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RESEARCH ARTICLE

FINANCIAL VIABILITY OF SOLID BIOFUEL GENERATION: A CASE STUDY IN A PELLET FACTORY IN WESTERN PARANA

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Abstract

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The growing demand for renewable and sustainable energy sources is driving the search for economically viable alternatives, such as wood pellet production. This article presents an economic analysis of a factory located in western Paraná, aiming to assess the financial viability of pellet production from wood residues, especially pine shavings and sawdust. To this end, fixed and variable costs were identified and quantified, the unit production cost per ton was calculated, the market selling price was analyzed, and a discounted cash flow forecast was prepared over 25 years. The data were obtained through a technical visit, an interview with the owner, and a survey of the assets and inputs used in the production process. The results indicated that the average production cost was R$759.48 per ton, with raw materials being the main component of the variable cost (46%). The economic analysis demonstrated a Net Present Value (NPV) of R$6,582,427.07, an Internal Rate of Return (IRR) of 22.36%, a discounted payback period of 8 years and 1 month, and a Benefit-Cost Ratio (BCI) of 1.12. It is concluded that wood pellet production is economically viable, especially after the stabilization of industrial operations. The study highlights the activity's potential as a strategy for valorizing forestry residues and diversifying the energy matrix, reinforcing the importance of logistical and energy efficiency improvements to maximize long-term results.

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Introduction:

As a renewable source, biomass becomes an alternative worthy of study. Couto[1]states that the use of forest biomass proves viable, both economically and ecologically. Furthermore, Brand[2]describes that social gains arise from the emergence of companies in the bioenergy sector, which utilize forest residues, thus generating jobs. The use of forest residues to produce pellets, briquettes, and other materials provides environmental benefits, including improved air quality in industrial sites and increased yard and/or warehouse space, as solids do not accumulate in theindustrial yard. It also presents the advantage of being linked to the sale of carbon credits and the generation of energy from waste, both of which generate revenue. The World Bioenergy Association[3] estimates that global wood pellet production reached 44.3 million tons in 2021, highlighting Europe as the largest producer, with a 56% share, followed by the Americas with 30%. Furthermore, Mordor Intelligence[4] reports that the global wood pellet market is

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expected to reach US$16.75 billion by 2027, with a Compound Annual Growth Rate (CAGR) of 7.28% from 2022 to 2027.

Brazil, in turn, stands out due to its potential to produce over 298 million tons/year of lignocellulosic residues from the processing of sugarcane, corn, soybeans, and wheat; and 6 million tons of residues generated by the harvesting of eucalyptus and pine[5]. Furthermore, the Brazilian Association of Biomass Pellet and Briquette Industries (ABIB)[6] reports that: “The generation of mechanically processed wood waste in Brazil was equivalent to 50,778,566.33 m^3, a value corresponding to a 45% loss in log processing. The region with the highest waste generation was the South with 21,188,983.25 m^3 (41.7%), Southeast (32%), and North (15.3%)”.

According to Brainer[7], in 2021, countries such as Brazil, the United States, China, India, Indonesia, the Russian Federation, and the Eurozone, which are wood pellet producers, improved their performance due to Gross Domestic Product (GDP) growth. However, regarding pellet consumption, the Brazilian market remains insignificant, despite presenting conditions for growth, due to its excellent climate and soil conditions, as well as its large territorial area[8].

In this context, studies on the use of renewable sources for various economic sectors are essential. To implement new energy generation sources, Pereira[8] points out that aspects related to environmental preservation, the availability and quality of raw materials, as well as the means of production, storage, forms of use, market, and existing technologies must be taken into consideration.

Furthermore, research such as that by Sartori[9], which analyzes the Brazilian pellet industry with a view to commercializing products in domestic and international markets, is essential. The study, conducted at a company located in southern Brazil, showed favorable results to produce solid wood pellets from reforested areas, thus creating an opportunity for diversifying the Brazilian energy matrix and/or exporting products to other countries. Given this scenario, the study proposes to analyze the economic viability of producing wood pellets manufactured by a company located in Western Paraná.

Literature Review:

This section briefly presents the factors that influence the supply and demand of biomass for energy generation, with an emphasis on the production of wood pellets.

Supply and Demand of Biomass for Energy Generation

Globally, in 2018, approximately 55% of wood biomass consumed was firewood or charcoal, used for cooking or heating homes, mainly in developing countries, where biomass is burned inefficiently, without fully utilizing the heat generated. Regarding Europe's energy matrix, an increase in the consumption of solid biomass was observed, which generally consists of wood—pellets, chips, briquettes, among others. Pellets are particularly noteworthy, as they are the largest consumer and importer in the world[10]. Diniz[11] presents a study that highlights the 10 largest countries in production, import, export, and apparent consumption of forest products for energy (FPE): China, India, Brazil, the United States, Ethiopia, Congo, Nigeria, Ghana, Uganda, and Indonesia. In 2020, they produced 1.3 billion cubic meters, representing approximately 52% of the global market. However, looking at 2020, Brazil is not ranked among the top countries in terms of FPE exports, due to production (175.32 million cubic meters) being practically equal to apparent consumption (173.44 million cubic meters).

However, the Food and Agriculture Organization of the United Nations[12] reports that Brazilian pellet exports increased by approximately 90% in 2021 compared to the previous year.

Furthermore, regarding the production of PFE by categories in 2020, the following countries stand out in the world market: India (302.24 million m3 of firewood), Brazil (18.21 million m3 of charcoal), China (44.38 million m3 of chips and 104 million m3 of wood waste), and the United States of America (USA, 11.60 million m3 of pellets)[11]. However, in 2020, due to the pandemic, there was a reduction in the global consumption of practically all forest products, except for paper, pellets, and other agglomerates[7].

The positive variation of around 0.5% in pellet consumption in 2020 can be justified due to a global change in consumer behavior (they adopted the preventive measure “stay at home”, due to Covid-19), who used pellets as thermal and/or electrical energy for residential heating, in plants and industries (with emphasis on food producers)[7].

Factors Influencing Pellet Production

As companies grow and mature in the production and marketing of wood pellets, competitiveness increases, resulting in reduced profit margins in the production chain and a scenario of insecurity for producers[13]. Due to production expansion (increased output – consequently, reduced unit costs), companies tend to make trade-offs, as large quantities of inputs are required, resulting in increased transportation and logistics costs[14].

The pellet production industry faces factors that influence production costs, such as the availability of raw materials and their quality (type and seasonality), as well as the widely varying prices, transportation and logistics, electricity rates, and, most importantly, the installed capacity of the plant[15]. Pereira[8] describes that for the company to be competitive, it becomes important to optimize these factors, since they directly influence the layout and location of the facilities, in addition to the quality of the products and, mainly, the final production cost.

Furthermore, according to Sartori[9], for the price and supply of pellets to remain stable (a fundamental condition for the product to be used as an energy resource), the company must analyze the possibility of a raw material shortage, as this represents an increase in production costs and a risk to its continuity.

Furthermore, Fritsche[13] report that “wood pellet prices (for industrial or residential purposes) are driven by factors such as exchange rate fluctuations, temperature changes throughout the year (for residential use), fuel prices (e.g., oil), and dependence on incentives for the use of renewable energy sources. In addition to these factors, it can be argued that the deficiency or scarcity of other energy sources can drive pellet consumption in countries that have infrastructure for their use”.

Wood Pellet Production Costs

The value-adding process in a wood pellet production chain begins with the acquisition of raw materials (50% - the purchase cost is low, but the initial investment to process it will be high) and ends with the delivery of biofuel to buyers or traders[16].

Wood pellet production costs (approximately 40%) include fixed costs (the annual depreciation cost of assets required for the plant's operation and operational and maintenance costs) and variable costs (costs for raw materials, electricity, telephone services, packaging, among others)[16].

A way to reduce wood pellet production costs, as it significantly reduces specific energy consumption. This is achieved by minimizing the amount of wood raw material sent to wet crushing hammer mills, which must undergo preliminary particle size classification. Implementing this measure can significantly reduce specific energy consumption for pellet production[17].

In Brazil, logistics remain a challenge for transporting wood pellets, as most are transported by truck, thus adding costs to the final product. Furthermore, when shipping solid biomass abroad, in some situations, the Free on Board (FOB) price may be added.

Methodology:

This study uses an empirical-analytical approach, focusing on the economic evaluation of wood pellet production. Initially, data on fixed and variable costs were collected from the company under study. Subsequently, an economic analysis of the product's production and marketing was conducted.

The scenario analyzed corresponds to a factory located in the Concórdia do Oeste district, Toledo, Paraná, with four years of operation and a 500 m² manufacturing plant. The region is an emerging pellet production hub, with three other companies located in nearby cities, between 100 km and 180 km away.

The analysis was conducted based on the following technical assumptions:

- The company has no active debt.
- Advertising and marketing were disregarded.
- The target market is regional.
- Annual inflation assumed: 5.79%[18].
- The conversion efficiency of raw materials into pellets was estimated at 75%, considering losses due to processing and internal use[19, 8].

• The maximum distance for transporting raw materials was limited to 150 km, considered economically viable[8].
• The selling price of pellets in the first two years was set at R$600/ton, with direct pickup from the factory[20].
• The nominal capacity from the fifth year onward was estimated at 5,040 ton/year;
• Sales are made exclusively in bulk, directly to the end consumer, with transportation limited to 100 km;
• It was assumed that the pellets are not intended for export, given the lack of international certifications and formal internal quality controls, in addition to logistical limitations[16].

Furthermore, land acquisition costs were calculated based on the average value of properties in capacity class A-I in Toledo (R$ 163,100.00/ha), with an annual appreciation of 13% above inflation[21].

Transportation and Tax Costs

To estimate annual transportation and tax costs, we considered the transportation of raw materials to the manufacturing plant (FOB freight) and the delivery of pellets to the end consumer (CIF freight). Calculations were based on the equations proposed by Pereira[8], considering the quantities transported, average freight costs per ton, taxes per kilometer, and distances traveled.

The following logistical assumptions were adopted:

• The raw material is collected entirely by the company, and 100% of production is delivered to the consumer (no on-site pickup).
• Two types of vehicles were used: medium-duty truck (11 ton) and heavy-duty truck (23 ton)[22].
• Maximum distance for raw material collection: 300 km (round trip).
• Maximum distance for final product delivery: 200 km (round trip).
• The average tax rate on freight was 9.57%, depending on the type of vehicle.
• The average freight and tax rates applied were obtained from updated road transportation industry sources[23,24](Tables 1 and 2).

Table 1:- Raw material collection logistics.

Item	Medium Truck	Heavy Truck
Average freight (R$/ton)	R$93.90	R$44.02
Average tax (R$/km)	R$0.33	R$0.32
Maximum distance (km)	300 (round trip)	300 (round trip)

Table 2:-Pellet Delivery Logistics.

Item	Medium Truck	Heavy Truck
Average freight (R$/ton)	R$65.86	R$31.30
Average tax (R$/km)	R$0.35	R$0.34
Maximum distance (km)	200 (round trip)	200 (round trip)

These parameters allow us to calculate the total logistics costs, which were integrated into the economic analysis of production, contributing to the final cost of wood pellets.

Cost of Pellet Production

The wood pellet production cost analysis was based on the model proposed by Mani[23], considering the fixed and variable costs associated with operating a manufacturing plant. The total fixed cost (C_a) was calculated based on the recovery of capital invested in equipment.

$$C_a = e \times C\_eq$$

Where: e: Capital Recovery Factor, given by Equation 4. C_eq: cost of the equipment [R$].

The capital recovery factor (e) was obtained by Equation:

$$e = (i \times (1 + i)^N) / ((1 + i)^N - 1)$$

Where: i: interest rate [%]. N: equipment amortization period [years].

Additionally, installation costs were estimated at 40% of the equipment acquisition value. The useful life of the plant's fixed assets was estimated using technical criteria consistent with the relevant literature[16], considering the following time horizons: 12 years for the pellet mill and dryer/furnace assembly, 10 years for the tractor and administrative furniture and equipment, 20 years for the industrial buildings, and 25 years for the land. These timeframes were used for both straight-line depreciation purposes and for assessing capital replacement over the project's life cycle.

The total annual production cost (C_T) was determined by Equation:

$$C\_T = C_a + C\_op$$

Investment analysis methods
The investment analysis was conducted using the discounted cash flow (DCF) technique, considering annual inflows and outflows over the project horizon. The present value (PV) of future revenues was calculated using Equation[24]:

$$PV = FV / (1 + i)^n$$

Depreciation was calculated using the straight-line method (cash basis), as per Equation:

$$D\_e = (VA – VR) / V\_u$$

Where VA: acquisition value, VR: residual value, and V_u: useful life of the asset. The residual value at the end of the useful life was estimated using Equation:

$$VR = \text{Initial Value} – (D\_e \times V\_u)$$

To assess the economic viability of the project, the Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit-Cost Ratio (BCR) indicators were used:

$$NPV = \sum (FC\_j / (1 + MARR)^j)$$
$$0 = \sum (FC\_j / (1 + MARR)^j)$$
$$BCR = \sum (FC\_j / (1 + MARR)^j) / FC_0$$

Where FC_j represents the cash flow in year j, FC_0 the initial investment, MARR the minimum attractive rate (12% per year), and n the number periods (25 years). Operating expenses (OPEX) were considered as 1% of the capital invested (CAPEX).

Results and Discussions:

The analysis was conducted using data collected during a technical visit to the plant in western Paraná in January 2023. During the visit, the main fixed and variable assets were identified, as well as the logistical steps involved in acquiring raw materials and distributing the final product. The initial investment reported by the owner was R$3,270,000.00, later updated to R$4,955,024.23 based on asset revaluations and an on-site survey.

The plant operates with seven employees working nine hours a day, six days a week, totaling 2,592 hours of annual operation. The raw material consists predominantly of pine shavings and sawdust, obtained from regional sawmills, at an average cost of R$350.00/ton. Initial production was 576 ton/year, reaching nominal capacity of 5,040 ton/year in the third year of operation. Operating losses, including flaring for internal consumption and waste, accounted for 25% of the total purchased.

Annual variable costs totaled R$3,293,828.98 in 2022, with raw materials accounting for 63% of this amount. The total fixed cost analysis considered items such as land, buildings, pellet mill, vehicles, dryer, and administrative infrastructure. The data are consolidated in Tables 3, 4, and 5, highlighting the annual capital cost, which reached R$523,445.04, representing an average unit cost of R$103.86 per ton produced.

Table 6 presents the detailed cost structure by stage of the production process. Raw materials represent the largest portion (46.08%) of the total unit cost, followed by electricity and fuel costs (18.18%). This breakdown is consistent with data in the literature[16], which reports a cost over 50% reduction in the purchase of wood shavings alone. Energy efficiency and the internal reuse of furnace waste demonstrate potential for reducing operating costs.

Based on the total cost of R$759.48/ton (excluding transportation), the logistical impact on the final price was assessed. Considering raw material transportation, it was found that the use of heavy-duty trucks reduces the cost to R$761.75/ton, while medium-duty trucks increase the cost to R$769.55/ton. For pellet delivery to the consumer, additional freight varies between R$6,927.68 and R$30,175.85 per year, depending on the type of vehicle, which significantly impacts the company's profit margin. Including these costs in the final sales price is crucial, especially considering that the pellets are delivered directly to the customer (CIF).

Furthermore, it was observed that some of the residual biomasses are stored outdoors, which can generate future environmental and operational costs. A recommended strategy is the physical and chemical characterization of this waste for eventual reuse, adding value to the process and reducing waste volume. The possibility of increasing the product's value by obtaining ENplus® certification was also highlighted, aiming for market penetration.

Finally, the results indicate that the project's economic viability depends heavily on logistics optimization, efficient management of energy inputs, and reduction of production losses. Full utilization of installed capacity—including the activation of the second pellet mill currently idle—is strategic for reducing fixed costs and increasing the plant's competitiveness in the regional and, potentially, international markets.

Table 3:-Annual quantity of raw material for effective production of wood pellets.

Year	Raw material consumed (tons/year)	Raw material losses (tons/year)	Furnace burning (tons/year)	Pellets produced (tons/year)
1	745.41	37.27	37.27	576
2	2,236.24	111.81	111.81	1,728
3 a 25	6,523.00	296.50	296.50	5,040

Table 4:-Structure of annual variable costs related to the production of wood pellets.

Item	Description	Value (R$)
Electricity	(12-month cost)	336,000.00
Administrative costs	Salaries and pro-labor, accounting, and taxes	263,128.98
Internet	(12-month cost)	1,200.00
Raw materials	Wood waste	2,075,000.50
Packaging	Packaging for pellet bags	252,000.00
Fuel	Gasoline and diesel	360,000.00
Starch	Binder	6,000.00

Table 5:-Composition of fixed investments applied in the wood pellet production plant.

Item	Description	Value (R$)
Land	Property area	1,973,510.00
Tools	Tooling for equipment operation and maintenance	30,000.00
Vehicles	Car (1 unit), Tractor (1 unit) and Truck (2 units)	1,080,448.00
Pelletizing	Pelletizer (2 units)	990,000.00
Dryer/furnace	Dryer	435,000.00
Factory (construction)	Factory area (500 m^2)	250,000.00
Furniture and computers	Administrative area	15,000.00
Sieve	Equipment	36,000.00
Vehicles	Tractor	150,000.00

Table 6:-Analysis of the composition of the total cost of production of wood pellets by stage of the industrial process.

Pelletizing Process Steps	Capital Cost (R$/ton)	Operating Cost (R$/ton)	Total Cost (R$/ton)	Cost Distribution (%)
Raw material	-	350.00	350.00	46.08
Dryer/furnace	13.93	0.86	14.80	1.95
Vehicles	37.94	2.44	40.38	5.32
Pelletizer	44.40	1.96	46.36	6.10
Sieve	1.26	0.07	1.34	0.18
Bagging	-	50.00	50.00	6.58
Storage	-	1.21	1.21	0.16
Miscellaneous Materials	-	8.93	8.93	1.18
Employees	-	29.32	29.32	3.86
Factory (construction)	6.32	49.60	55.93	7.36
Taxes	-	22.89	22.89	3.01
Electricity	-	66.67	66.67	8.78
Fuel	-	71.43	71.43	9.40
Internet	-	0.24	0.24	0.03

Economic Analysis

The economic evaluation of the project was performed considering the plant's 25-year accounting useful life, with cash flows adjusted to constant currency and depreciation amounts adjusted for inflation. Operating costs remained constant from the third year onward, with variation only in depreciation, given its real decline over time.

Financial Viability Indicators

Depreciation of fixed assets was estimated based on the straight-line method and adjusted for inflation, as suggested by Quéno[16], resulting in an average annual cost of R$40.43 per ton of pellets produced. At the end of the assets' useful life, the estimated residual value corresponds to approximately 20% of the initial investment, totaling R$617,000.

Considering an average annual production of 5,040 tons of pellets, sold at R$1,100.00 per ton from the third year onward, annual gross revenue stabilizes at R$5.54 million. However, from the tenth year onward, a possible reduction in net revenue is expected due to equipment obsolescence, the need for reinvestment, and increased operating costs, as noted by Orellana (2019).

Based on the projected cash flow and a minimum attractive rate (MAR) of 12%, the economic and financial performance indicators indicate a Net Present Value (NPV) of R$6,582,427.07 and an Internal Rate of Return (IRR) of 22.36%. Because the IRR exceeds the MAR, the investment is considered economically viable. The discounted payback period was estimated at 8 years and 1 month, indicating the time required for a return on the invested capital. In addition, the Benefit-Cost Index (BCI) was 1.12, confirming that the benefits exceed the costs over the analysis horizon, consolidating the economic attractiveness of the project.

Conclusion:-

This study aimed to assess the economic viability of wood pellet production at a facility located in western Paraná, identifying and measuring fixed and variable costs, calculating the production cost per ton, analyzing the market price, and developing a discounted cash flow over 25 years of operation.

The results show that raw materials represent the largest portion of variable costs (46%), due to the limited local access to wood residues suitable for pellet production. Fixed costs, in turn, are significantly impacted by the acquisition of machinery and manufacturing infrastructure, particularly the pellet mill and logistics vehicles. The total cost analysis revealed an average production cost of R$759.48 per ton, excluding freight, a value consistent with the market price in nearby regions.

With production stabilization starting in the third year, annual revenue reached R$5.54 million, yielding positive economic results. Financial indicators corroborate the investment's viability, with a Net Present Value (NPV) of

R$6,582,427.07, an Internal Rate of Return (IRR) of 22.36%, and a discounted payback period of 8 years and 1 month. Furthermore, the Benefit-Cost Ratio (BCI) of 1.12 reinforces the project's attractiveness, indicating a return higher than the opportunity cost of capital.

Therefore, it can be concluded that, under the adopted assumptions, wood pellet production is economically viable and represents a promising alternative for adding value to lignocellulosic waste, in addition to contributing to the diversification of the energy matrix with a renewable source. However, it is recommended that energy efficiency strategies be adopted and that supply chain logistics be reassessed to mitigate operating costs and maximize economic gains over time.

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