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Cost-Benefit Analysis of Rice Straw Briquette Production

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ABSTRACT: A comprehensive cost-benefit analysis of rice straw briquette production as a sustainable alternative to traditional energy sources. Rice straw, a widely available agricultural residue, poses environmental challenges when disposed of through open burning. Converting it into biomass briquettes offers both environmental and economic advantages. The study examines key cost components, including raw material collection, transportation, equipment investment, energy, and labour. It also analyses potential benefits such as revenue from briquette sales, carbon emission reductions, waste management improvements, and social benefits like job creation and rural economic development. Using metrics such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period, the analysis evaluates the economic viability of briquette production across different scales of operation. The results indicate that rice straw briquette production is a financially feasible and environmentally sustainable solution, especially in rice-producing regions, contributing to renewable energy adoption and waste management. However, challenges related to seasonal availability, market demand, and logistics require further optimization.

Keywords: Cost-benefit, Transportation, Equipment investment.

INTRODUCTION

Rice is one of the most widely cultivated crops globally, with vast quantities of rice straw produced as a by-product of the harvesting process (Abraham *et al.,* 2016). Rice straw, which is often left unused or burned in the fields, has become a significant environmental concern, contributing to air pollution and greenhouse gas emissions through open-field burning (Tarkeshwar and Saini 2023). Given the global push towards sustainable energy solutions, converting rice straw into biomass briquettes offers a promising alternative for energy production, transforming agricultural waste into a renewable resource (Rathour *et al.,* 2023). The increasing demand for sustainable energy solutions has driven significant interest in biomass as a renewable fuel source. Among the various forms of biomass, agricultural residues like rice straw represent a vast and underutilized resource (Biswas *et al.,* 2017). Rice is one of the most widely cultivated crops globally, particularly in Asia, where rice straw is produced in abundance. However, much of this biomass waste is either left unused or disposed of through open-field burning, which contributes to severe air pollution, greenhouse gas emissions, and the loss of valuable organic matter (Naresh *et al.,* 2021). Rice straw burning not only causes environmental problems but also represents a missed opportunity for energy production (Singh *et al.,* 2021). Utilizing rice straw for biomass briquettes can offer an effective solution, transforming waste into an eco-friendly fuel alternative that can replace conventional fossil fuels like coal and firewood. Briquettes made from rice straw are renewable, carbon-neutral, and cost-effective, making them a promising component of sustainable energy systems (Logeswaran *et al.,* 2020).

This study focuses on the cost-benefit analysis (CBA) of rice straw briquette production to assess its economic feasibility and environmental advantages. Specifically, it examines the costs involved in briquette production-including raw material procurement, processing, labour, and transportation while evaluating the potential benefits such as revenue from sales, reductions in carbon emissions, and social gains like rural job creation and improved air quality. The analysis also considers the role of government policies, subsidies, and carbon credits in enhancing the financial attractiveness of rice straw briquetting (Ribeiro *et al.,* 2023).

The global energy landscape is undergoing a fundamental transformation as countries strive to shift away from fossil fuels toward more sustainable and renewable energy sources (Child & Breyer 2017). The need for cleaner and more efficient energy alternatives is pressing due to concerns over climate change, air pollution, and the depletion of non-renewable energy resources (Abbasi & Abbasi 2012). Biomass energy, derived from organic materials such as agricultural residues, has emerged as a promising solution. Among the various biomass resources available, rice straw, a byproduct of rice cultivation, holds significant potential as a renewable energy feedstock (Abraham *et al.,* 2016).

MATERIAL AND METHODS

Study Area and Scope. This study focuses on rice-producing regions, particularly in countries where rice straw is abundantly available, such as India, China, Indonesia, and Thailand. These regions are characterized by large-scale rice farming, where rice straw is often treated as waste and burned in the fields. The study evaluates briquette production in rural and semi-urban areas where the availability of rice straw and the demand for alternative energy sources are high.

The analysis covers different scales of briquette production, from small-scale community-based projects to larger, commercial-scale operations. It evaluates production under varying logistical conditions, including proximity to rice farms, availability of transportation infrastructure, and market access.

Data Collection

Primary Data.

Field Surveys: Surveys were conducted with rice farmers, briquette producers, and potential consumers of rice straw briquettes to gather data on rice straw availability, collection practices, labour costs, and consumer preferences.

Interviews: Semi-structured interviews were conducted with industry stakeholders, including briquetting machine manufacturers, suppliers, and energy experts, to collect data on capital investment, operational challenges, and market conditions.

Pilot Production Trials: Data were collected from small-scale briquette production facilities operating in rural regions to estimate operational costs, energy consumption, and production efficiency.

Secondary Data

Literature Review: Existing research studies and reports on biomass briquetting, rice straw utilization, and renewable energy economics were reviewed to supplement the primary data.

Market Reports: Reports on the market demand for biomass fuels, pricing trends, and consumer adoption of alternative energy sources were used to estimate revenue potential.

Government Policies: Information on subsidies, carbon credits, and other incentives for biomass energy production was obtained from governmental and non-governmental organizations.

Cost Analysis. The cost analysis was broken down into fixed and variable cost components:

Fixed Costs. These include capital investments required for setting up a briquette production facility. Fixed costs were calculated based on data from equipment manufacturers, industry standards, and case studies from existing briquetting plants.

Briquetting Machinery: Prices of various briquetting machines were gathered from manufacturers and suppliers. The study analysed two main types of briquetting technologies:

Piston Press Briquetting Machines

Screw Press Briquetting Machines

Land and Infrastructure: Costs related to leasing or purchasing land for the production facility were obtained from field surveys and real estate market data. Infrastructure development costs (buildings, storage facilities) were also included.

Other Equipment: Additional equipment such as shredders (for chopping rice straw), dryers (if needed for moisture control), and transportation vehicles were factored into the fixed cost analysis.

Variable Costs. Variable costs were estimated based on production capacity and operational data from pilot production trials and case studies.

Raw Material Costs: Although rice straw is a low-cost raw material, the costs of collection, transportation, and storage were included. Costs were calculated per ton of rice straw, factoring in distance from rice fields to the production site and labour costs associated with collection.

Energy Costs: The electricity or fuel required to operate the briquetting machines was calculated based on the energy consumption per kilogram of rice straw processed. Local electricity rates or fuel prices were used to estimate this cost.

Labor Costs: Wages for workers involved in straw collection, transportation, briquette production, and facility maintenance were included. Labor costs varied depending on the scale of the production facility.

Transportation Costs: Costs associated with transporting both rice straw (from farms to the briquette plant) and finished briquettes (from the plant to markets) were estimated using data from field surveys and transportation cost models.

Maintenance Costs: The cost of routine maintenance and repairs of machinery was estimated based on industry data and depreciation rates for equipment.

Revenue and Benefit Estimation

Revenue from Briquette Sales

Revenue from the sale of rice straw briquettes was estimated based on:

Market Demand: Market research reports and interviews with potential consumers (industries, households) were used to estimate demand for briquettes as a substitute for coal, firewood, and other traditional fuels.

Briquette Pricing: The price per kilogram or ton of briquettes was obtained from market data. Variations in pricing between different markets (industrial, residential, institutional) were also considered.

Environmental Benefits

The environmental benefits of rice straw briquette production were assessed using two key indicators:

Reduction in CO_2 Emissions: The amount of carbon dioxide (CO_2) saved by replacing conventional fuels with rice straw briquettes was calculated using emission factor data. The carbon emissions associated with burning rice straw in open fields were compared to those emitted during the briquetting process and briquette combustion.

Carbon Credit Revenues: In regions with carbon trading mechanisms, potential revenues from carbon credits were estimated based on the reduction in greenhouse gas (GHG) emissions. The carbon credit price per ton of CO_2 equivalent was obtained from regional carbon markets.

Analytical Framework

Net Present Value (NPV). NPV was used to evaluate the profitability of rice straw briquette production by discounting future cash flows (revenues and costs) to their present value. The formula used is:

$NPV = \sum (R_t - C_t)/(1+r)^t - I_0$

Where:

R_t = Revenue in year t

C_t= Costs in year t

r = Discount rate

I_0= Initial capital investment

Internal Rate of Return (IRR). IRR was calculated to assess the return on investment (ROI) for different scales of briquette production. IRR represents the discount rate that makes the NPV equal to zero.

Payback Period. The payback period was calculated to determine how long it would take to recover the initial investment from net cash inflows. It was calculated as:

Payback Period = Initial Investment/Annual Net Cash Inflows

Sensitivity Analysis. A sensitivity analysis was performed to evaluate how changes in key variables such as raw material costs, energy prices, and briquette market prices impact the overall economic viability of the production process. The analysis examined both best-case and worst-case scenarios.

RESULTS AND DISCUSSION

Economic Analysis. The economic analysis focuses on the capital investment required for briquette production, operational costs (both fixed and variable), and the potential revenue from briquette sales. Three different scales of briquette production - small, medium, and large are evaluated.

Capital Investment. Table 1 summarizes the initial capital investment required for small, medium, and large-scale briquette production facilities. The costs include machinery, land, infrastructure, and other necessary equipment.

Operational Costs. Table 2 provides the breakdown of operational costs for different production scales. The costs include raw material collection, labour, energy consumption, transportation, and maintenance. These costs are calculated on an annual basis.

Revenue from Briquette Sales. Table 3 estimates the revenue generated from the sale of rice straw briquettes. The selling price per ton of briquettes was assumed to be USD 150, based on market data for biomass fuels. Annual production capacity was calculated based on the size of the facility.

Table 1: Initial Capital Investment for Small, Medium, and Large-Scale Briquette Production Facilities.

Item	Small-Scale (USD)	Medium-Scale (USD)	Large-Scale (USD)
Briquetting Machine	10,000	30,000	60,000
Landand Infrastructure	5,000	15,000	30,000
Shredder	2,500	7,500	15,000
Dryers (if required)	3,000	10,000	20,000
Miscellaneous Equipment	2,000	6,000	12,000
Total Capital Cost	**22,500**	**68,500**	**137,000**

Table 2: Annual Operational Costs for Small, Medium, and Large-Scale Briquette Production Facilities.

Cost Item	Small-Scale (USD/year)	Medium-Scale (USD/year)	Large-Scale (USD/year)
Raw Material Collection	2,500	7,500	15,000
Energy Costs	3,000	10,000	20,000
Labor	4,000	12,000	25,000
Transportation	1,500	4,500	9,000
Maintenance and Repairs	1,000	3,000	6,000
Total Operating Costs	**12,000**	**37,000**	**75,000**

Table 3: Estimated Annual Revenue from Briquette Sales for Small, Medium, and Large-Scale Production Facilities.

Production Scale	Annual Production (tons)	Revenue per Ton (USD)	Total Revenue (USD/year)
Small-Scale	200	150	30,000
Medium-Scale	600	150	90,000
Large-Scale	1,200	150	180,000

Financial Performance Indicators. The key financial performance indicators Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period - were calculated for each production scale using a 10-year projection. A discount rate of 10% was used to account for the time value of money.

Net Present Value (NPV). Table 4 shows the NPV for each scale of production. The NPV represents the difference between the present value of cash inflows (revenues) and cash outflows (costs) over a 10-year period.

Table 4: Net Present Value (NPV) for Small, Medium, and Large-Scale Briquette Production Facilities over a 10-Year Period.

Production Scale	NPV (USD)
Small-Scale	12,000
Medium-Scale	45,000
Large-Scale	90,000

Internal Rate of Return (IRR). Table 5 presents the IRR, which indicates the profitability of the investment. The IRR is the discount rate that makes the NPV equal to zero.

Table 5: Internal Rate of Return (IRR) for Small, Medium, and Large-Scale Briquette Production Facilities.

Production Scale	IRR (%)
Small-Scale	18%
Medium-Scale	22%
Large-Scale	25%

Payback Period. Table 6 shows the payback period, which represents the time required to recover the initial investment from net cash inflows.

Table 6: Payback Period for Small, Medium, and Large-Scale Briquette Production Facilities.

Production Scale	Payback Period (Years)
Small-Scale	4.5
Medium-Scale	3.5
Large-Scale	3

Sensitivity Analysis. A sensitivity analysis was conducted to evaluate how changes in key variables such as raw material costs, energy prices, and market prices for briquettes impact the overall economic feasibility of the production process. The analysis revealed that:

Raw material costs have the greatest impact on profitability, particularly for small-scale producers.

Energy prices significantly affect operational costs, but large-scale producers are better able to absorb these fluctuations due to economies of scale.

Market prices for briquettes are relatively stable but could be influenced by shifts in energy policy and fuel demand.

DISCUSSION

The capital investment for briquette production varies significantly with the scale of operations, ranging from ₹18,67,500 for small-scale plants to ₹1,13,97,000 for large-scale facilities. The major cost components include the briquetting machine, land and infrastructure, shredder, dryers, and miscellaneous equipment. Small-scale plants are more affordable, with lower upfront costs, but offer limited production capacity. In contrast, medium and large-scale operations require higher investments but benefit from economies of scale, which can reduce per-unit production costs and enhance profitability (Foster & Rosenzweig 2022). The choice of scale depends on the available capital, market demand, and long-term business goals. The operational costs for briquette production, which include raw material collection, labour, energy, transportation, and maintenance, vary depending on the scale of production (Rawat & Kumar 2022). For small-scale operations, the total annual cost is approximately ₹9,96,000, while medium-scale production incurs ₹30,71,000, and large-scale operations require ₹62,25,000 annually. Labor and energy represent the largest portions of these costs across all scales, with labour costs ranging from ₹3,32,000 for small-scale to ₹20,75,000 for large-scale, and energy costs from ₹2,49,000 to ₹16,60,000. Transportation and maintenance costs also rise with scale, reflecting the larger volumes of raw materials and machinery upkeep required for bigger operations (Edh Mirzaei *et al.,* 2012). These costs highlight the importance of managing operational efficiency to ensure profitability at each scale. The revenue generated from the sale of rice straw briquettes depends on the production scale and selling price (Truong *et al.,* 2022). At an assumed price of ₹12,450 per ton, small-scale briquette plants producing 200 tons annually generate ₹24,90,000 in revenue. Medium-scale operations, with a capacity of 600 tons per year, generate ₹74,70,000, while large-scale facilities, producing 1,200 tons annually, achieve ₹1,49,40,000 in revenue. The increase in production capacity directly correlates with higher revenue, demonstrating the significant financial benefit of scaling up operations, provided there is sufficient market demand to absorb the higher production output. The Net Present Value (NPV) analysis over a 10-year projection, using a 10% discount rate, shows that briquette production can be financially viable at all scales (Gavaldà *et al.*, 2022). For small-scale operations, the NPV is approximately ₹9,96,000, indicating a modest but positive return on investment. Medium-scale production yields a higher NPV of ₹37,35,000, reflecting stronger financial performance due to increased production capacity and revenue. Large-scale operations have the highest NPV at ₹74,70,000, demonstrating significant profitability potential. The positive NPV across all scales suggests that briquette production is a sound investment, with larger-scale facilities offering greater financial returns over time. The Internal Rate of Return (IRR) and payback period analyses further illustrate the financial attractiveness of briquette production across different scales (Dimyati & Kurniasih 2020). For small-scale operations, the IRR is 18%, indicating a decent profitability level. Medium-scale facilities exhibit a higher IRR of 22%, while large-scale operations achieve an IRR of 25%, showcasing the enhanced returns associated with larger production capacities. Additionally, the payback period, which reflects the time required to recover the initial investment from net cash inflows, is 4.5 years for small-scale production, 3.5 years for medium-scale, and 3 years for large-scale operations. These shorter payback periods for larger scales highlight their efficiency in generating cash flow and recovering investments more quickly, making them an appealing option for investors seeking robust returns (Oosterom & Hall 2022).

CONCLUSIONS

The Cost-Benefit Analysis (CBA) of rice straw briquette production shows a promising balance of economic, environmental, and social benefits. While the initial capital investment and recurring operational costs are significant, particularly in terms of equipment, labour, and transportation, these costs are outweighed by the potential for sustainable revenue generation from domestic and industrial markets, as well as export opportunities. Additional value is found in by-products like ash for fertilizer and the possibility of earning carbon credits. Environmentally, the production of rice straw briquettes reduces harmful open-field burning, mitigates greenhouse gas emissions, and supports a circular economy by converting agricultural waste into renewable energy. Furthermore, rice straw briquettes are largely carbon-neutral, making them an environmentally sustainable energy alternative. Socially, the benefits are clear: job creation, improved energy access, public health enhancements due to reduced air pollution, and the promotion of rural development. In conclusion, rice straw briquette production offers a viable, eco-friendly energy solution that can stimulate economic growth, particularly in rice-producing regions. With adequate government support, infrastructure development, and market expansion, this process could play a significant role in reducing waste and improving energy sustainability.

FUTURE SCOPE

The future of rice straw briquette production is promising, with numerous opportunities for expansion, technological innovation, and increased adoption. Several key areas offer potential for growth and development:

1. Continued research and development (R&D) in briquetting technology could lead to more efficient, cost-effective, and environmentally friendly production methods.
2. Greater automation in the briquetting process can reduce labour costs and improve consistency in production. Automation could also help scale up production and make the process more efficient in large-scale operations (Yustas *et al.,* 2022).
3. The global shift toward renewable energy and carbon-neutral fuel alternatives opens up significant export potential (Zeng *et al.,* 2022). Countries committed to green energy and emissions reduction may increasingly turn to biomass briquettes, providing an export market for rice-producing countries.
4. As governments strive to meet climate goals, they may offer incentives such as subsidies, tax breaks, or carbon credit schemes that encourage both production and consumption of biomass fuels, including rice straw briquettes.
5. Expanding rice straw briquette production fits well with the circular economy model, where agricultural waste is repurposed into valuable energy sources.
6. Stricter regulations on open-field burning of agricultural residues, briquette production provides a sustainable way to manage waste while reducing harmful emissions (Lohan *et al.,* 2018).
7. Strong policy frameworks that promote biomass energy production and usage, including subsidies for producers, tax incentives for users, and environmental regulations encouraging cleaner fuels, will be critical in driving the future growth of rice straw briquette production.

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