so on. These factors have obvious regional differences. Subsidies for biomass power generation based on externalities' internalization should also reflect these differences, so as to adapt to local conditions. If the subsidy policy of biomass power generation is one-size-fits-all, it will inevitably lead to over-development of biomass power generation enterprises in areas where the externality scale is relatively small.
- (2) From the current policy environment for biomass power generation, building a biomass power plant using apple branches as the primary biomass fuel is economically feasible, and the assumed biomass power plant has a larger profit margin. The price of biomass fuel, which accounts for 60% of the total cost of biomass power, has a significant impact on whether a biomass power generation project can be profitable. Because of the lower price of biomass fuel, projects of biomass power generation have broad market prospects in areas of western China with an abundance of biomass power fuel.
- (3) It is difficult for a biomass power generation project to be profitable without governmental support policies. Comparing the scale of the positive externalities of biomass power generation with the scale of government subsidies, we believe that the scale of government subsidies exceeds the positive externalities that biomass power generation can generate. As far as biomass power generation is concerned, the current price subsidy intensity is about US\$0.0132 higher per kWh than the reasonable level. Furthermore, our study results indicate that the parameters frequently applied in the calculation of the prices of a pollutant emission reduction in Chinese research papers is relatively small, which would be only half of their actual values.
- (4) The Chinese government should maintain their policy support intensity for the development of biomass power generation. China's support policy should be adjusted so that the subsidies that enterprises could receive from the government are as close as possible to the externalities that biomass power generation can generate. Whether renewable electricity policy brings about a

fiscal burden for the government is not a correct criterion to judge the rationality of this policy. The scientific criterion is whether this policy can internalize the positive externality of renewable electricity. Accurate monetization measurement of the positive externalities generated by biomass power generation is still a key question.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2071-1050/11/12/3426/s1>, File 1: Explanation of equations and Parameters of Bioenergy-effect-policy System Dynamics model that make the biomass power generation project economically feasible.

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Nomenclature

a_t	coefficient of current year profit
b_t	coefficient of income tax rate
B_t	electricity generated by biomass power plant in t year
CDM	clean development mechanism
CF	cash flow
E_{bst}	increased income from biomass sales in t year
E_b	emission factors of pollutants
E_{et}	positive environmental externality in t year
E_{eit}	benefits of employment increase in t year
E_{st}	social benefits in t year
E_t	positive externality produced by biomass power generation in t year
EAIT	earnings before interest and tax
EFB	empty fruit bunch
EM_e	effective emission reduction of e th pollutants of biomass power generation compared with on-grid electricity
ER_d	theoretical emission reduction of pollutants of biomass power generation compared with on-grid electricity
ET	total emissions from the transportation of biomass raw materials
FIT	feed-in tariff
FS_t	government's fiscal subsidy in t year
GHG	greenhouse gas
I_t	income tax exempted in t year
IRR	Internal rate of return
LHV	lower heating value
M_f	annual biomass requirement
NPV	net present value
P_e	market price of the environmental loss generated by the e th pollutant
P_t	current year profit of biomass power plant
PBP	payback period
Q	indicator of externality internalization
RPS	renewable portfolio standards
S	initial investment
T_o	output tax
T_i	input tax
TGCs	tradable green certificates
TI	total investment
TT	truck load per trip
V_t	value-added tax exempted

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