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Techno-Economic Feasibility of Briquettes Produced from Carbonized *Cordia Africana* Sawdust as a Sustainable Energy Source

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Abstract

The heavy dependence on traditional biomass in Ethiopia is leading to different environmental and socio-economic problems. The transformation of biomass briquettes into sustainable energy solutions is essential for minimizing such issues and promoting sustainable energy use. To provide trustworthy observations and encourage the sustainable development of new products, many scholars these days have always been interested in exploring novel approaches to economic evaluation. Therefore, this study focused on the techno-economic feasibility of briquettes produced from carbonized *Cordia Africana* sawdust as a sustainable energy source, assessing both the technical viability and economic profitability. The findings of the profitability measures were a high IRR of 86.50%, a positive NPV of \$7,930,327.80, a short PBP of 1.2 years, and a strong ROI of 64.46%, indicating the a high economic viability to use carbonized *Cordia Africana* Sawdust as a conventional fuel. Again, the total capital investment and the operating costs were estimated as 1,818,573.5 and 935,879.19 USD, respectively. In Ethiopia, where sawdust waste is plentiful, carbonized *Cordia Africana* sawdust-derived briquettes are a sustainable energy source that support a waste-to-energy endeavor, according to the profitability indicators' overall results.

Keywords: *Briquettes, Carbonization, Cordia Africana, Feasibility study, Sawdust, Sustainable energy*

1. Introduction

Global population growth, economic integration, fast industrialization and urbanization are all contributing factors to increased energy demands and consumption [1-5]. Better healthcare, education, financial prospects and even a longer lifespan are all made possible by having access to modern, sustainable and environmentally friendly energy [3]. Renewable energy sources from various sources can be used as a supplementary energy source to decrease dependency on coal and fossil fuels [6]. More than 88% of global energy consumption still comes from limited, non-renewable and centralized fossil fuel energy sources, despite the importance of renewable energy for the circular economy and human well-being [7-8]. As renewable energy sources like solar, wind and biomass are clean, ecologically benign and never run out, they are regarded as sustainable alternative energy sources [9-10]. Biomass is the third most abundant energy source in the world that could potentially be used for heating and cooking [3,11]. Wood and wood wastes account for 64% of biomass energy production, with solid waste coming in second at 24%, agricultural waste at 5% and landfill gases at 5% [10]. Due to its lower NO_x and SO_x emissions [6], low cost and absence of net carbon emissions [12-13], biomass-to-energy has become a popular and frequently used source of renewable energy fuel [14]. The goal of becoming carbon neutral has taken precedence in the 21st century, propelling initiatives to lower greenhouse gas emissions and to alleviate the energy crisis [15]. The establishment of suitable institutions and technology to generate renewable energy from biomass is of great value on a global scale [16]. Biomass energy sources for industrial, residential, and space heating applications include dry grass, wood, sawdust, straw, manure, solid kitchen and municipal trash, chicken waste, paper waste, and forests [11,17]. To enhance their handling and combustion qualities as well as sustainable energy solutions, bio-residues could be densified into briquettes [14].

Briquetting is a mechanical process of compacting loose biomass wastes at a pressure to create a solid block that is highly dense and has a higher energy content than the raw material [12], [14,18]. Sawdust [19-21], sugarcane bagasse [9], sesame stalk [10,22], rice husk [23-24], millet husk [25] or a combination of the aforementioned biomass wastes [26-29] can all be used to make a briquette. Among the many benefits of biomass briquettes are their higher calorific value, cost-effectiveness, renewable nature and lack of sulfur, which prevents environmental pollution. Bio-briquettes have a lower ash content than coal (2–10% and 20–40%, respectively); they burn more uniformly than coal; they are made close to the consumers (avoiding long-distance transportation); and they have a much higher boiling efficiency

because of their higher density and lower moisture content [30]. In terms of land usage, air and water quality, soil and biodiversity conservation, and carbon stock preservation, the manufacture and use of biomass briquettes are environmentally and economically sustainable [3]. The goal of biomass briquettes is to provide biomass fuel with consistent size and shape, high calorific values, low ash and moisture contents, and improved bulk density [10]. By offering a substitute for burning wood for home and commercial heating and cooking, the creation of biomass briquettes from carbonized sawdust also minimizes forest destruction and can stop soil erosion and desertification [11,20].

According to many studies, Ethiopia now has one of the lowest rates of access to modern energy services, with biomass serving as the main source of energy [20]. About 91% of Ethiopia's primary energy comes from biomass, 7% from petroleum, 2% from electricity [31], and 1.6% from hydropower [20]. For a variety of reasons, Ethiopia's vast and unlimited biomass resources aren't being turned into economically valuable [21]. In the residential sector, biomass consumption makes up more than 98% of the total supply [31]. With 75 million metric tons of biomass, 1120 million metric tons of firewood, and 20 million metric tons of agricultural waste, Ethiopia has a substantial amount of untapped potential in the biomass sector [9]. Except in a few limited locations, wood waste from domestic industries, such as sawdust and chips, is not used to produce power. It is currently estimated that the total amount of wood waste produced is 171,000 m³ in Ethiopia [21]. Sawdust has numerous uses in addition to energy production, including building construction, pollution containment, and water purification, as illustrated in fig.1 [4]. Sawdust, which is among biomass energy sources, is one of the several by-products generated during the production of wood products that have little or no market value [32].

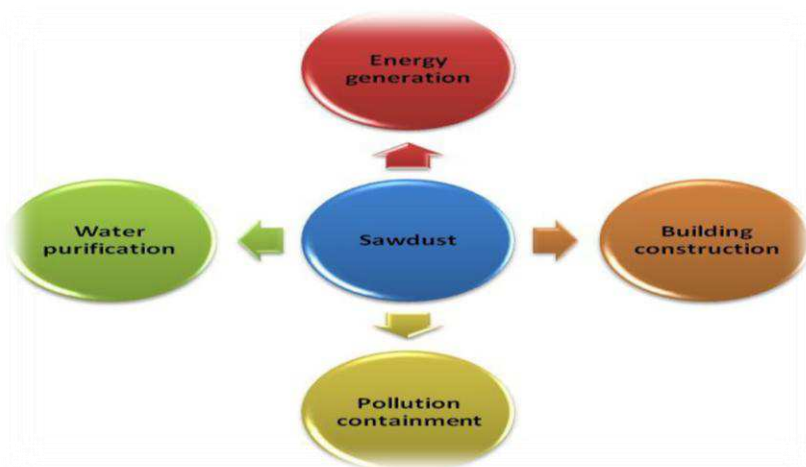


Fig. 1 Key areas of application of sawdust [4]

The cost and accessibility of local feedstock, current and potential technologies that may be used to produce the desired outputs, can all be used to evaluate the feasibility of a certain set of processing technologies [32]. Four elements determine whether a technology, including briquetting, is economically feasible: the type of equipment utilized, the biomass type, human resource capabilities, and the cost of investment [3]. Both capital and operating costs are estimated in the economic analysis [32], along with the fundamental economic indicators of Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP), and Return On Investment (ROI) [3]. Numerous researchers have already examined the financial viability of biomass's energy potential, and their primary finding is that local conditions at the project site, such as the cost of labor and utilities, biomass waste raw material costs, and biomass logistics costs, affect how viable biomass projects are [16]. Therefore, the goal of this study was to acquire a sustainable renewable energy source from carbonized sawdust. Moreover, it investigates the techno-economic analysis of the production of briquettes derived from carbonized *Cordia Africana* sawdust.

2. Materials and Methods

2.1. Description of the Study Area

The study was carried out in Mekelle city, which is located at latitudes 13°25'30" N and longitudes 39°27'0" E. It is 2,044 meters above sea level and covers 242.8 km² in total, as shown in fig.2. Mekelle, the administrative center of Ethiopia's Tigray province, is 780 kilometers away from Addis Ababa, the country's capital.

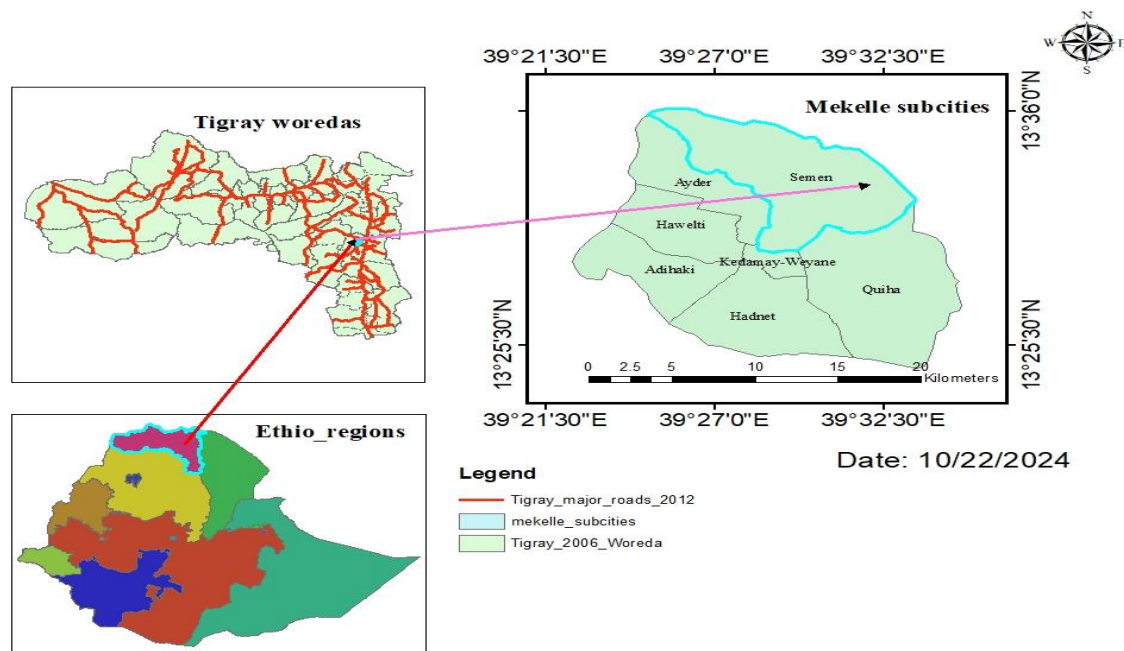


Fig. 2 Study area map of Mekelle City (GIS software)

2.2. Methodological Framework

This study looked at the three specified methodological approaches. These include establishing technology readiness levels, investigating costs, market conditions, and economic viability and analyzing profitability.

2.2.1. Assessing Technology Readiness Level (TRL)

Technology evaluations are a critical stage in the design and development of products. When it comes to techno-economic evaluation, the level of preparedness of a project influences not only the availability and quality of data but also assumptions and, above all, the selection of metrics, which in turn influences the results and interpretability [33,34]. Because TRL is a fundamental and distinct part of the iterative techno-economic analysis process, it must be studied as the initial stage in the evaluation process [35]. Additionally, the entire project needs to be examined and modified regularly [33]. In this study, TRLs were examined for the profitability indicators.

Comparing earnings and costs is a common way to assess a project's profitability, but it rarely provides sufficient justification for a deliberate choice; instead, other indicators are required. As shown in table 1, Giacomella, 2021, offers guidelines for selecting the most appropriate profitability metrics based on the project's progress [33].

Table 1 Profitability indicators and TRL

TRL	1	2	3	4	5	6	7	8	9
Profitability Indicators	Qualitative evaluation – e.g. comparison with benchmarks)	Relative gross profit	Relative profit	Static profit	NPV	Inclusion of interest rates for different cost items.	Economic simulations	Actual data for CapEx	Deeper economic simulations
			Specific profit	Static payback period	Dynamic ROI	Specifications on how CapEx is financed.			Past economic activities are summarized in accounting for cost checks and profit calculations.
				Static ROI	IRR				

Source: Giacomella, 2021 [33]

2.3. Economic Analysis

Before the commercialization of briquetting technology, it is imperative to ascertain the technique's economic feasibility. Because of the recently suggested energy conversion systems,

it is being conducted in the energy community with an emphasis on the renewable contribution [36]. Method, type of equipment, location, and availability of raw materials all affect the economic evaluation's findings. Therefore, the feasibility of each briquette technical path needs to be evaluated [37]. The raw materials largely dictate the technology and equipment used in the briquetting process, as well as the briquettes' variable manufacturing costs and quality. When proposing the construction of a briquetting facility, the cost is an important consideration [3]. Calculating capital investment costs, operational costs, and profitability analysis are the main economic assessments [38]. Based on capital and operating expenses, it seeks to calculate overall costs [32].

2.3.1. Capital investment costs

The total capital investment or capital expenditure represents the total amount of money invested in the energy plant used to erect it and it is determined as the total of all fixed capital expenses, start-up costs and working capital expenses [33]. Fixed capital investment costs include direct and indirect costs. Direct costs denote the capital necessary for the installed process equipment with all auxiliaries that are needed for the direct operation process. Indirect costs are costs that are required for construction overhead and for all plant components that are not directly related to the process operation [39-40]. Working capital for an industrial plant consists of the total amount of money invested in raw materials and supplies carried in stock, finished products in stock and semi-finished products in the process of being manufactured, and accounts receivable. The ratio of working capital to total capital investment varies with different companies, but most chemical plants use an initial working capital amounting to 10-20% of the fixed capital investment [30,41], and an average of 15% was taken for this study.

2.3.2. Operating costs estimation

Operating costs, which include process expenses, especially those associated with materials and processing, are an essential aspect of energy production [17]. It is a cost related to the briquetting plant's operations and product sales. Including fixed charges, direct production costs, plant-overhead, and general expense prices, it is the total of both variable and fixed production costs [39].

The profit and the total cost of the plant's operation are the ultimate goals of a process [42]. An order-of-magnitude estimate (ratio estimate) or predesign method was used to estimate the economic analysis since the cost of the purchased equipment serves as the basis for the pre-design approach. Delivery costs are influenced by the size of the equipment, the location of the equipment supplier, and the location of the delivery site. Using the logarithmic connection

known as the six-tenths-factor rule, which assumes that process parameters like temperature and pressure remain constant in comparison to the base case, it was estimated using Eqn. (1) [43-46].

$$Cost_2 = Cost_1 * \left(\frac{Size_2}{Size_1} \right)^n \quad 1$$

Where n is a constant depending on the equipment type.

The costs of some sources are often outdated, and these data were estimated by using Eqn (2) for the time impact using cost indexes [39,43,46].

$$Present\ Equipment\ Cost = Original\ Equipment\ Cost \left(\frac{Present\ index\ value}{Original\ Index\ value} \right) \quad 2$$

2.3.3. Methodological framework of economic analysis

Economic analysis of any process is useful for determining the final cost of production, but it is more important for identifying the key factors affecting it. Instead of providing a static depiction of the process, economic analysis should provide a dynamic instrument that decision-makers can use to support their choices [17]. The economic study of a process must be done clearly and simply; otherwise, it is pointless [15]. It should be mentioned that the proposed work just provides the instruments required to carry out the ensuing analysis, replete with relative ranges and characteristic values.

Calculation Details; A techno-economic examination of the project as a whole requires many techno-economic computations. An initial estimate of all costs and revenue that the project is anticipated to generate will be provided via an economic model. Additional technical computations will provide more information about the project's performance.

Economic Calculation; To cover all expenses when developing the economic model, it is best practice to start with the project life cycle and then progressively break down the costs of the various phases. This lifetime also indicates the level of detail to be used in calculating each part. By providing an (estimative) calculation model for each component in this lifetime, a comprehensive economic model is built. Finally, it's important to keep in mind that the authors separate operating costs and infrastructure components based on their origins [47].

Technical Calculations; Utilizing the input from the market study and network design, performance measures such as capacity, energy consumption, reach, dependability, and other technical indicators can be calculated. These technological criteria are then necessary for the techno-economic evaluation [47].

Techno-economic Evaluation; A holistic assessment that considers many facets of technology, economics, and market dynamics is provided by the techno-economic analysis, which is essential in determining the economic feasibility of bioenergy production [17]. The techno-economic evaluation considers the results of both investment and performance analysis to determine the most cost-effective option for a certain scenario and performance requirements.

Investment Analysis; The profitability of the project is calculated by adding up all cash flow expenses and revenues over time in a standard investment analysis [38]. Important performance indicators include cash balance, NPV, and IRR for a certain interest rate. Since the NPV and IRR offer the most accurate evaluation of the project's overall economic value by indicating the time value of money, the authors typically use these profitability measures as the determining metrics [32].

Performance Analysis; Technological and economic calculations can be used to evaluate techno-economic performance metrics. One of the performance measures is the cost per capacity unit for every user. It might be a more informative indicator than the cost per user because it would allow for a fair comparison of different access technologies. The relationship between dependability and cost must also be evaluated [47].

2.4. Analysis of Profitability

The profitability analysis, which is the result of collecting and analyzing costs and market conditions, provides a substantial qualitative perspective of the project's economic performance and contributes to its evolution [33]. It entails figuring out fundamental profitability metrics like NPV, IRR, PBP and ROI while taking into account several variables like operational expenses, investment costs, energy output, and associated income [30,46]. Therefore, the profitability analysis in this study was estimated using these methods.

2.4.1. Payback Period

PBP is the time needed for the investment's stream of cash proceeds to match the initial cash outlay, or the amount of time needed for the project to pay for capital expenditures (CapEx) through earnings of Annual Net Profit (ANePro). A shorter PBP is preferable since it offers the investor a clear idea of the time that the initial outlay will be at risk, and it was calculated using Eqn (3) developed by Alizadeh et al., 2023 [32].

$$PBP = \frac{CapEx}{ANePro}$$

2.4.2. Return on Investment

One measure of an investment's profitability that can be represented as a yearly percentage is the ROI. It displays the amount of profit or loss on an investment in relation to the CapEx. Eqn (4) was used to determine the standard percent ROI, which is the fractional return represented by the ANePro divided by the Total Capital Investment (TCI) required and multiplied by 100 [39,42].

$$ROI = \frac{ANePro}{TCI} * 100\% \quad 4$$

2.4.3. Net Present Value

Because it takes into account the time value of money and how it affects profitability calculation, NPV is the most commonly used methodology to evaluate the profitability of investments. It is the total of the present worth of all cash inflows minus the TCI. It represents the discounted value of the net cash inflows to the project and is estimated as follows using Eqn (5) [32,36,48].

$$NPV = \sum_{k=1}^k \frac{CF_k}{(1+R)^k} - TCI \quad 5$$

Where CF_k refers to the cash flow of year k , and R refers discount rate of the project, which is assumed to be 8% a year [44]. According to Al-Wahaibi et al., 2020, the positive value of NPV makes the project acceptable, and if it is negative, it must be rejected [49].

2.4.4. Internal Rate of Return

IRR is the highest interest rate that could be applied to the resources used in a project to recoup all expenses and still break even [3]. It is a metric that is frequently used in financial budgeting to evaluate the potential profitability of investments [32]. Eqn 6 was used to estimate the IRR, which is the discount rate at which the NPV of all investment cash flows equals zero [48,50].

$$NPV = \sum_{k=1}^k \frac{CF_k}{(1+IRR)^k} - TCI = 0 \quad 6$$

3. Result and Discussion

3.1. Economic Analysis

Table 2 shows the estimated costs of the equipment with its material of construction used for the briquetting production, from which the equipment is erected, to identify the carrying capacity of the equipment based on the selected material of construction.

Table 2 The capacity and cost of the main unit operations

S.N	Equipment	Construction material	Capacity	Unit	Quantity	Cost in USD
1	Drum dryer	Carbon steel	11	m ²	2	92796
2	Carbonizer	Carbon steel	5.7	m ³	1	97000

3	Mortar grinder	Carbon steel	3.6	m ³	1	12100
4	Vibrating screen	Carbon steel	3.9	m ³	1	29129
5	Mixer	Stainless steel	3.9	m ³	1	17600
6	Hydraulic universal test machine	Carbon steel	10,000	KN	1	328500
7	Water storage	Carbon steel	3.58	m ³	1	53131
8	Soaked tank	Stainless steel	7	m ³	1	21975
Total						652,231

3.1.1. Capital investment costs

The total production cost of briquettes and charcoal comprises fixed costs, operational costs, and the cost of repair and maintenance [51]. As shown in table 3, the total capital investment cost is the sum of Fixed Capital Investment (FCI) cost and Working Capital (WC). Again, the FCI is the summation of the total direct costs and indirect costs with a value of 1,304,462 and 241,325.47USD, respectively. Then the FCI and WC were estimated at 1,545,787.47 and 272,786.03 USD, respectively. Finally, the Total Capital Investment (TCI) was estimated as 1,818,573.5 USD, as shown in table 3. The details of each parameter were extracted from the techno-economic analysis of a comparable study and the plant design and economics, specifically for chemical engineers' textbooks.

Table 3 General summary of cost estimation for TCI cost

Parameters	Description	Costs, USD
Direct Cost (DC)		
Purchased equipment	100% of PEC	652,231
Purchased equipment installation	25% of PEC	163,057.75
Instrumentation and control	10% of PEC	65,223.1
Piping (installed)	15% of PEC	97,834.65
Electrical(installed)	10% of PEC	65,223.1
Building (including service)	11% of PEC	71,745.41
yard improvement	5% of PEC	32,611.55
Service facilities	35% of PEC	228,280.85
Total Direct Cost (TDC)		1,304,462
Indirect Cost (IC)		
Engineering and Supervision	14% of PEC	91,312.34
Construction expenses and Contractor's fee	15% of PEC	97,834.65
Contingency	8% of PEC	52178.48
Total Indirect Cost (TIC)		241,325.47

FCI (TDC + TIC)		1,545,787.47
WC	15% FCI	272,786.03
TCI	FCI + WC	1,818,573.5

3.1.2. Estimation of operating cost

Operating costs are costs related to materials and processing of the briquetting and charcoaling plant, and the selling of the briquette product [51]. As shown in table 4, it is the sum of fixed charges with a value of 309,157.8USD, direct production cost with a value of 466,851.59 USD, and general expenses with a value of 159,869.83USD. Lastly, the total operating cost was determined as 935,879.19USD as indicated in table 4.

Table 4 Summary of cost estimation for the total operating cost

Parameters	Description	Cost, USD
Fixed Charges		
Depreciation	10% of FCI	154,578.74
Local Tax	1% of FCI	15,457.87
Insurance	1% of FCI	15,457.87
Rent	8% of FCI	123,663
Total Fixed Charges (TFC)		309,157.8
Direct Production Cost		
Operating Labor cost	15% of TPC	140,179.30
Direct supervision and clerical labor	14% of Operating labor	19,625.10
Utility	5% of TPC	46,726.40
Maintenance and repair	3% of FCI	46,373.62
Operating supplies	10% of FCI	154,578.74
Laboratory Charges	15% of operating labor	2,943.75
Patent and Royalties	1% of TPC	9,345.28
Plant overhead cost	5% of TPC	46,726.40
Total Direct Production Cost (TDPC)		466,851.59
General Expenses		
Administrative cost	4% of TPC	37,381.14
Distribution and selling	10% of TPC	94,452.84
Research and Development cost	3% of TPC	28,035.85
Total General Expense (TGE)		159,869.83
Total operating costs = TFC + TDPC + TGE		935,879.19

3.1.3. Profitability analysis

When performing a profitability study, the following assumptions were taken into account: the factory would work 300 days a year, the tax rate is 35%, the Minimum Acceptable Rate

(MAR) is 12%, and the net profit is constant annually. Additionally, the amount of the product per hour is 4,000kg and is operated for 16hrs a day. Once more, the projected cost of the generated fuel briquette, with the unit selling price paid to users, is \$0.174/kg.

Upon the closure of any business, the proceeds from the sale of all business assets at that time are anticipated to exceed the initial investment. Therefore, assessing the viability of any business requires an economic examination [51]. According to this study, the plant's maximum utilization rate is 82%, and it can produce 15,744,000kg of charcoal sawdust briquettes annually. A net profit of 1,172,324.91USD can be made annually from this quantity of products. The profitability analysis was calculated utilizing the fundamental analysis techniques of ROI, PBP, NPV, and IRR, as shown in table 5, with corresponding values of 64.46%, 1.2years, 7,930,327.80USD, and 86.50%. If the NPV result is negative, the project should be rejected; if it is zero, neither value creation nor loss is taking place [48-49]. Once more, the project is not viable and should be turned down if the ROI and IRR are less than 10% [43]. Once more, Dranka et al., 2020, state that if the project's ROI value exceeds MAR, it is acceptable in terms of ROI [48]. The project is satisfactory in terms of ROI, with a value of 64.46%, higher than MAR (12%). Furthermore, the project is acceptable if the IRR value is higher than the MAR value, as stated by Dranka et al., 2020, therefore, the IRR, which was assessed at 0.8650 (86.50%), is also acceptable [48]. This indicates that the charcoal sawdust briquetting is also acceptable in terms of IRR. Therefore, in this study, the project is feasible in terms of all profitability indicator measures. The project's economic viability is influenced by several factors in the bioenergy production process, such as raw material prices, energy costs, operating expenses, and the impact of pretreatment of raw materials and related chemical transformations on product efficiency, yield, reliability, and environmental impacts [17].

Table 5 Summary of profitability analysis

Parameters	Values
Return on Investment (ROI), %	64.46
Payback Period (PBP), year	1.2
Net present value (NPV), USD	7,930,327.80
Internal Rate of Return (IRR), %	86.50

4. Conclusion

For sustainable energy use, briquettes made from carbonized *Cordia Africana* sawdust were the subject of a techno-economic analysis in this study. It treats biomass waste from agriculture and wood processing facilities, in addition to using sawdust as an energy source. The results of the economic study demonstrated that it is economical to produce and use briquettes made

from carbonized *Cordia Africana* sawdust as a conventional fuel. The findings of the profitability measures were a high IRR of 86.50%, a positive NPV of \$7,930,327.80, a lower PBP of 1.2 years and a higher ROI of 64.46%. This is due to the abundance of the *Cordia Africana* sawdust feedstock in the country. Briquette usage can help to reduce biomass waste and plant deforestation, which is in line with the region's environmental goals, in addition to easing the energy problem. Carbonized *Cordia Africana* sawdust can provide a viable renewable energy option, combining economic viability and environmental advantages. It is appropriate and practical for alternative domestic energy sources. This fuel is safe for handling, transportation and storage and is free of pollutants.

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Availability of data; The data sets used or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate; Not applicable.

Consent for publication; Not applicable.

Competing Interests; The authors declare no competing interests.

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