THE INFLUENCE OF TECHNICAL FACTORS AND FUEL SOURCES ON SMALL-SCALE BIOMASS POWER PLANT INVESTMENT AND SOLUTIONS

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ABSTRACT

This paper introduces the influence of technical parameters, fuel zones on the investment, production and business of small capacity biomass power plants, as well as analyzes some factors affecting the investment and business activities of small capacity biomass power plants in Vietnam. Based on the economic analysis and financial efficiency of the biomass power project, solutions were proposed to solve the difficulties for investors. From the issues mentioned, the paper provided more information for enterprises to orient technology transfer, training units to orient training and scientific research.

Keywords: *Biomass, cashew nut skin, economic analysis, biomass power plant.*

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1. INTRODUCTION

Vietnam is currently one of the highest exporters of wood chips and pellets in the world. It has increased rapidly in recent years. Biomass fuel sources, such as cashew residues, coffee husks, rice husks, rice plants, and food crops have a significant volume, and are used in several ways with different purposes and properties. Vietnam is currently one of the highest exporters of wood chips and pellets in the world. It has increased rapidly in recent years. Biomass fuel sources, such as cashew residues, coffee husks, rice husks, rice plants, and food crops have a significant volume, and are used in several ways with different purposes and properties. The trend of co-firing and firing with biomass fuel in industrial boilers has been widely applied for decades. The orientation of burning biomass fuel in thermal power plants was initially studied and strongly considered in the current period and in the future. A number of oriented and promoting policies of the government, electricity prices corresponding to different types of fuel sources: waste, renewable energy, solar power, and biomass fuel have been issued. With the area of forests and hills accounting for three-quarters of Vietnam's territory, Vietnam's biomass potential is still very large and promises a lot of potential. The conversion of energy from biomass fuel to clean electric energy, in order to reduce transportation costs, converting energy at the source, can be considered as a suitable solution to promote economic development in regions. Raw materials, towards a circular economy, using energy - renewable fuel, in line with the orientation of society and Vietnam's commitments at COP26. In which, the decision to build a small capacity biomass power plant located in raw material areas is a necessary solution. When investing in a biomass power plant, the influence of technical parameters, factors on fuel areas, economic and financial indicators, was indicated in this research.

2. METHODS

In order to have a complete, reliable and appropriate basis for this paper, the research methodology is as follows:

Conduct field surveys of raw material areas, directly interview representatives of biomass fuel suppliers in the South, North and Central regions, collect data on market prices and shipping charges from 2018 to 2022. Researching the market, collecting quotations to supply equipment and technology for biomass power plants of some firms in the world, with manufacturing plants in China, India and some G7 countries. Based on financial data, current interest rates and actual costs in production of similar technological processes.

Based on the issued and effective management documents of ministries and branches. The documents, survey parameters, collected data, calculation methods and results are stated in this research as follows: Decision No. 2068/QD-TTg dated November 25, 2015 approving the

development strategy of renewable energy of Viet Nam by 2030 with a vision to 2050; Decision No. 24/2014/QD-TTg dated March 24, 2014 and Decision No. 08/2020/QD-TTg dated March 05, 2020 on support mechanism for development of biomass power projects in Viet Nam; Circular No. 16/2020/TT- BCT dated July 7, 2020 of the MOIT on amending and supplementing a number of articles under the Circular No. 44/2015/TT- BCT dated December 9, 2015 of the MOIT on project development, avoided cost tariff and standardized power purchase agreement for biomass power projects.

3. RESULTS AND DISCUSSION

3.1. Survey results

3.1.1. Fuel used for the project

Based on the actual survey, the approximate analysis, the approximate value of the mixed fuel based on the ratio calculated for the project are shown in Table 1.

Table 1. Proximate and ultimate analysis of mixed fuels

No.	Criteria	Value	Unit
1	Carbon, C^{lv}	32.78	%
2	Hydrogen, H^{lv}	3.87	%
3	Nitrogen, N^{lv}	0.24	%
4	Sulphur S^{lv}	0.02	%
5	Ash, A^{lv}	0.90	%
6	Moisture, W^{lv}	36.68	%
7	Chloride, Cl^{lv}	0.01	%
8	Oxygen, 0^{lv}	25.51	%
9	Low heat value: Q^{lv}_t	10.317	MJ/kg

Price and heat value cost of biomass sources

Based on the survey, the price of biomass sources fluctuated with a big range in recent years due to the unstable price of fossil fuel in the market (Fig. 1). In addition, it also changes, depending on different seasons in the year.

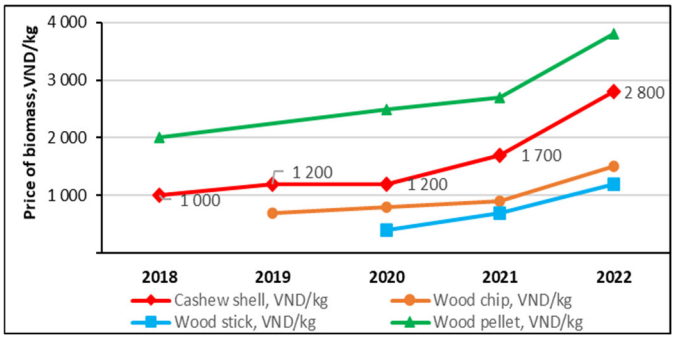

Fig. 1. Fluctuation of biomass price in recent years

Table 2. Price of biomass types (biomass and coal)

Type of fuels	2020		2021		2022	
	VND/kg	VND/MJ	VND/kg	VND/MJ	VND/kg	VND/MJ
Cashew shell	1,200	68	1,700	96	2,800	159
Wood chip	800	88	900	99	1 500	165
Wood pellet	2,500	131	2,700	142	3,800	200
Fine coal (Indonesia)	2,284	111	3,500	170	4,370	212

Source: Interview and synthesis in April, 2022

The Comparison of the fuel prices and the energy prices between fine coal of Indonesian origin and some other biomass fuels within the scope of the project is shown in Table 2.

The transportation cost

The transportation cost of cashew shell and woodchips is different, depending on the transport distance, as shown in Fig. 2. Low bulk density materials (350 - 415kg/m^3) occupy more space, hence costing more to deliver per unit of weight and increase feedstock costs. In addition, materials with lower moisture content cost less to transport and can reduce the amount of handling.

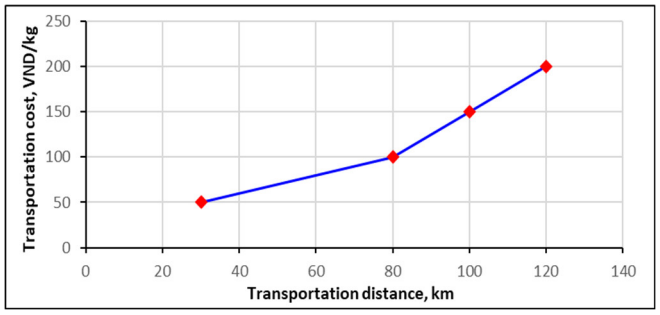

Fig. 2. Transportation cost of cashew shell and wood chips

3.1.2. Technology comparison for options

The general diagram of a thermal power plant is shown in Fig. 3, in which the main equipment is boiler, turbine, condenser, supply pump, deaerator and some heaters. In particular, the boiler integrated with the fuel combustion zone is one of the important points for deciding the main technology of the thermal power plant.

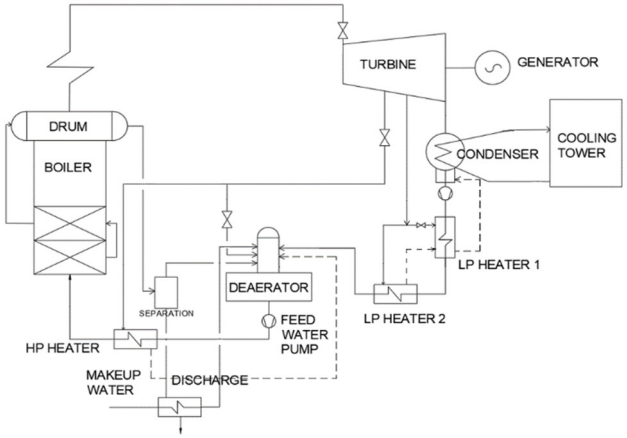

Fig. 3. The general diagram of a thermal power plant

The heat energy from the fuel combustion process is carried away by the smoke and conducts the heat exchange process at the heat exchanger surfaces: the water heater, the steam generator and the superheater to generate superheated steam. The superheated steam is led into the steam condensing turbine, the heat energy of the steam is

converted into mechanical energy to rotate the turbine and drive the generator. In addition, a part of steam is extracted for the heat exchanger, and deaerator. Wet-saturated steam exits the turbine and is condensed in the condenser. The condensate is then returned to the water supply system. The air at the cooling tower cools the water that cools the condenser.

For a power generation capacity of 12MW, the thermodynamic parameters selected and analyzed are listed in Table 3. The analysis of the principle heat balance system for different thermodynamic parameter pairs is part of this project to determine the plant's technical and economic analysis. These are 5 options calculated, analyzed from there to determine the optimal option with the lowest technical and economic parameters for detailed calculations for the contents of this project.

Table 3. Summary of thermodynamic parameters

No	Criteria	Formula	Unit	CH1	CH2	CH3	CH4	CH5
1	Superheated steam pressure	P_0	bar	40	64	64	90	90
2	Superheated steam temperature	t_o	°C	400	480	480	540	540
3	Pressure of degassing tank	P_{bkk}	bar	2,7	6	2,7	6	9
4	Temperature of supply water	t_{nc}	°C	130	160	160	190	210

3.1.3. The financial plan of raising capital for investment

For projects with a high total investment, it is necessary to mobilize more loans from commercial banks and low-interest funds. The rate of capital mobilization from shareholders or the enterprise's own capital should not exceed 30%. With this type of project, it is being encouraged by the state, contributing to reducing greenhouse gas emissions. Many commercial banks and funds have lending policies if the project's effectiveness is good. Total investment capital of the project is around: 386,123 million VND, where: The owner's equity is 20% of total investment capital. Corresponding amount is 104,826 million VND. The loan capital is 80% of total fixed investment capital. Corresponding amount is 281,297 million VND and the grace period during construction. The loan term is 10 years.

Operation and Maintenance Costs

Factory operating costs include: (i) Direct manufacturing costs (electricity, chemicals, human resources); (ii) General management expenses; and (iii) Maintenance and repair costs. The increase in operating expenses is estimated at 2%/year - in accordance with the average inflation rate. The direct manufacturing costs include cost of materials such as electricity, oil, chemicals, labor costs and the cost of burying the remaining solid waste after treatment (if any).

The general management expenses include the expenses for factory managing officials and the cost of operating the factory management office. The maintenance and repair costs, calculated averagely in % annually, including the following main cost streams such as the quarterly and annual maintenance; the small repair which carried out every 5 years; the medium repair which carried out every 10 years and the major repair which carried out every 15 years.

3.2. Techno-economic analysis

3.2.1. Key parameters for analysis

With the collected data and assumptions for calculation, the results are summarized as shown in Table 4.

Table 4. Summary of key parameters of a 12MW biomass power plant

No	Mentioned object	Quantity	Unit
1	Kind of wood chips	408.2	Tons/day
2	Type of boiler	Bubbling Fluidized Bed Boilers	
3	Type of turbine	Extraction-condensing Turbines	
4	Thermal capacity boiler	35.0	MW_{th}
5	Installed capacity generator	12	MVA_e
6	Conversion factor /overall efficiency (From biomass fuel to kWh)	28.88 (Gross) 24,08 (Net)	%
7	Net export capacity	10.0	MW
8	Full load hours per year	8,000	h/year
9	Total parasitic capacity	2.0	MW
10	Investment cost	386,123	1,000,000 VND
11	Annual fuel cost	108,864	1,000,000 VND/year
12	FIT feed in tariff	0.105 2,370	USD / kWh VND/ kWh
13	Annual revenue from operation	230,658	1,000,000 VND/year
14	Internal Rate of Return (IRR)	13.7	%
15	Payback Period	15.7	Years

Based on the selected options, the detailed calculation of the heat part, the analysis of factors affecting the investment efficiency of the project are carried out in this article. Through thermodynamic parameters and economic and technical indicators, key parameters were presented in Table 5.

Table 5. Summary of thermodynamic parameters and technical indicators

No	Criteria	Formula	Unit	CH1	CH2	CH3	CH4	CH5
1	Total efficiency (The actual thermal efficiency, Gross/Net power electricity)	η_c	%	23.30 18.72	26.64 21.96	26. 60 21.93	28.88 24.08	28.9 24.10

2	Fuel consumption	B_{tc}	t/h	21.08	18.44	18. 74	17.01	17,0
3	Self-consumption electricity	W_{td}	kW	2.360	2.108	2.105	1.993	1.995
4	Capacity of the boiler	D_{LH}	Tons/h	64.97	53.41	53.50	47.14	47.1
5	Condenser cooling water flow	D_{LM}	m^3/h	3.706	3.066	3.063	2.715	2.717

Technical parameters of the thermal cycle

In this calculation, the results show that: Through thermodynamic parameters and economic and technical criteria, option 4 (CH4 or LH-12-90-540-BKK 6.0 bar) is chosen because of following reasons: The heat value of the fuel can ensure the increase of pressure parameters, the superheated steam temperature reaches 90 bar, 540 °C stably and meet the requirements of unstable loads; The superheated steam pressure and temperature are higher than options 1, 2, 3, so the boiler's steam output needs to be smaller while still ensuring the designed power generation capacity; Fuel consumption for the option 4 is 17.01 tons/hour, approximately 408.2 tons/day and option 5 is 17.0 tons/hour, approximately 408.00 tons/day. The two options are more fuel-efficient than options 1, 2, and 3. This is the key point to determine the project's economy; The total efficiency (The actual thermal efficiency - Gross/Net power electricity) of configuration 4 and 5 is higher than that of configuration 1, 2, 3. The deaerator works at a pressure of 6 bar, which is widely used in thermal power plants and shows high safety and reliability. This degassing pressure ensures that the concentration of non-condensable gasses (residual oxygen, CO_2) is low enough to ensure safety in accordance with regulations and minimize oxidation problems at heat exchangers, high temperature areas of the plant superheater, the current transmission part of the turbine.

Capital Costs including clear underlying assumptions

Total investment of the power plant is expected 386,123 million VND with a generating capacity of 12MW. The investment items are shown in Table 6 and the operating costs are shown in Table 7.

Table 6. Estimated total project investment

No.	Items	Value
I	Fixed Capital (1.1 + 1.2 + 1.3+1.4)	351.622
1.1	Equipment cost	256.760
1.2	Construction costs	36.916
1.3	Other costs	55.161
1.4	Cost of site clearance	2.785
II	Paying interest on loan demand during construction period	0
III	Working capital for 3 months	34.502
IV	Total project investment capital	386,123

Table 7. Annual operation and maintenance costs

No	Item	Unit	Amount	Unit cost	Total
I	***Operation cost***				***117,339***
1.1	Electricity	kWh	1,295,450	0.002370	3,071
1.2	Cashew shell	ton/year	0	0.000	0
1.3	Other fuel source	ton/year	136,080	0.800	108,864
1.4	Diesel oil	Liter	0	0.025	0
1.5	Industrial water	m^3	18,855	0.015	283
1.6	Cooling water	m^3	391,102	0.0005	196
1.7	Water treatment	m^3	2,647	0.0800	212
1.8	Treatment of ash, slag and solid waste	ton/year	924.3	0.0500	46
1.9	Lime powder	kg	0	0.0018	0
1.10	Maintenance (2%*Average)	2%	0.02	4,668	4,668
II	***Salary and administration costs***		***45***		***6,684***
2.1	Factory manager	Capita	1	300.00	300
2.2	Technical director	Capita	1	240.00	240
2.3	Operation block	Capita	27	108.00	2,916
2.4	Maintenance block	Capita	6	108.00	648
2.5	Accounting department	Capita	2	96.00	192
2.6	Sanitation	Capita	2	72.00	144
2.7	Reception	Capita	2	84.00	168
2.8	Security	Capita	4	84.00	336
2.9	Frequent cost		0.005		587
2.10	Other				1,153
III	***Pretax cost (I+II)***		***10%***		***124,023***
	Value-Added Tax (VAT)				***12,402.3***
IV	***Total cost including VAT***				***136,425***
V	***Depreciation***				***17,799***
VI	***Bank loan interest expense***				***28.130***
VII	***Total***				***182,354***

3.2.2. Economic - financial and social benefits of the project

Considering the income from the sale of carbon credits of the plant, the selling price of electricity is 10.05 cents/kWh, mobilizing investment capital with low interest, the economic indicators are relatively attractive and ensure the feasibility of the project in Table 8.

Table 8. Summary of economic indicators

No.	Indicators	Symbol	Value
1	Discount rate	i	10.50%
2	Net present value (million VND)	NPV	120,465

3	Internal Rate of Return	IRR	13.70 %
4	Payback Period	year	15.7

The energy price of fuel

Although the price of biomass types is different, the comparison for fuel is considered in heat value-based cost (VND/MJ). The price of fuel in energy was calculated based on its price in mass (VND/kg) and its heat value (MJ/kg) at corresponding moisture content, as shown in Table 9.

Table 9. Low heat value and moisture content of fuel types

Fuel type	Low heat value, MJ/kg	Moisture content, %
Cashew shell	17.2	9.8
Wood chips	8.7	46.0
Wood pellets	19.0	9.0
Fine coal (Indonesia)	20.6	12.4

As shown in Fig. 4, the price of cashew shell is the lowest (159VND/MJ), compared to that of coal of 212VND/MJ (imported coal from Indonesia). In addition, the price of wood chips is 165VND/MJ, higher than that of cashew shell. At the condition of heat value, the energy cost of cashew shell will be equal to that of coal (212VND/MJ) when its price increases to reach 3,750VND/kg. In short, it is still cheaper to use cashew shell and wood chips as fuel with the price of 2,800VND/kg.

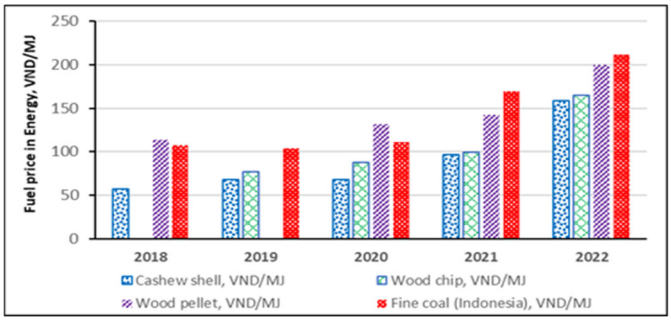

Fig. 4. Comparison of biomass fuel price in energy project

3.2.3. Sensitivity analysis

Case 1: The selling price of electricity changes

Considering the inevitable trend of increasing electricity prices, stemming from the management orientation from the government and the electricity prices proposed by the Ministry of Industry and Trade, several scenarios were proposed, such as electricity prices have a direct impact on efficiency with the project's investment results, the financial efficiency of the project needs to be achieved, for the minimum electricity price of 2,370VND/kWh (10.05cents/kWh) with the woodchip fuel price of 800VND/kg (Table 10).

Table 10. Parameters calculated in case of selling price of electricity changes

Parameter	Unit, Cent/VND/kWh	8.47/1,998	10.05/2,370	12/2,830	15/3,538
NPV	million VND	-126,163	120,465	424,847	893,127
IRR	%	7.18	13.70	22.10	35.77
Payback period (T_{hv})	Year	-	15.7	6.2	3.5

Case 2: The price of fuel changes

A change in fuel price results in changes to the following parameters. When the electricity selling price is 2,370VND/kWh (10.05cents/ kWh). The fluctuation of the fuel prices by market, oil and coal prices, is a trend not only in Vietnam but also in many countries around the world. The actual fuel price scenario has many fluctuations from 2018 to 2022. With the results of calculating some scenarios according to the above actual fuel prices, when the fuel price increases from 1,000VND/kg or more, the economic indicators of the project are no longer attractive, the feasibility of the project is not guaranteed (Table 11). Therefore, proactively providing input fuel at a reasonable price is the third necessary point, investors need to pay attention and ensure.

Table 11. Parameters calculated in case of the price of fuel changes

Parameter	Unit, VND/kg	600	800	1,000	1,500
NPV	million VND	305,586	120,465	-237,441	-936,794
IRR	%	19.04	13.70	4.39	-
Payback period	Year	8.2	15.7	-	-

Case 3: Total amount of investment changes

A change in the total investment results in the following changes. When the electricity selling price is 2,370VND/kWh (10.05cents/kWh). With the quotes on key equipment such as boilers, turbines, circulating water coolers, wastewater treatment systems, and the research group experience in implementing other projects, the figures listed in the report are based on selection of the price of equipment at a low level, which can be provided by domestic and Chinese units. The total investment of the project can increase if equipment is selected from developed countries, or with higher quality levels, higher efficiency, and better automation of modern technology (Table 12).

When considering reducing the investment capital to about 250 billion VND, this is a great advantage when other calculation conditions are kept unchanged. With the initiative to source fuel with a low price, below 800 VND/kg, this project is very feasible to implement soon.

Table 12. Parameters calculated in case of the total amount of investment changes

Parameter	Unit	35% decrease 251,621	15% decrease 328,888	386,123	15% increase 423,325	30% increase 503,454
NPV	million VND	391,526	235,810	120,465	45,491	-115,993
IRR	%	27.33	17.99	13.70	11.59%	8.18%
Payback period (T_{hv})	Year	4.1	9.3	15.7	21.2	-

Case 4: Loan interest rate changes

Changes in loan interest rates lead to changes in the following parameters. The Shareholder Equity Ratio is 80%. When the electricity selling price is 2,370VND/kWh (10.05cents/kWh). According to the calculation results (Table 13), the project needs to mobilize low or zero loan interest sources to ensure the feasibility of the project.

Table 13. Parameters calculated in case of the loan interest rate changes

Parameter	Unit	0.0%	2,6%	5,25%	10,5%	12.0%
NPV	million VND	120,465	87,938	55,411	-10,893	-29,659
IRR	%	13.70%	12.73%	11.84%	10.26%	9.86%
Payback period (T_{hv})	Year	15.7	17.4	20.3	-	-

Case 5: Changes in equity/loan capital structure

Changes in equity/loan capital structure lead to changes in the following parameters. When the electricity selling price is 2,370VND/kWh (10.05cents/kWh). The lower the change in investment lending rate, the higher the project efficiency (Table 14).

Table 14. Parameters calculated in case of the equity/loan capital structure changes

Parameters	Unit, %	80/20	70/30	60/40	50/50
NPV	million VND	120,465	141,108	161,751	182,394
IRR	%	13.70%	14.32%	14.96%	15.62%
Payback period (T_{hv})	Year	15.7	14.2	12.2	11.2

Table 15. Parameters calculated in case of the equity/loan structure changes

Parameters	Unit, billion VND	386,123	(*) 246,547	(**) 255,398	(***) 264,256
NPV	million VND	120,465	493,298	241,046	26,374
IRR	%	13.70%	32.38%	20.13%	11.49%
Payback period (T_{hv})	Year	15.7	3.1	8.9	22.7

(*) With ideal conditions, along with low total investment, the project efficiency is higher.

(**) With the total investment reduced to 255,389 billion VND, reducing the price of electricity sold to the grid to only 8.47cents/kWh, and raising the interest rate on bank loans to 5.2%/year, the host enterprise If the fuel source can be mobilized and the price is reduced to 700 VND/kg, this project is still a good investment.

(***) When considering the new steam parameter entering the turbine, the temperature is about 400 degrees Celsius, the pressure is 40 bar, which will increase the fuel consumption so about 500 tons/day to produce output 12MWe. With a total investment of 264,256 billion VND, the selling price of electricity to the grid is 8.47cents/kWh, bank loan interest rate is 5.2%/year, fuel price is 700VND/kg, the project is not really attractive. This means, the selection of technology parameters according to configuration 4 (CH4) is a suitable solution.

Case 6: Ideal project conditions and some other scenarios: Bank loan interest is 0%/year; electricity selling price is 10.05cents/kWh, loan ratio is 80%; fuel price is 800VND/kg; fuel consumption is 370 tons/day, self electricity capacity less than 2,000kW; Consider the reduced total investment of the project (Table 15).

4. CONCLUSIONS

Technical factors affecting the whole plant cycle, which play a key role, have been proposed in this article in accordance with the application trend in biomass power plants.

The source of raw materials affects the cost of purchasing, collection and transportation, which are summarized by the group in the article, have practical significance.

Several scenarios when changing the price of fuel, changing the loan ratio, changing the loan interest rate, and changing the selling price of electricity, have been calculated in this study. To ensure the feasibility, the scenarios indicate that the project needs to ensure the following main points: Low enough fuel price, from 800VND/kg or less; The proposed electricity price should be high enough at 10.05cents/kWh or more; Loan interest rate should be guaranteed at 2.6% or less; Reduce investment capital to less than 250 billion VND and Ideal conditions if applied simultaneously.

For some recommendations based on this study, the investment in biomass power plant needs the participation of functional agencies and governmental management units in policy with a number of specific support proposals including: The planning of fuel sources should be of a stable nature in terms of reserves, and the fluctuating prices of input fuels should be synchronized with the change in electricity selling prices as regulated by the government; Adjust the electricity selling price to the grid from 10.05cents/kWh or higher; Support clean ground clearance, expand the power line to release capacity for the plant, allowing the operating time of the incinerator line to be over 8,000 hours/year; Consider reducing value-added tax and import tax for all equipment and materials used in the construction and commercial operation of the plant; Creating conditions for enterprises investing in biomass power projects to receive preferential loans with low interest rates. Considering the loan interest rate that businesses have to pay is less than 50% lower than the interest rate of commercial banks in VietNam at the moment and reduce total investment, use low-cost fuel.

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