Research paper

Case Study on Economic Evaluation of Gasification Investment Using Bamboo Processing Residue in Zhushan Area, Taiwan

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【Summary】

Taiwan is a country highly dependent on imported energy, but it possesses abundant bamboo residue resources; therefore, it is important and necessary to make the best use of those resources to develop technologies to convert residues into biomass energy. The purpose of this study was to evaluate the costs and benefits of two investment plans for an updraft gasification power generation system using bamboo residues in the Zhushan area, Nantou County, central Taiwan. According to the annual amount of bamboo residue from an individual bamboo processing company and from most bamboo processing industries in the Zhushan region, this study investigated 2 investment plans of gasification power generation: a single plant and a regional plant. The evaluation results showed that the single-plant investment plan, with an operating time of 1,000 h yr^{-1}, power generation of 80,000 kWh yr^{-1}, and bamboo residue consumption of 300 tons yr^{-1}, could create an operating benefit of around NT$1,354,000 yr^{-1} (the exchange rate in 2019 was US$1≈New Taiwan (NT)$31.09), but the operation still exhibited a financial loss after deducting necessary costs. The net present value (NPV) calculated for an operation period of 15 yr was -NT$4,497,588 with an internal rate of return of -2.26% and a required payback period of more than 59 yr. The regional-plant investment plan, under an operating time 5600 h yr^{-1}, power generation of 2,240,000 kWh yr^{-1}, and bamboo residue consumption of 8,400 tons yr^{-1}, created an operating benefit of around NT$35,482,000 yr^{-1}. The NPV of this investment plan calculated over 15 yr was NT$107,663,898 with an internal rate of return of 26.54%, and only 5 yr was required to recover the initial investment costs. In comparison, the regional-plant investment plan of gasification power generation would be a more-feasible and better choice for investors because of larger-scale advantages and relatively greater profits.

Key words: bamboo residue, biomass energy, gasification power generation, cost-benefit analysis.

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研究報告

竹加工剩餘資材氣化發電投資計畫之效益研究—以南投竹山地區為例

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摘 要

如今台灣既高度仰賴進口能源，境內竹剩餘資材量又大，故有研發且應用轉換廢棄物為再生能源技術之必要性。本研究目的在於評估上吸式氣化發電系統，以竹山地區竹剩餘資材為原料的投資計畫之成本與效益。本研究依據該地區某竹製品公司和全竹山地區每年的剩餘資材量設置「單廠型氣化發電投資計畫」和「區域型氣化發電投資計畫」。以單廠型氣化發電規模而言，每年設備穩定運轉1,000小時，可發80,000度電，剩餘資材年消耗量為300噸。每年可創造135萬餘元的營業收入，扣除建設成本、營運費用和其他雜費，其每年營運狀況呈虧損局面。營運期假設15年，其淨現值為-449萬餘元，內部報酬率為-2.26%，需要長達59年以上才能由虧轉盈。區域型氣化發電投資計畫，每年設備運轉5,600小時，可發224萬度電剩餘資材年消耗量為8,400噸，每年主副產品銷售收入達3,548萬餘元。15年內的淨現值高達1.07億元，內部報酬率為26.54%，只需要5年就可回收期初投資成本。相較之下，區域型竹剩餘資材氣化發電投資計畫因規模較大，盈利空間也相對多，所以是良好的選擇。

關鍵詞：竹剩餘資材、生質能源、氣化發電、成本效益分析。

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INTRODUCTION

Energy is an indispensable necessity for humans to pursue social and economic development. However, people are over-reliant on traditional fuels such as oil and coal due to their convenient supply. At the same time, people often neglect concerns about environmental damage, excessive consumption of resources, and huge amounts of wastes created, all of which have gradually emerged from excessive emissions of carbon dioxide, methane, nitrous oxide, and other greenhouse gases, which have caused global warming to become more serious. The energy and industrial sectors are the main sources of carbon dioxide contributed by various sectors. In view of this, countries are committed to developing a sustainable development model to balance economic development with environmental protection and social justice. Concepts of waste minimization, 4R (reduction, reuse, regeneration and recycle) (Chang 2004), cradle-to-cradle (McDonough and Braungart 2010), sustainable material management (OECD 2010), and the circular economy (Ellen MacArthur Foundation 2013) have sprung up; at the same time, they are also being highly valued by the public. It is hoped that limited resources can be properly utilized without jeopardizing the interests of future generations, and the waste generated can be reused for other purposes as much as possible to improve the efficiency of material use. In this context, countries are actively developing clean energy strategies to resolve energy shortages and environmental problems. Renewable energy sources such as solar, wind, hydroelectric, biomass, and waste energy (hereafter referred to as biomass) were born. Compared to other renewable energy sources, biomass energy or waste energy is renewable, rich in raw materials, highly economically efficient, able to supply energy and environmental protection, and can be operated on a small scale; thus, it has become a key energy plan in many countries (WBA 2017).

Taiwan's geographical environment is unique and rich in resources, especially in forests and bamboo. According to the 4th Forest Resource Inventory by the Forestry Bureau, the total area of bamboo in Taiwan is 137,785 ha, accounting for about 6% of the total forest land area. Bamboo is a plant with high economic value, grows rapidly, and matures early within 3~5 yr. Taiwan has a high demand for raw bamboo, and according to research by Lin et al. (2017a), the domestic demand for raw bamboo in 2014 was 90,058 tons, and the estimated waste from production processes was about 8997 tons, which is about 10% of the total demand for raw bamboo. In addition to being used for crafts and the production of bamboo shoots in the early stage, Taiwanese bamboo is also used to produce bamboo building materials, composite materials, bamboo charcoal, bamboo vinegar, and other products based on technological advancements in the later stage (Lin 2011). With the direct use and processing of bamboo materials, it is inevitable that different types of wastes are produced, such as bamboo powder and chips. In view of the fact that Taiwan consumes a large amount of bamboo materials every year, it is reasonable that the volume of bamboo residue cannot be ignored. In recent years, in order to expand the bamboo industry, people began to explore ways to fully utilize bamboo resources and promote recycling technologies of bamboo residues to become increasingly mature. So far, traditional methods of enterprises for dealing with bamboo residues include selling them to others, paying for transport, and giving them to manufacturers (Lin et al. 2017b). These treatments are not in line with the principles of environmental protection, and the economic benefits are relatively low. However, the processing of biomass fuels, chemical products, composite materials, and other agricultural products (Chen and Yeh 2017) is technically and economically feasible as a way to recycle.

Although the abovementioned methods for reusing bamboo residue have various advantages, energization is currently a great way to realize the development potential of re-use. Under pressure of limited oil resources and the continued rise in oil prices, energization can avoid damaging the environment while also saving energy, maintaining the environment, and benefiting economics through major applications. Nowadays, many EU countries have chosen to crush, screen, and dry biomass wastes and then press it into pellets or ingot fuel. After being molded into shape, the pelletized fuel has a uniform size, small volume, and uniform heat value. It is easy to store, convenient to transport and manage, produces less soot when combusted, and can be directly used for various types of boilers. According to a statistical assessment, the global wood pellet consumption in 2010 was around 13.5×10^6 tons, the future consumption demand for wood pellets could exceed 50×10^6 tons in 2025, and over 25% of global wood pellets are consumed in the EU (Statista 2015)

In addition to advantageous wood pellets, gasification power generation is another technology to convert biomass into energy. It involves a chemical reaction of carbonaceous materials with oxygen or water vapor at high temperature to produce synthetic gases, which are removed by a purification system and then sent to an engine for power generation. Nowadays, Europe and the US are ahead of Taiwan in promoting this technology. In Europe, countries such as Switzerland, Austria, and Germany all have developed biomass gasification power, which has mainly adopted woody biomass from forests and timber mills (Yamasaki 2005). In the US over the past 20 yr, over 50 companies have sprung up to provide gasification facilities to businesses. The majority of gasification facilities power small commercial buildings or manufacturing plants (Whitty et al. 2015). Gasification power generation is feasible for regional energy, and its development not only can solve the current problem of waste disposal, but also increases the added value of resources; at the same time it also can provide society with cleaner energy, so the potential for industrial applications is enormous. If the application of biomass or waste gasification for power generation can be more widely promoted, then environmental problems can be ameliorated and the dependence on traditional fuels can be reduced. It will be beneficial to Taiwan to establish a sustainable society. Therefore, Taiwanese can cooperate with each other and actively develop this technology through policies, society, laws, technology, and economics so that “sustainable social development” is no longer an impossible goal.

Since the 1990s, research focusing on these technologies or beneficial evaluations of biomass gasification power generation has increased year by year (Kirkels and Verbong 2011). Europe, the US, Japan, and China are leaders of related studies, and now those studies can be used as basic references for investment research and development for manufacturers, and can also provide references for governments to support related industries and develop policies.

The environmental benefits of gasification of biomass or waste power generation include impacts on human health, ecosystem quality, climate change, and resource consumption (Fernández et al. 2017). According to a study in Taiwan by Ho (2001) of annual rice husk production for simulated gasification power generation, the annual gasification of about 290,000 tons of rice husks could produce 65×10^{6} kWh of electricity and reduce carbon dioxide emissions by 54,813 tons. Sinha et al. (2010) analyzed the economic feasibility of developing a gasification power generation system with abandoned bamboo powder in Assam, India. Results showed that the gasification power generation system could reduce costs and also could save 1100×10^{6} tons of coal yr^{-1} in Assam, effectively reducing greenhouse gas emissions.

Gasification power generation technology has many advantages which cannot be neglected, such as flexibility of raw materials, product diversity, and contributions to emission reductions. To solve problems of waste dumping and sanitation, to save transportation costs on waste delivery, to reduce electricity from outside sourcing, and to obtain extra profits from byproducts, this study attempted to set up 2 operation gasification power generation types: one for a single company and the other for regional utilization using annual bamboo residues in the Zhushan area of central Taiwan. In addition, to avoid excessive particle sizes of residues which can cause burst problems due to the porous structure of the gasification process and promote process efficiency, surplus bamboo materials like bamboo chips and bamboo powder from factories need to be crushed 2 or 3 times to match the gasification conditions of a particle size range of 0.3~1.0 cm. The gasifier used in this study was an updraft type that can accept raw materials with a large particle size and high ash content (up to 15%); it is relatively easy to operate and has lower construction costs (Chopra and Jain 2007). Materials with small particle sizes were sent to the gasifier for gasification after drying and crushing, and most of the impurities were removed via a purification system. The tar, carbon, and condensate were discharged, and finally synthetic gas was produced to send to an internal combustion generator to generate electricity.

This study proposes 2 investment plans based on the above mentioned 2 gasification power generation scenarios for bamboo residues, and analyzed their economic feasibility and the possibility of promoting industrial development through a cost-benefit analysis. Then, a follow-up decision analysis was conducted for decision-makers to evaluate the most appropriate plan for future development and promotion of gasification power generation in the Zhushan area.

MATERIALS AND METHODS

Study case background

The study case was conducted in Zhushan Township, Nantou County, where the main product is processed semi-finished bamboo swords and other accessories using Makino bamboo (*Phyllostachys makinoi*) and Moso bamboo (*P. pubescens*). All products are sold to China, Japan, Europe, and the US. Up to now, the bamboo residue from processing was sent to boilers built in the factory to burn for heat energy for the process of bamboo boiling and washing. This factory also leased free space to other small factories for the processing and manufacturing of bamboo chopsticks, bamboo sticks, and related agricultural bamboo products. Most of the bamboo residue is in the form of chips, filaments, knots, tails, and so on. According to the actual investigation, the total amount of bamboo residue produced by this factory and the related processing factories is around 300 tons yr^{-1}, which is equivalent to around 25 tons mon^{-1} of bamboo residue.

In addition, according to an investigation of raw material production and waste disposal conducted by the Forestry Research Institute in the Zhushan area in 2014, the total demand for bamboo materials for the bamboo processing industry in 2014 was around 37,000 tons, and the amount of bamboo residue was 8,395 tons, with an estimated residue amount of around 700 tons mon^{-1}. The main types of residues are bamboo chips and filaments at 33 and 30%, respectively, and the rest consists of bamboo heads (16%), nodes (15%), tails (4%), branches (1%), and tubes (1%).

Therefore, this study analyzed the economic benefits of 2 investment plans for gasification power generation based on the amount of bamboo residue: one was a single factory type using 300 tons yr^{-1}, and the other was a regional type using 8400 tons yr^{-1}.

Note that all monetary figures in this paper are given in New Taiwan (NT) dollars, and the average exchange rate in 2019 was US$1.00≈NT$31.09.

Analysis methods

This study used a cost-benefit analysis (CBA) to evaluate expenditures and benefits of the 2 investment plans at different time points, and then selected the more-suitable or more-profitable investment plan based on various criteria. Furthermore, different gasification power generation investments were discussed using a break-even analysis (BEA), so that investors could learn how much waste materials need to be purchased each year for gasification power generation to reach a balance of profit and loss for an investment, as this is important reference information for investors.

Since any investment plan has many potential risks and uncertainties, decision-makers seeking to avoid wrong decisions must analyze risks caused by any uncertainties or change the investment plan. Thus, this study used a sensitivity analysis to determine related sensitive factors to the investment plan of bamboo residues for gasification power generation, and then made reasonable assumptions when applying a scenario analysis to estimate future business conditions. Predicting different development situations is also very significant information for decision-makers formulating an investment plan.

A. Cost-benefit analysis (CBA)

CBA is a tool to estimate strengths and weaknesses of alternatives used and compare completed or potential courses of actions, or to estimate the value against the cost of a decision, project, or policy. It is commonly used in commercial transactions, business and policy decisions, and project investments. The following four evaluation indicators were used for the CBA in this study (Boardman 2006, European Commission 2008).

1. Net present value (NPV)

The NPV is the sum of the present value of all investment benefit discounts of all investment periods deducted from the discounted investment capital (net benefit). When the NPV is positive, the investment will bring in more value to the enterprise; executives can also choose the highest net present value from multiple plans to invest in.

$$\mathrm{NPV} = \sum_{t=0}^{N} [B_t/(1+r)^t] - \sum_{t=0}^{N} [C_t/(1+r)^t] = \sum_{t=0}^{N} [B_t - C_t/(1+r)^t] \quad \text{......(1)}$$

where B_t is income for period t, C_t is expenditure of period t, r is the discount rate, and t is time.

2. Benefit-cost ratio (BCR)

The BCR represents the ratio of the total present value of all benefits divided by the total present value of costs. When the BCR is > 1, it means the overall benefit of the plan is greater than the cost; that is, this plan is worthy of investment. If there are different plans, the decision-maker can choose the one with the highest ratio of benefits.

$$\mathrm{BCR} = \frac{\sum_{t=0}^{N} B_t/(1+r)^t}{\sum_{t=0}^{N} C_t/(1+r)^t} \quad \text{......(2)}$$

where B_t is the income for period t, C_t is the expenditure of period t, r is the discount rate, and t is time, as in formula (1) above.

3. Internal rate of return (IRR)

The IRR is the discount rate leading the net present value to 0, which means that the IRR is equal to the interest rate when the present value of the investment cost reaches the present value of the expected benefit. Decision-makers can decide on the priority of investment plans usually based on the IRR from high to low.

$$\sum_{t=0}^{N} [B_t/(1+r)^t] - \sum_{t=0}^{N} [C_t/(1+r)^t] \quad \text{......(3)}$$

where B_t is the income for period t, C_t is the expenditure of period t, r is the internal rate of return, and t is time.

4. Payback Period (PP)

The PP refers to the period of time for the investment cost to be returned in years. Decision-makers can choose the period they plan after comparing the PPs of different plans.

$$\sum_{t=0}^{N} = \frac{(B_t - C_t)}{(1+r)^t} = 0 \quad \text{......(4)}$$

where B_t is the income for period t, C_t is the expenditure of period t, r is the discount rate, and t is the return period.

B. Decision analysis

1. Break-even analysis (BEA)

The BEA is an important way for companies to manage and develop business. It not only can show the importance of fixed costs and variable costs, how product sales affect costs and income, and how product price fluctuations cause changes, but also explains how scale expansion will affect costs, income, etc.. Thus, it is used as a basis for investors to control production volumes, costs, and the sale price to avoid losses.

The common analytical methods of break-even include the equation method, contribution margin method, and graphical method. This study used the equation method to determine the smallest-scale investment with zero net profit of the investment plan; however, the diverse products in this study (electricity, biochar, and vinegar) had different production ratios, so only the following formula was used (Schweitzer et al. 1991):

Total revenue - total cost = net operating profit = 0... (5)

2. Sensitivity analysis

Sensitivity analyses are mainly divided into single-factor and multifactor sensitivity analyses. The analytical principles are the same, but the premise of the multifactor sensitivity analysis is that multiple factors that change at the same time are independent of each other, and the probability of fluctuating with each other is the same. Decision-makers can identify the most sensitive factors that may affect economic performance indicators and assess the scope of the changes they cause. At the same time, it can further analyze the causes of fluctuations and then adjust and avoid risks in a timely manner. On the other hand, it can also compare the sensitivity of many programs and choose the least sensitive and safest investment case (Saltelli 2000). When the NPV of an investment plan dramatically changes due to changes in some factors, that investment plan could pose a huge risk, and contrarily, it might represent investment cases that are trustworthy.

3. Scenario analysis

Scenario analysis is a process of analyzing future events by considering alternative possible outcomes (Aaker 2001). In this study, it refers to a method of analyzing impacts of multiple factors on the NPVs of investment plans when they change simultaneously. An early application was mainly used to evaluate overall macro-economic or political factors.

C. Operational parameters

1. Output efficiency of gasification power generation

This study used an improved updraft gasifier which controlled the gasification temperature within a range of 900~1,200℃, and based on the equipment design efficiency, the speed at which bamboo residues were fed to the unit was set to around 300 kg h^{-1} to produce 100 kWh of electricity. However, considering that bamboo residues have high cellulose contents, the calorific value is similar to that of wood, and some energy will be lost when the synthetic gas is converted into electricity, so the actual power generator production was set to 80 kWh. In addition, byproduct (charcoal and vinegar) output during the gasification process will increase or decrease with changes in the gasification temperature, air flow rate, fuel, air equivalent ratio, and raw material moisture content. Therefore, this study set charcoal and vinegar production rates to 2 and 4% of the raw material, respectively (Fig. 1).

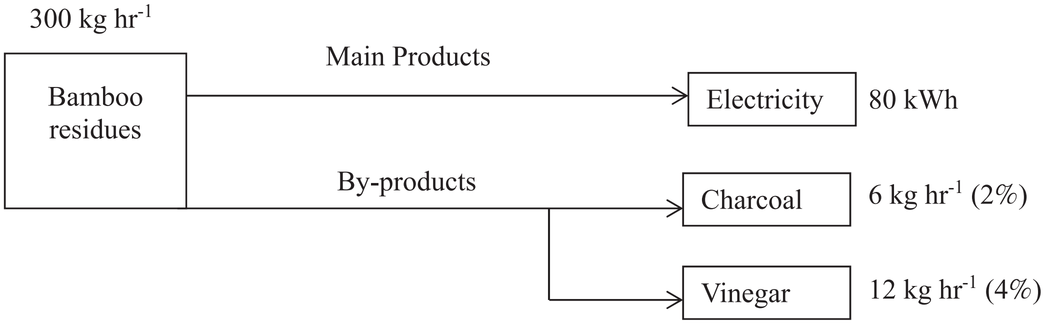

Fig. 1. Schematic diagram of the output of the gasification power generation.

2. Operational plan for gasification power generation

The operational plan was based on actual visits and results of a questionnaire survey conducted by the Forestry Research Institute in 2014, and refers to the design of gasification power generation equipment in the Taiwanese market. The plan for gasification power generation was divided into a single-plant type (with a throughput of 300 tons yr^{-1}) and a regional type (with a throughput of 8,400 tons yr^{-1}), and other related operational data are described in Table 1. In addition, relevant evaluation parameters for the investment plans were modified from a study by Arena et al. (2015), which was a cost-benefit evaluation for an investment plan for a small-scale gasification power generation system established for solid recovered fuel (Table 2).

3. Costs and benefits of the gasification power generation investment plans

Table 3 shows the construction costs, operational expenses, and other costs for this study, with quotations calculated based on governmental regulations and market prices provided by related factories. Among them, maintenance costs, power costs, and cost of

Table 1. Operation plans for 2 investment scenarios

Item	Single plant	Regional plant
Pre-processing equipment (no. of sets)	1	1
Gasification power generation (no. of sets)	1	5
Operators[1)] (workers yr^{-1})	1	9
Operating hours[2)] (h yr^{-1})	1,000	5,600
Consumption of raw materials (tons yr^{-1})	300	8,400
Net power generation[3)] (kWh yr^{-1})	80,000	2,240,000

1) The regional-plant equipment is based on a 24-h operation system, and 3 shifts are needed, including vacation.

2) The operating hours are the amount of raw materials divided by (300 kg h^{-1} × the number of gasification power generation equipment groups); the operating hours are the time that the equipment can be operated, deducting the time for inspection and maintenance when shut down, and the time of switching and warming up machines; the running rate is about 90%.

3) The net power generation is the operating hours × the amount of gasification power generation × 80 kWh h^{-1}; the annual net power generation is the annual amount of electricity remaining after deducting the amount of electricity supplying other equipment in the plant.

sales were calculated in accordance with coefficients derived from historical experience and related references. Table 4 shows potential economic benefits and non-economic benefits from the investment plan, which were based on related market prices, public regulations, and references.

Based on abovementioned costs and potential benefits, annual cost estimations and annual benefit estimations for 2 types of plants (single-plant and regional-plant) of gasification power generation were calculated in Tables 5 and 6, respectively.

RESULTS

A. Cost-benefit analysis

1. Cost and benefit comparisons of investment plans of the 2 types of plants

Table 7 shows comparisons of cost estimations for investment plans of the 2 types of plants within a discount period of 15 yr with a discount rate of 5.25%. Results show that for single-plant gasification power generation, the construction cost was the highest proportion at 56.4% (NT$10,320,000), and

Table 2. Operational parameters of gasification power generation

Item	Parameter value	Reference and description
Evaluated period	15 yr	Based on Arena et al.'s (2015) operating schedule
Evaluated basis	From January of the first year	The phase 0 is the establishment and operation test
Equipment lifetime	15 yr	Based on Arena et al.'s (2015) operational period of regular maintenance equipment
Discount rate	5.25%	Based on the parameters for "Renewable Energy Power Purchasing Rate 2018" (Energy Bureau, the Ministry of Economic Affairs, 2017)
Business tax	5%	Based on the minimum tax rate in the *Value-Added and Non-Value-Added Business Tax Law* (National Tax Administration, Ministry of Finance, 2017)

Table 3. Cost of the gasification power generation investment plan

Category	Item	Cost	Reference and description
Construction cost	Land cost	NT$15 sf^{-1} [1)]	Calculated by the rent cost for agricultural use in 2017[2)].
	Building expense	NT$18,000 sf^{-1}	Based on the Standard Table for Estimate Construction Cost of Building in Nantou County (2017).
		NT$200,000 set^{-1}	Referred by Ho (2001) steel plate simple scaffolding price.
	Equipment and installation	NT$8,000,000	Prices from local manufacturers, total price for a gasification generator set[3)] with grab machine.
		NT$2,120,000	Included 1 set pre-processing equipment[4)] See study by Mani et al. (2006).

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Operational expenses	Raw material purchasing	NT$300 ton^{-1}	Quotations provided by clearance operators in Zhushan.
	Raw material transportation	NT$300 ton^{-1}	
	Labor cost	NT$140 h^{-1}	Following the hourly minimum wage system of the Ministry of Labor (2018).
		NT$550,000 yr^{-1}	Based on the annual salary of a technician or operator[5)].
	Maintenance	2% of equipment cost	According to the research setting of Chang (2003) and Lee (2010).
	Power cost	1.01% of building cost	According to Fernández et al. (2015) to set the annual cost of water and other consumables.
		NT$2.4 kWh^{-1}	According to Sultana et al. (2010) to estimate power consumption 50 kWh h^{-1} for 2 tons by a pre-calculation of processing equipment and the average circulating electricity bill for low-voltage power by Taipower Co.
	Cost of sales	20% of byproduc income	Referring to data of foreign development, including packaging, transportation, advertising, and other expenses.
Others	Insurance	0.5% of construction Cost	Referring to gasification power generation experience by Arena et al. (2015).
	Business Tax	5% of products	According to the *Value-Added and Non-Value-Added Business Tax Law* announcement in 2017.

1) 1 sf means 1 Taiwanese square footage = 3.30579 m^2.

2) The rent for agricultural use calculated on an average basis based on the land renting website and the Nantou County rent price of the young farmers’ counseling platform 2017.

3) Including the gasifier body, turbine feeder, condensation tower, purifier, separator, circulating water pump, pipeline, internal combustion engine, transformer, etc.

4) A set of pre-processing equipment containing a crusher and conveying trough equipment.

5) The annual salary was based on Ho (2001), the “statistical report on the number of employees and average salary” from the open platform of government information and statistics of 104 Human Resources Banks..

the operational cost was second-highest at 37.3% (NT$6,835,642). For the regional-plant, the operational cost was the highest proportion at 68.3% (NT$173,608,563), and the construction cost was relatively lower at 23.7% (NT$60,273,097). Other costs for the single plant and regional plant were 6.3% and 8.0%, respectively. Among individual cost items, the highest proportions were the cost of equipment and installation at 55.3%

(NT$10,120,000) for the single plant and sales cost at 21.6% (NT$54,869,937) for the regional plant. The labor cost at 19.9% (NT$50,521,984) and the cost for raw materials at 19.7% (NT$50,132,711) were both similarly the second highest for the regional plant. Obviously, the investment plan for the regional plant needed more capital at ca. 13.87 times that for the single plant. However, the operating cost of residue disposal for the regional plant was relatively lower at NT$1,380.94 ton^{-1} compared to the single

Table 4.Benefits of the gasification power generation investment plan

Category	Item	Cost	Reference and description
Economic benefits	Shipping cost savings	NT$300 ton^{-1}	Quotation provided by the clearance transporter industry in Zhushan.
	Electricity sales income	NT$3.8 kWh^{-1}	Based on the “Regulations for Installation and Management of Renewable Energy Power Generation Equipment” (Bureau of Energy, Ministry of Economic Affairs 2015) and the “Renewable Energy Wholesale Purchasing Rate” (Bureau of Energy, Ministry of Economic Affairs 2017).
	Byproduct sales income	Charcoal: NT$20 kg^{-1}	Based on current market prices in Taiwan. Production rate: ca. 2% to bamboo residue per ton
		Vinegar: NT$70 kg^{-1}	Based on current market prices in Taiwan. Production rate: ca. 4% to bamboo residue per ton.
Non-economic benefits	Carbon dioxide emission reductions	0.554 kg CO_2 kWh^{-1}	Based on the “The electric power emissions coefficient in 2017” by Bureau of Energy, Ministry of Economic Affairs (2018).
		85% carbon content	The amount of carbon fixed based on a study of hypothesis carbon content by Hu (2004) and assuming that 80% of the carbon of the charcoal remains in the soil (Roberts et al. 2009)
	Job increase		1-9 worker

Table 5. Cost estimation for 2 types of gasification power generation plants

Items	Annual amount (NT$ yr^{-1})		Description
	Single-plant	Regional-plant	
Land cost	0	15,000	**Single:** The equipment was set up next to the existing factory, without extra cost **Regional:** 1,000 sf^{-1} 1) × NT$15 sf^{-1} yr^{-1}
Plant construction	200,000 (1 set)	18,000,000	**Single:** Based on current market unit price of plant construction (Ho, 2001) **Regional:** 1,000 sf^{-1} × NT$18,000 sf^{-1}

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Equipment & and installation	10,120,000 (1 set)	42,120,000	**Single:** NT$8,000,000 set^{-1}+NT$2,120,000 set^{-1} **Regional:** (NT$8,000,000 set^{-1}×5 sets)+ (NT$2,120,000 set^{-1})
Raw material acquisition	0	2,430,000	**Single:** Using self-produced bamboo residue[2)] **Regional:** 8,100 ton×NT$30 ton^{-1} [3)]
Raw material transportation	0	2,520,000	**Single:** Using self-produced bamboo residue[2)] **Regional:** 8,400 ton×NT$300 ton^{-1}
Labor costs	155,120	4,950,000	**Single:** NT$140 hr^{-1}×1worker×1,108 hr yr^{-1} **Regional:** NT$550,000 yr^{-1}×9 workers[4)]
Maintenance fee	162,400	642,400	**Single:** NT$8,120,000×2% **Regional:** NT$32,120,000×2%
Power costs	100,012	807,000	**Single:** 7,500 kWh×NT$2.4 kWh^{-1} + NT$8,120,000×1.01% **Regional:** (210,000 kWh yr^{-1}×NT$2.4 kWh^{-1}) +(NT$32,120,000×1.01%)
Sales costs	192,000	5,376,000	**Single:** NT$960,000 yr^{-1}×20% **Regional:** NT$26,880,000 yr^{-1}×20%
Insurance	40,600	160,600	**Single:** NT$8,120,000 yr^{-1}×0.5% **Regional:** NT$32,120,000 yr^{-1}×0.5%
Business taxs	63,200	1,769,600	**Single:** NT$1,264,000 yr^{-1}×5% **Regional:** NT$35,392,000 yr^{-1}×5%
Total	9,033,332	69,340,600	

[1)] 1 sf means 1 Taiwanese square footage = 3.30579 m^2.
[2)] The source of bamboo residue is produced by the case factory, so there are no extra costs to obtain raw materials.
[3)] In addition to our own residues of 300 tons yr^{-1}, 8,100 tons of raw materials need to be purchased outside.
[4)] This plan requires 24-h operation for equipment, so it needs 3 shifts including vacations.

Table 6. Benefit estimation for 2 types of gasification power generation plants

Items	Annual amount (NT$ yr^{-1})		Description
	Single-plant	Regional-plant	
Save on shipping	90,000	90,000	**Single:** 300 ton×NT$300 ton^{-1} **Regional:** 300 ton×NT$300 ton^{-1}
Electricity sales	304,000	8,512,000	**Single:** 80,000 kWh×NT$3.8 kWh^{-1} [1)] **Regional:** 2,240,000 kWh×NT$3.8 kWh^{-1}
Charcoal sales	120,000	3,360,000	**Single:** 300 ton×0.02×(NT$20 kg^{-1}) **Regional:** 8,400 ton×0.02×(NT$20 kg^{-1})
Vinegar sales	840,000	23,520, 000	**Single:** 300 ton×0.04×(NT$70 L^{-1}) **Regional:** 8,400 ton×0.04×(NT$70 L^{-1})
Total	1,354,000	35,482,000	

[1)] Wholesale purchase price per kWh of general waste renewable energy.

Table 7. Comparison of cost estimations for 2 types of plant investment planss

Category	Item	Single plant Discounted value (NT$)	%	Regional plant Discounted value (NT$)	%
Construction costs	Land cost	-	0	153,097	0.0
	Plant construction	200,000	1.1	18,000,000	7.1
	Equipment and installation	10,120,000	55.3	42,120,000	16.6
Subtotal		**10,320,000**	**56.4**	**60,273,097**	**23.7**
Operational costs	Raw material	-	0	50,132,711	19.7
	Labor cost	1,583,274	8.6	50,521,984	19.9
	Maintenance	2,065,788	11.3	8,597,923	3.4
	Power cost	1,226,939	6.7	9,486,008	3.7
	Sales cost	1,959,641	10.7	54,869,937	21.6
Subtotal		**6,835,642**	**37.3**	**173,608,563**	**68.3**
Others	Insurance	516,447	2.8	2,149,481	0.9
	Business tax	645,048	3.5	18,061,354	7.1
Subtotal		**1,161,495**	**6.3**	**20,209,835**	**8.0**
Total		**18,317,137**	**100**	**254,091,495**	**100**
Operating costs of residue disposal (NT$ ton^{-1})		1,519.03		1,380.94	
Operating cost of power generation (NT$ kWh^{-1})		5.70		5.18	

[1)] The total amount was discounted over a period of 15 yr, at a discount rate of 5.25%.

plant at NT$1,519.03 ton^{-1}, and the operating cost of power generation for the regional plant was also lower at NT$5.18 kWh^{-1} compared to the single plant at NT$5.70 kWh^{-1}.

Table 8 shows comparisons of benefit estimations for investment plans of the 2 types of plants within the same period and the same discount rate as mentioned above for the cost estimation, and all earnings were added up through the discount rate to the ready-made NPV. The greatest economic benefits for both investment plans were not from electricity sales, which were estimated to be around NT$3,102,764 for the single plant and NT$86,877,400 for the regional plant, but from vinegar sales. The benefits of vinegar sales for the single plant and regional plant were estimated to be NT$8,573,428 and NT$240,055,975, respectively. Comparatively, the investment plan for the regional plant could realize 28-fold economic benefits from only vinegar sales compared to the investment plan for the single plant, and the overall economic benefit of the investment plan of the regional plant (at NT$362,145,668) was around 26.2-fold that of the single plant (at NT$13,819,549). Meanwhile, the investment plan for the regional plant could provide more non-economic benefits in terms of carbon dioxide emissions reduction of up to 1,659.84 tons yr^{-1} compared to around 59.28 tons yr^{-1} for the single-plant, and the plan could provide more job opportunities for up to 9 people.

The CBA results are shown in Table 9. The NPV for the investment plan of the single-plant with a 15 yr operating period was -NT$4,497,588, the CBR was 0.754, and the

Table 8. Comparison of benefit estimations of 2 types of plant investment plans

Category	Item		Single plant	Regional plant
Economic benefits (NT$)	Save on shipping costs		918,582	918,582
	Electricity sales		3,102,764	86,877,400
	Byproduct sales	Charcoal	1,224,775	34,293,711
		Vinegar	8,573,428	240,055,975
Total			13,819,549	362,145,668
Non-economic benefits	Carbon dioxide emissions reductions (ton yr^{-1}) reducing (ton yr^{-1})		59.28	1,659.84
	Job provision		1 worker	9 workers

1) The total amount was discounted over a period of 15 yr, at a discount rate of 5.25%.

Table 9. The cost-benefit analysis indicators between the single-plant and regional-plant investment plans

Item	Single plant	Regional plant
Net present value (NT$)	-4,497,588	107,663,898
Cost-benefit ratio	0.754	1.423
Internal rate of return (%)	-2.26%	26.54%
Payback period (yr)	59	5

1) The total amount was discounted over a period of 15 yr, at a discount rate of 5.25%.

IRR was -2.26%. In addition, it would take 59 yr to recover the capital. Obviously, this long uncertainty indicates a high risk, which would not be a beneficial investment plan. Relatively, the NPV of the investment plan of the regional plant could reach NT$107,663,898, the CBR was 1.423, the IRR was 26.54%, and the payback period was 5 yr. Based on this cost-benefit analysis, the plan for the regional plant could be an economically feasible investment.

2. Break-even analysis (BEA)

Based on the CBA results of the gasification power generation investment plans for the single plant and regional plant, gasification power generation operation using bamboo residues would obviously produce economic benefits within 15 yr, the investment scale would need to exceed the single-plant investment plan, and the disposal capacity of bamboo residues could reach 300~8,400 tons yr^{-1} in the Zhushan area. Therefore, this study simulated 5 investment plans in accordance with 5 sets of equipment (1~5 sets) and analyzed their break-even points, particularly to determine the minimum amounts of bamboo residue to be supplied annually. This is important information as a reference for investors.

Results of the BEAs are shown in Table 10. The number of equipment sets was closely correlated with residue consumption and power generation. The disposal capacity of residue should be at least ca. 1,347 tons yr^{-1} and at least ca. 359,364 kWh yr^{-1} of electricity should be generated to achieve a break-even point when only 1 set of equipment is set up. The status when 5 sets of equipment are set up were that the disposal capacity of residue should be at least ca. 3,011 tons yr-1 and the electricity generated would be ca. 802,958 kWh yr^{-1} to achieve the break-even point. Under this scenario, all of the bamboo residues in the Zhushan area would basically be a sufficient amount to supply the investment plans.

B. Sensitivity analysis results

1. Cost single-factor sensitivity analysis

This study analyzed the sensitivity of three single factors of raw material costs, labor costs, and electricity costs, and results are shown in Table 11. In comparison, the raw material cost had the highest sensitivity to the NPV. Once the cost of raw materials increased to 30% (from NT$600 to NT$780 ton^{-1}), the NPV was reduced to NT$92,507,303, and the rate of change was -14.1%. Conversely, once the cost of raw materials decreased 30% (from NT$600 to NT$420 ton^{-1}), the NPV increased to NT$122,820,494, with a rate of change of 14.1%. Labor costs were highly susceptible to inflation and financial market turmoil as well, and once the average employee's salary increased 30% (from NT$550,000 to NT$715,000 yr^{-1}), the NPV decreased to NT$92,978,542, with a rate of change of -13.6%. Conversely, once the average labor salary decreased 30%, the NPV increased to NT$123,283,311, with a rate of change of 14.5%. Regardless of a change in the cost of raw materials or labor within a range of ±30%, the NPV remained positive, which means that investment in regional-plant gasification power generation still had a profitable space.

For long-term operation, the electricity costs could be considered a sensitivity factor due to power peak periods and summer seasons. However, an increase or decrease in the electricity cost within ±30% influenced the NPV only slightly within a range of ±1.4%. Obviously, the electricity cost was not significantly sensitive for the investment plan of regional-plant gasification power generation.

2. Benefit single-factor sensitivity analysis

Table 12 shows sensitivity analysis results of 3 single factors of the wholesale purchase price of renewable energy, the charcoal price, and the vinegar price. Among these 3 factors, fluctuation in the vinegar price was most sensitive to the NPV, the wholesale purchase price of renewable energy was the second-most sensitive factor, and the charcoal price was a relatively weakly sensitive factor. The current vinegar price in Taiwanese markets varies within a wide range of NT$50~200 L^{-1}. This study adopted a price of NT$70 L^{-1} as a basic value for ease of estimation. Once the sale price of vinegar increased 30% (from NT$70 to NT$91 L^{-1}) or decreased 30% (from NT$70 to NT$49 L^{-1}), the NPV increased to NT$176,079,851 with a rate of change of 63.5% or decreased to NT$39,247,946 with a rate of change of -63.5%, respectively.

Table 10. Break-even analysis of investment plans for different equipment sets

No. of equipment sets	Item				
	Operation time (hr yr^{-1})	Residue consumption (tons yr^{-1})	Power generation (kWh yr^{-1})	Unit cost of residue disposal (NT$ ton^{-1})	Unit cost of power generation (NT$ kWh^{-1})
1	4,492.05	1,347.62	359,364.36	1,390.20	5.21
2	2,734.41	1,640.65	437,505.79	1,268.68	4.83
3	2,391.24	2,152.11	573,896.72	1,367.69	5.13
4	2,093.18	2,511.81	669,816.21	2,915.64	5.02
5	2,007.40	3,011.10	802,958.92	2,907.56	5.18

[1)] The unit costs were calculated at the present value with a discount rate of 5.25%.

Table 11. Cost single-factor sensitivity analysis to net present value (NPV)

Cost	Raw materials		Labor costs		Energy charges	
Rate of change	NPV (NT$)	Rate of change	NPV (NT$)	Rate of change	NPV (NT$)	Rate of change
+30%	92,507,303	-14.1%	92,978,542	-13.6%	106,120,681	-1.4%
+25%	95,033,402	-11.7%	95,496,219	-11.3%	106,377,884	-1.2%
+20%	97,559,501	-9.4%	98,022,319	-9.0%	106,635,087	-1.0%
+15%	100,085,601	-7.0%	100,548,418	-6.6%	106,892,290	-0.7%
+10%	102,611,700	-4.7%	103,074,517	-4.3%	107,149,493	-0.5%
+5%	105,137,799	-2.3%	105,600,616	-1.9%	107,406,696	-0.2%
0%	107,663,898	0.0%	107,663,898	0.0%	107,663,898	0.0%
-5%	110,189,998	2.3%	110,652,815	2.8%	107,921,101	0.2%
-10%	112,716,097	4.7%	113,178,914	5.1%	108,178,304	0.5%
-15%	115,242,196	7.0%	115,705,013	7.5%	108,435,507	0.7%
-20%	117,768,295	9.4%	118,231,112	9.8%	108,692,710	1.0%
-25%	120,294,394	11.7%	120,757,212	12.2%	108,949,913	1.2%
-30%	122,820,494	14.1%	123,283,311	14.5%	109,207,115	1.4%

The wholesale purchase price of renewable energy was formulated by the Taiwanese energy authority based on the *Renewable Energy Development Act*, which is to promote renewable energy development. Obviously, the NPV was significantly affected by the wholesale purchase price of renewable energy. Once the wholesale purchase price increased 30% (from NT$3.80 to NT$4.94 kWh^{-1}) or decreased 30% (from NT$3.80 to NT$2.66 kWh^{-1}), the NPV increased to NT$132,423,957 with a rate of change of 23.0% or decreased to NT$82,903,839 with a rate of change of -23.0%, respectively.

With regard to the sale price of charcoal, there was only a small impact on the NPV of the investment plan. Once the charcoal price increased 30% or decreased 30%, the NPV increased or decreased in value only with a rate of change of ±9.1%.

Based on the above-described analytical results, in general, labor costs, raw material costs, vinegar prices, and the wholesale purchase price of renewable energy were sensitive factors that impacted the NPV of investment in regional-plant gasification power generation.

3. Discount rate sensitivity analysis

Table 13 shows that the effect of the discount rate on the NPV varied. Once the discount rate increased 8%, the NPV was reduced to NT$80,589,167, which was 25% less than the original base value. When the discount rate increased 12%, the NPV sharply decreased to nearly 51.9% to NT$51,843,720, but the NPV remained positive, which means that the general investment plan could still meet the requirements of economic benefits, and the investment risk was within tolerance.

C. Scenario analysis

According to the multiple sensitivity analytical results, the costs of raw materials, labor costs, and the vinegar price were obviously significant sensitive factors for the economic benefits of the investment plans. Therefore, to provide a more-valuable reference for investors, this study further explored the uncertainty caused by changes in these factors through a

Table 12. Benefit single-factor sensitivity analysis to net present value (NPV)

Benefits	Wholesale purchase price of renewable energy		Charcoal price		Vinegar price	
Rate of change	NPV (NT$)	Rate of change	NPV (NT$)	Rate of change	NPV (NT$)	Rate of change
+30%	132,423,957	23.0%	117,437,606	9.1%	176,079,851	63.5%
+25%	128,297,281	19.2%	115,808,655	7.6%t	164,677,192	53.0%
+20%	124,170,604	15.3%	114,179,703	6.1%	153,274,534	42.4%
+15%	120,043,928	11.5%	112,550,752	4.5%	141,871,875	31.8%
+10%	115,917,251	7.7%	110,921,801	3.0%	130,469,216	21.2%
+5%	111,790,575	3.8%	109,292,850	1.5%	119,066,557	10.6%
0he	107,663,898	0.0%	107,663,898	0.0%	107,663,898	0.0%
-5%	103,537,222	-3.8%	106,034,947	-1.5%	96,261,240	-10.6%
-10%	99,410,545	-7.7%	104,405,996	-3.0%	84,858,581	-21.2%
-15%	95,283,869	-11.5%	102,777,045	-4.5%	73,455,922	-31.8%
-20%	91,157,192	-15.3%	101,148,093	-6.1%	62,053,263	-42.4%
-25%	87,030,516	-19.2%	99,519,142	-7.6%	50,650,604	-53.0%
-30%	82,903,839	-23.0%	97,890,191	-9.1%	39,247,946	-63.5%

Table 13. Effect of various discount rates on the net present value (NPV)

Discount rate (%)	5.25	8.0	10.0	12.0
NPV (NT$)	107,663,898	80,589,167	64,916,250	51,843,720

scenario analysis of raw material costs, labor costs, and the vinegar price under the worst and the best conditions. As shown in Table 14, under the worst investment scenario, once annual raw material costs and labor costs rose 30%, and the vinegar price dropped 30%, the NPV decreased from NT$107,663,898 to NT$17,336,714, the internal rate of return sharply dropped to 9.30%, the cost-benefit ratio was 1.064, and up to 11 yr was needed to recover the capital payback period. Conversely, once the best investment condition occurred with raw material costs and labor costs down 30%, and vinegar price up 30%, the NPV had a very high profit margin of NT$221,996,680, which was double the original base value. In addition, the internal return rate was up to 45.82%, the cost-benefit ratio was 2.046, and only 3 yr was needed to recover the initial investment capital.

DISSCUSION

A.Costs and benefits

As to the cost structure of single-plant gasification power generation, the construction cost was the highest proportion (56.4%), but for the regional-plant type, the operational cost was the highest proportion (68.3%); the main reason was the need to pay more to purchase raw materials and hire more employees to operate in order to reach the electricity generation target. According to studies by other scholars, the cost structure of related equipment operation is mainly divided into two categories: capital expenditures and operating expenses. Capital costs include construction costs, equipment costs, installation costs, insurance, and overhead costs. Operating expenses usually refer to ongoing expenses, including labor costs, management

Table 14. Scenario analysis based on different conditions

Item	Basic scenario	Worst scenario	Best scenario
Raw material costs (NT$ ton^{-1})[1)]	600	780	420
Labor costs (NT$ yr^{-1})[2)]	550,000	715,000	385,000
Vinegar price (NT$ kg^{-1})	70	49	91
Net present value (NT$)	107,663,898	17,336,714	221,996,680
Internal rate of return (%)	26.54	9.30	45.82
Cost-benefit ratio	1.423	1.064	2.046
Payback period (yr)	5	11	3

[1)] The sum of the raw material purchase cost and transportation fee.
[2)] Annual average salary for each employee.

costs, electricity consumption or fuel costs, maintenance costs, and residual waste disposal costs. In the cost structure for gasification power generation, equipment costs account for a relatively high proportion of total costs, among which the gasifier cost accounted for the highest proportion (about 30~50%) (Wu et al. 2002, Moon et al. 2011, Arena et al. 2015), and labor costs and gasification waste disposal costs were mainly higher among operating expenses (Arena et al. 2015). In addition, Wu et al. (2002) and Arena et al. (2015) also included expenditures of biomass or waste pretreatment, such as crushing, drying, screening, etc. in operating expenses. Moon et al. (2011) evaluated the costs and benefits of two biomass conversion technologies of gasification power generation and direct incineration, and results showed that the special power generation costs of the 2 power generation systems were inversely proportional to the capacity of the device, when they assumed the investment plan operated for 330 days a year with a discount rate of 3%.

On the other hand, the benefits of gasification power generation can be divided into economic benefits and environmental benefits, and the economic income is mainly the feed in tariffs or renewable energy subsidies of various countries, and the income is from sales of byproducts. For example, Rentizelas et al. (2009) conducted an evaluation of the technical and economic feasibility of a medium-scale gasification power generation system (< 1 MW), and from a technical perspective, the power-to-heat ratio of the gasification power generation technology was higher than that of the organic Rankine cycle (ORC); the internal rate of return for the gasification power generation system investment plan was 18%, and the cost could be recovered in just 7.8 yr, which was economical. This also shows that gasification power generation technology is a future developmental industry. In addition, according to Arena et al.'s (2015) research, gasification of waste for power generation can also help save landfill gate fees. The payback period of the investment plan of the regional-plant in this study was 5 yr with an internal rate of return of 26.54%; obviously, the plan could be an economically feasible investment as well.

However, the operating cost of power generation for the regional plant (NT$5.70 kWh^{-1}) and the single plant (NT$5.18 kWh^{-1}) were both higher than the current tariff of the wholesale purchase price for renewable energy of NT$3.8 kWh^{-1}. Compared to other renewable energy costs, the cost of gasification power generation was higher than conventional hydropower (at NT$1.54 kWh^{-1}), wind power (at NT$3.48 kWh^{-1}), and energy from wood chips (at NT$2.24 kWh^{-1}) and wood pellets (at NT$2.7 kWh^{-1}), but was lower than solar energy (at NT$10.14 kWh^{-1}) (Lin and Pan 2016). Thus, the main economic benefits of the investment plan under current circumstances were from the sale of vinegar with a beneficial price before the wholesale purchase price of renewable energy rises.

B.Break-even analysis

In general, operating costs will increase with an expansion of the gasification power plant scale, because it requires more raw materials and labor input. In the case of adopting only 1 set of equipment, to avoid losses, it is necessary to produce at least ca. 359,364 kWh yr^{-1} of electricity, with residue consumption of ca. 1,347 tons yr^{-1}. Once the equipment increased to 2 sets, 437,505 kWh yr^{-1} of electricity needed to be produced with ca. 1,640 tons of bamboo residue to reach a balance of benefits and losses of the investment. Likewise, once equipment sets increased, electricity generation and residue consumption demand simultaneously increased. However, comparing the 5 simulations, the unit cost of residue disposal and the unit cost of power generation were not lowest for 5 sets of operated equipment, but 2 sets of operated equipment had the lowest values of NT$1268.68 ton^{-1} and NT$4.83 kWh^{-1}, respectively. That means the operation scale using 2 sets of equipment should be the most economical and feasible for investment, under a break-even point at a disposal capacity of residue of ca. 1,640 tons yr-1 and electricity generation of ca. 437,505 kWh yr^{-1}.

The reason that the unit cost of residue disposal and the unit cost of power generation under 1 set of equipment were both higher than with 2 sets of equipment was the labor cost of the 2 sets of equipment was the same as that with 1 set of equipment, but with an increasing production scale, the unit cost of production declined. However, when the scale of gasification power generation exceeded a certain scale, to reach the break-even point, it required more labor when the factory planned to produce more electricity. Undoubtedly, extra labor costs would increase the unit cost of production (power generation).

C.Sensitivity analysis

Many operation factors such as raw material prices, labor costs, fuel prices, and other expenses may fluctuate in the future. To let investors easily determine the risks of investment plans, it is necessary to conduct a sensitivity analysis of factors that could significantly affect the economic benefits of the investment, and evaluate the level of influence of these factors on the investment plans. Based on results of the sensitivity analysis in this study, raw material and labor costs were the most sensitive factors in the cost structure for the regional-plant investment plan. In terms of labor costs, the range of fluctuation depends on the price index and inflation rate at that time. Also, changes in raw material prices will depend on the growth of biomass and the trend of international biomass energy that year. As for economic benefits, the vinegar price and the wholesale purchase price of renewable energy had the most significant impacts on the net present value of the investment plan and the internal rate of return, while the price of vinegar was affected by development trends of the agricultural product market, and the wholesale purchase price of renewable energy depends on governmental energy policies. Regardless of changes in the raw material costs, labor costs, vinegar prices, or wholesale purchase prices of renewable energy within a range of ±30%, the NPV remained positive, which means that investment in a regional-plant for gasification power generation still has a profitable space.

CONCLUSIONS

In the 1960s~1980s, bamboo-related processing industries were important industries in Taiwan and greatly contributed to economic improvements for bamboo farmers, local communities, and the government. But since 1982, the number of bamboo-processing factories rapidly declined year by year due to loss of the advantage of lower labor costs. In 2004, there were fewer than 100 registered factories still in operation as small businesses in Taiwan, with most currently clustered in the Zhushan area (Lin 2011). For these small bamboo processing factories, the accumulated bamboo processing residue is causing critical economic and environmental problems for business management (Lin et al. 2017). Therefore, developing a multifunctional approach to resolve the above-mentioned problem is an important issue for local industries.

The purposes of this study were to evaluate the cost structure and economic and non-economic benefits of single-plant and regional-plant gasification power generation using bamboo processing residue in the Zhushan area, and explore investment values through NPV estimations. All these analyses can serve as useful references to utilize bamboo processing residues for government or industry in the future.

Regardless of the economic or non-economic benefits, it would be feasible and worthwhile to invest in gasification power generation using bamboo residues. Although gasification currently requires higher capital investment and there are higher relative unit costs than other renewable energy sources, it still possesses advantages and potential in product diversity. Compared to solar energy, wind power, or hydroelectric power, the biomass from bamboo residue could produce not only electricity, but also byproducts such as ash, biochar, tar, and vinegar. All of these products are extremely valuable as agricultural additives.

Once a gasification power plant is successfully established and operated in the Zhushan area, numerous contributions are expected for the local economy through economic benefits and job creation. In addition, gasification power generation using bamboo residues could solve disposal problems that have existed for a long time, simultaneously promoting regional industrial activity and development, and avoiding continued shrinkage of local related bamboo processing industries.

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