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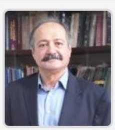

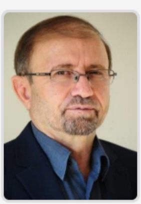

Volume & Issue: Volume 12, Issue 1, February 2025

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Research Article | Environmental Impacts and Sustainability

Assessment of Environmental and Economic Dimensions of Paddy Production in Iran

Mehri Alijani; Yaser Feizabadi; Mostafa Goudarzi

Volume 12, Issue 1 , February 2025, Pages 1-9

https://doi.org/10.30501/jree.2024.464665.1967

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https://doi.org/10.30501/jree.2024.446813.1864

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Volume 12, Issue 1 , February 2025, Pages 19-32

https://doi.org/10.30501/jree.2025.447645.1870

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Abstract Sawdust is a byproduct of wood cutting that has not been optimally utilized, despite its potential as an alternative fuel to replace fossil fuels. This study aims to assess the potential and efficiency of utilizing sawdust biomass waste as an alternative fuel for drying tea leaves using a cyclone burner ... Read More

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Mihoub Sofiane

Volume 12, Issue 1 , February 2025, Pages 56-70

https://doi.org/10.30501/jree.2025.466756.1987

Abstract The development of long-duration thermal energy storage materials has become crucial for improving the performance of Concentrated Solar Power (CSP) plants. Therefore, identifying suitable materials that meet various criteria—such as their properties, their impact on overall plant performance, ... Read More

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Mostafa Rahimnejad; Ramzi A Abd Alsaheb; Mohammed A Atyiab

Volume 12, Issue 1 , February 2025

https://doi.org/10.30501/jree.2025.476414.2070

Abstract The growing global demand for sustainable energy has intensified interest in bioethanol production from renewable sources. Integrating green nanoparticles derived from renewable sources or produced using eco-friendly techniques such as green chemistry into fermentation processes offers significant environmental ... Read More

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Research Article

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ABSTRACT

Sawdust is a byproduct of wood cutting that has not been optimally utilized, despite its potential as an alternative fuel to replace fossil fuels. This study aims to assess the potential and efficiency of utilizing sawdust biomass waste as an alternative fuel for drying tea leaves using a cyclone burner machine. The research was conducted at a tea processing factory in West Java Province, Indonesia. The results indicate that the innovation of using a cyclone burner fueled by sawdust for drying tea leaves shows promising prospects due to its efficiency, effectiveness, environmental friendliness, and significant contribution to reducing global warming. The innovation of utilizing sawdust waste as fuel in a cyclone burner has great potential for offering tea entrepreneurs energy savings, with a reduction in costs of $6,934 per month, or 73.56% greater efficiency compared to LPG fuel. Calculations using a simple linear regression mathematical model project that the production of sawdust biomass will reach 10.15 million cubic meters by 2040, with a growth rate of 8.19% per year. Meanwhile, sawdust production is projected to reach 6.62 million tons in 2025 and increase to 10.15 million tons by 2040, with an average annual growth rate of 8.19%.

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1. INTRODUCTION

The wood processing industry in Indonesia is widespread and generates substantial waste, which, if not properly managed, could lead to environmental issues due to the organic substances that can contaminate water and harm living organisms. Sawdust and wood chips resulting from sawing and cutting wood present opportunities as potential energy sources. The volume yield of roundwood is determined by the diameter of the wood, type, region, and cutting tools used. The average yield of sawn wood ranges from 66.60% to 80.01%, with the remainder being sawdust and peeling waste (Wahyudi, 2013). Sawmill waste can be categorized into four types: offcuts, sawdust, shavings, and bark (Haryanto et al., 2021).

Indonesia remains heavily dependent on fossil fuels such as petroleum, natural gas, and coal, which are derived from finite resources and will eventually be depleted if exploited continuously (Aisah & Herdiansyah, 2020). Therefore, it is crucial to diversify energy sources to ensure sustainable and guaranteed energy availability. Samuel et al., (2024). recommend prioritizing renewable energy policies, streamlining the regulatory approval process, and offering incentives for infrastructure investment to meet the 2030 sustainable development goals (SDGs) for environmental quality and sustainability. One promising innovation involves utilizing biomass waste as an alternative renewable energy source (Bahfie et al., 2021; Strielkowski et al., 2021). Biomass waste, as an environmentally friendly alternative fuel, has the potential to reduce the reliance on fossil fuels, which contribute significantly to global warming—accounting for about 85.5% of global CO2 emissions (Žižlavský, 2014; Santos et al., 2022; Udo et al., 2024).

The using biomass waste as an alternative fuel is more economically advantageous than using fossil fuels (Pimentel, 2019; Choe, 2021; Alonge et al., 2024; Clauser et al., 2021). Thermochemical biomass conversion technology, specifically direct combustion, is widely used in industries to produce heat

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or (Pang, 2019; Azizi et al., 2018). This process has also been utilized by Azizi et al. (2018) to generate biofuel. Meanwhile Siburian et al., (2024), explore opportunities for producing graphene from biomass waste, which could serve as a sustainable and high-performance energy storage system. Other technological innovations capable of converting biomass into energy include direct combustion, gasification, pyrolysis, enzymatic hydrolysis, fermentation, and liquefaction (Kumar et al., 2021; Osman et al., 2021).

Indonesia's tea production in 2023 amounted to 11,496 tons, reflecting a 6.5% decrease compared to 2022 (BPS, 2024)(BPS, 2024). The leading tea-producing regions are West Java (65.0%), followed by Central Java (11.5%), North Sumatra (8.6%), Jambi (6.1%), West Sumatra (3.0%), South Sumatra (2.0%), Bengkulu (1.9%), East Java (1.8%), and Yogyakarta (0.2%) (Figure 1).

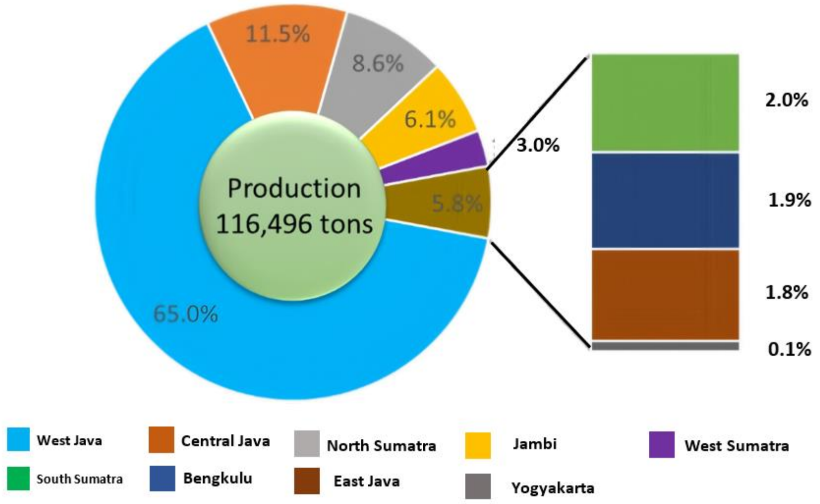

Figure 1. Distribution of tea production by province in Indonesia in 2023

This study investigates the use of energy derived from sawdust biomass waste as a fuel source for drying tea leaves, utilizing a cyclone burner. A cyclone burner is a device designed to convert biomass into thermal or electrical energy (Choe, 2021). This tool is essential in the tea processing industry, as its thermal energy can efficiently reduce the moisture content of tea leaves after wilting. Research on the application of cyclone burners fueled by sawdust waste remains limited, making this study a novel contribution to evaluating the efficiency of using cyclone burners with sawdust biomass waste for drying tea leaves.

2. METHOD

This study utilized both survey and desk study methods. The survey method was employed to collect primary data, while the desk study was used for gathering secondary data. Primary data collection took place in West Java Province, Indonesia, chosen purposively due to its status as the primary tea-producing region in the country. The sample for the study was the tea factory of PT. Perkebunan Nusantara VIII. The primary data consisted of results from experiments on the combustion process using sawdust in a cyclone burner, as well as data on tea production, processing capacity, and fuel consumption by the cyclone burner. Secondary data were sourced from relevant institutions such as the Central Statistics Agency, the Tekmira Mineral and Coal Testing Center, the Ministry of Forestry, and the Ministry of Energy and Mineral Resources of the Republic of Indonesia. The collected data were processed and analyzed to estimate growth rates, roundwood production volumes, sawmill residues, potential heat energy generation, and the potential for carbon emission reductions.

2.1. Time Series Analysis Models

To predict the growth of sawdust production and demand over time, a simple regression model obtained from various relevant references is used (Suseno, 2015; Alexander et al., 2022; Santos et al., 2022). This model is used to determine the tendency of changes (trends), seasons, and cycles in time series and to predict data for the future (Alqatawna et al., 2023). The simple linear regression model used to predict parameters is the ordinary least squares method (Huang et al., 2020; Xu et al., 2023). The time series analysis method is an indicator used to help monitor production growth over time (Shammi & Meng, 2021).

The mathematical formula of the simple linear regression model is:

$$\widehat{\omega_\tau} = \widehat{\beta_0} + \widehat{\beta_1}\tau \quad (1)$$

The coefficients $\widehat{\beta_0}$ and $\widehat{\beta_1}$ are calculated using the formula:

$$\widehat{\beta_0} = \frac{\sum\omega_t\sum\tau - \sum\tau\sum\tau\omega_t}{n\sum\tau^2 - (\sum\tau)^2} \quad (2)$$

$$\widehat{\beta_1} = \frac{n\sum\tau\omega_t - \sum\tau\sum\omega_t}{n\sum\tau^2 - (\sum\tau)^2} \quad .(3)$$

Note:
$\widehat{\omega_\tau}$: production variable in year τ (ton)
τ : time (year)
$\widehat{\beta_0}$: calculated value of the intercept line
$\widehat{\beta_1}$: calculated value of slope or regression coefficient
n : number of time periods

2.2. Technology Process for Tea Leaves Drying

Tea drying is a crucial step in the tea production process, aimed at reducing the water content to ensure the tea's longevity and maintain its quality during storage (Ulandari et al., 2019). Typically, fossil fuels are used in the drying machines for this purpose. Various factors, such as equipment, temperature, and heating systems, affect the energy consumption during the drying or heating process. According to research (Suprianti, 2020), the average energy consumption in the drying process at tea factories is 7,940 kWh per kilogram of tea produced. This energy use is considered , inefficient.

Kumar et al. (2021) report that tea factories consume around 3.5–6 kWh per kilogram of tea, with carbon dioxide emissions ranging from 2.15–2.86 kg.

The withering and drying stages are the most energy-intensive parts of tea processing (Suprianti, 2020; Ulandari et al., 2019). The process begins with the receipt of tea shoots from the plantation (Aditamahafiz, 2017; Sukma & Subagja, 2022) followed by the withering process, which is considered complete when the tea leaves reach a water content of 2.5–3% through heating at 110–140°C. Next, the tea undergoes rolling with an open top roller (OTR) machine. After rolling, the tea enters the Double Indian Bellbreaker Net Sorter machine, where it is sieved from the largest to the smallest mesh sizes, producing powder 1 and powder 2. The results are then processed through the Press Cap Roller (PCR) machine, followed by sieving into powder again. The tea powder is placed on a tray and transferred into the enzymatic oxidation chamber, where humidity is maintained above 90%, and the temperature is kept below 25°C (Aditamahafiz, 2017).

The final drying process involves using a Fluid Bed Dryer (FBD) fueled by sawdust. The drying equipment includes a wood-burning stove, blower, heat exchanger, drying chamber, and cyclone. Sawdust is burned in the furnace, and the heat from the combustion is directed by the blower through the heat exchanger, which then supplies the drying machine. The drying temperature is carefully monitored to remain between 110–140°C to ensure optimal drying conditions (Supriyanti, 2020). The machine will automatically stop if the output temperature falls below 60°C, ensuring that the drying process is optimal and the tea powder is not too wet. During drying, the first cyclone removes fine powder from the FBD, which will later become dry tea. The second and third cyclones, located near the blower, help balance the hot air, removing water vapor and releasing it through the chimney. After drying, the tea proceeds to the dry sorting stage, which uses equipment like midleton, druck roll, vibrex, and nissen. The final tea products are categorized into different types, weighed, and temporarily stored in silos or sacks.

2.3. Technical Specifications of Cyclone Burner for Drying Tea Leaves

The optimal equipment setup for the drying unit in the factory consists of five cyclone burner units, each equipped with a hammer mill, along with one jaw crusher (JC) that will serve all the cyclone burners. The cyclone burners, including the hammer mills, will be located in the furnace/heat exchanger area. In contrast, the jaw crusher (JC) will be positioned in the fuel stockpile area, the scheme can be seen in Figure 2.

Figure 2. Drying tea leaves using cyclone burner technology fueled by wood sawdust

2.4. Capacity and Fuel Consumption by Cyclone Burner

A cyclone burner is a type of burner that converts solid fuel into thermal energy. It consists of a cylindrical combustion chamber (either horizontal or vertical), a hopper or feeder for feeding fuel material, and a blower to direct the fuel into the combustion chamber. The cyclone burner used in this study was produced by the Center for Mineral and Coal Testing, Tekmira, Ministry of Energy and Mineral Resources (Figure 3). This cyclone burner, designed for tea drying, has a capacity of 100 kg per hour for each combustion furnace. With a diameter of 100 cm and a length of 200 cm, it can be installed in the factory area without altering the room layout. The cyclone burner will be equipped with a screw feeder for feeding fine fuel. For coarser fuels, it is equipped with grinding equipment such as a hammer mill and jaw crusher, capable of grinding fuel to a size of 5 cm.

Initially, the cyclone burner operated on coal fuel. However, it has since been adapted to use various types of biomass or a blend of biomass and coal (blending). The combustion characteristics of coal or biomass in a cyclone burner are similar to those of fuel oil or gas, meaning it can substitute either of those fuels (Choe, 2021). Cyclone burners can be used in a wide range of industries: large-scale industries, such as the boiler industry with rotary kilns (Nørskov, 2012); medium-sized industries, such as lime burning (Lundqvist, 2009), and smelting (Sumaryono, 2008); and smaller industries, such as oyster mushroom cultivation and soy sauce manufacturing. Cyclone burners are available in various sizes and capacities, depending on the energy needs of the industrial users.

Figure 3. Cyclone burner (Monika & Suprapto, 2011)

The cyclon burner made by BBPMB-tekmira is a cylindrical combustion chamber with a horizontal position. The type of fuel that is put into the cyclon burner combustion chamber is sawdust.

2.5. How the Cyclone Burner Works

The method and equipment used for solid fuel combustion in cyclone burners involve blowing fine fuel particles tangentially into a cylindrical chamber where they burn in a stable combustion process. This process can be electronically controlled, adjusted, and automated. The fuel used in cyclone burners can be coal flour or biomass powder. Coal flour typically has a particle size of -0.5 mm, while biomass powder is larger, with particles ranging from 2 to 5 mm. In boiler systems with a 5 tons/hour capacity, sawdust is commonly used as fuel, with consumption rates ranging from 1.1 to 1.2 tons per hour. The combustion technique involves spraying fine particle fuel using turbulent air flow in a high-temperature combustion chamber. This results in fast and complete combustion, producing a flame similar to that of fuel oil, stable combustion without soot, and low unburned carbon. Consequently, cyclone burners offer high thermal efficiency, a compact design, and environmental friendliness. The blower generates air pressure that blows the fuel tangentially into the combustion chamber, where it burns in the cyclone motion (Monika & Suprapto, 2011).

The small particle size of the fuel and the turbulent air flow facilitate excellent contact between the fuel and oxygen, requiring less excess oxygen compared to the combustion of larger solid fuel particles. This results in perfect combustion, with minimal excess air requirements, leading to high thermal efficiency and fuel savings. The combustion process in cyclone burners differs from traditional bottom-up burning furnaces, such as wood stoves or wood pellet burners. In those systems, fuel is placed on a grate, and combustion air is supplied from below, passing through the fuel bed. During pyrolysis, volatiles and hydrocarbons evaporate towards a cooler zone, releasing these compounds into the atmosphere. In cyclone burners, however, the combustion process is top-down. Volatiles, hydrocarbons, and quinones (such as anthraquinones and hydroquinones) evaporate towards a hotter zone (ranging from 700°C to over 1,200°C), where they undergo cracking and complete combustion into harmless CO2 and water vapor. This makes cyclone burners ideal and safe for food and beverage applications.

Cyclone burners can utilize various alternative fuels, including sawdust, quinine dregs, coffee grounds, and other solid biomass materials. The ability to use such diverse fuel sources makes the supply for cyclone burners both safe and adaptable. As fuel prices fluctuate, cyclone burners offer an effective solution by substituting more expensive fuels with lower-cost alternatives. The increasing use of biomass fuel, a renewable energy source, is in line with government initiatives to reduce CO2 emissions, making it an environmentally friendly option. The fine biomass residue from sawmills, used in the combustion chamber, is emitted by the turbulent air flow, which ensures fast and complete combustion. This results in a stable flame, no soot, and minimal unburned carbon, further contributing to its environmental benefits. Additionally, the high thermal efficiency of cyclone combustion technology (Sumaryono, 2008) leads to fuel savings.

3. RESULT AND DISCUSSION

3.1. Potential Biomass Waste Generated from Roundwood Sawing

Indonesia's economic growth in 2022, as measured by Gross Domestic Product (GDP), increased by 5.31%. In addition, the contribution of the wood industry to Indonesia's GDP saw a remarkable fivefold increase compared to the previous year (BPS, 2024). This indicates a strengthening economy and a growing demand for goods, including wood, over the past decade. The demand for roundwood has surged, reaching 28.85 million m³, with an export value of $12.13 billion (Mutaqin et al., 2022). Time-series data on Indonesia's roundwood production from 2012 to 2022 demonstrates a steady upward trend (Figure 4). The coefficients $\widehat{\beta_0}$ and $\widehat{\beta_1}$, calculated using the formulas in Equations (2) and (3), are shown in Table 1.

The regression forecasting model for production time is:

$$\widehat{\omega\tau} = 3631.49 + 256.15\tau$$

The model was used to estimate wood production until 2040, the results of which can be seen in Figure 5.

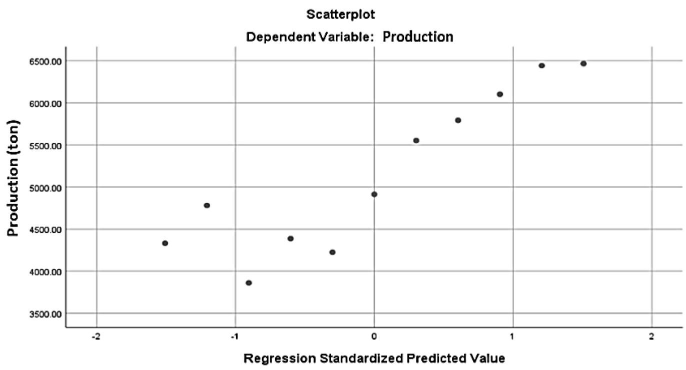

Figure 4. Trends in the development of roundwood production.

Table 1. Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Significance level
1	(Constant)	3631.491	274.476		13.231	.000
	Year	256.145	40.469	.904	6.329	.00014

Note: a Dependent Variable: Production

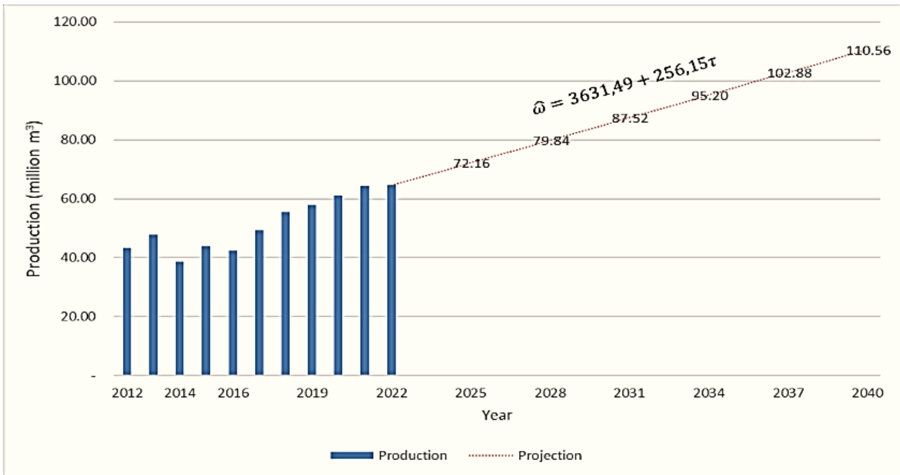

Figure 5. Realization and projection of roundwood production in Indonesia 2023-2040 (million m3)

Roundwood production in Indonesia is projected to reach 11.06 million m³ by 2040. Although production is increasing, the annual growth rate remains modest at 2.99%. To ensure the sustainability of Indonesia's roundwood industry, production growth must be accompanied by an increase in the frequency of wood planting. However, current data reveals that the growth rate of both production and planting in Indonesian wood forests is slowing and even showing signs of decline (Mutaqin et al., 2022). Contributing factors include the suboptimal utilization of forest resources upstream, where wood is still sourced from natural forests. One key governmental initiative should be to encourage companies to focus on developing sustainable industrial forest plantations (IFP) rather than expanding them, ensuring a steady supply of biomass residues for the cyclone burner industry. To support this transition, four biomass strategies are crucial: seeking managerial solutions, relying on technological innovation, preparing future solutions, and reducing the exploitation of natural resources (Awasthi et al., 2020; Boyer et al., 2023).

According to the Circular Letter of the Ministry of Forestry No. SE. 7/VI-BIKPIIH/2010, which defines the conversion of cubic meters (m³) to tons, 1 m³ of roundwood is equivalent to 1.0464 tons (Ministry of Forest Indonesia, 2012). The sawmill industry generates 40.48% waste by volume, including sawdust (22.32%), wood chips (9.39%), and shavings (8.77%) (Purwanto, 2009). Sawdust production is expected to reach 6.62 million tons by 2025 and increase to 10.15 million tons by 2040, reflecting an average annual growth of 8.19% (Figure 6).

3.2. Application of Cyclone Burner in Tea Factory

The cyclone burner utilizes sawdust as fuel, as many tea companies continue to rely on coal, LPG, MFO, and wood pellets. In 2021, a trial of the cyclone burner was conducted at a tea factory in Cianjur, West Java, Indonesia. The heat generated by the cyclone burner is used to dry tea shoots (Figure 7). The cyclone burner is installed on an endless chain pressure (ECP) type tea drying machine, where sawdust is used as fuel with an average feed rate of 40 kg/hr. The installed cyclone burner has a capacity of 100 kg/hr per combustion furnace, operating for 16 hours and 20 minutes each day. The cyclone burner measures 100 cm in diameter and 200 cm in length. In addition to a screw feeder for fine fuel input, the burner is equipped with a hammer mill and a jaw crusher, which serve to reduce biomass to a size with a filter pass of 5 cm. The factory's drying unit is configured with 5 cyclone burner units, each paired with a hammer mill, and 1 jaw crusher unit. The cyclone burners and hammer mills are placed next to the heat exchange furnace, while the jaw crusher is located in the fuel stockpile.

3.3. Technical Efficiency Analysis

A trial using the cyclone burner was conducted at a tea plantation that had been using coal as fuel. The cyclone burner is connected to an endless chain pressure (ECP) type machine, which contains a tray where the tea to be dried is placed. Sawdust is supplied at a rate of 40 kg/hr. Over a period of 6 hours and 20 minutes, the cyclone burner, operating at a temperature of 900°C, successfully dried 1,910 kg of wet tea leaves to a water content of 30-40% (BBPMB Tekmira, 2021). This value is lower than the requirement set by the Indonesian National Standard, which specifies a minimum water content of 45% (Prawira-Atmaja et al., 2021).

During the drying process, 253 kg (or 0.253 tons) of sawdust fuel was consumed. The cost of sawdust fuel is $133 per ton, which means the cost of sawdust used in this trial is $34. Thus, to produce 1 ton of dry tea leaves, the sawdust fuel cost is $18. A comparison of the cost of using sawdust versus four other commonly used fuels in the tea drying industry—coal, sawdust briquettes, LPG, and marine fuel oil (MFO)—is based on their calorific values and prices, as shown in Table 2.

Based on the calculation results, the sawdust-fueled cyclone burner is more efficient compared to using coal, LPG, wood pellets, or MFO fuel. In other words, using sawdust in the cyclone burner to heat tea leaves proves to be more cost-effective than using coal, LPG, MFO, or wood pellets (Figure 8). Each ton of dry tea leaves processed with the sawdust-fueled cyclone burner requires 253 kg of sawdust. While the amount of fuel used is higher than the other four fuel types, the cost of using sawdust remains lower. Therefore, the sawdust-fueled cyclone burner is a technically viable solution for the tea processing industry, offering a potential replacement for tools that currently use MFO, LPG, or wood pellets.

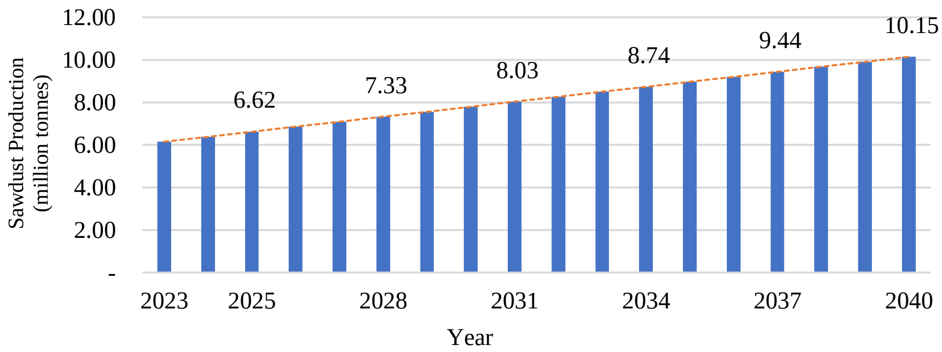

Figure 6. Projection of sawdust production until 2040 (million tons)

Figure 7. A set of tea dryers consisting of cyclone burners, hammer mills, jaw crushers and heat exchangers (BBPMBTekmira, 2021)

Table 2. Comparison of the cost of using several types of fuel to produce 1 ton of dried tea leaves

Fuel type	Calorific value (kg calorific.kg^{-1})	Consumption (ton)	Price (\$.ton^{-1})	Cost of fuel consumption (\$)	Cost of fuel/tea leaf production (\$.ton^{-1})
Sawdust powder	4,611*)	0,253	133	34	18
Batubara	5,377**)	0,217	172	37	20
Wood powdered charcoal briquette (*sawdust briquette*)	5,770***)	0,202	867	175	92
LPG	11,255	0,10	1,200	125	65
MFO	10,941	0,11	1,263	135	71

Note: *) (Hudaya & Hartoyo, 1988); **) (Ogara et al., 2023); ***) (Arifin et al., 2019)

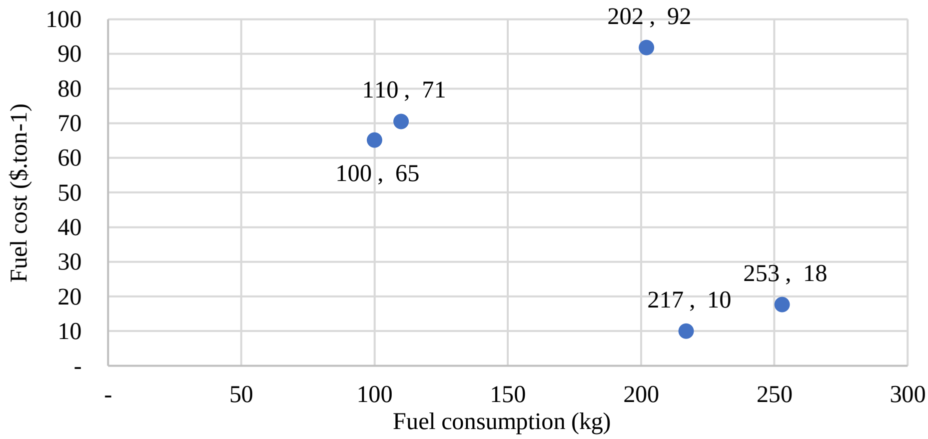

Figure 8. Consumption and cost of drying tea leaves of each type of fuel.

3.4. Savings

The consumption of LPG fuel used to generate heat in the cyclone burner amounts to 7,856 kg per month, costing $9,427. In contrast, using sawdust as fuel only incurs a cost of $2,493. This results in a monthly savings of $6,934, making sawdust 73.56% more cost-efficient than LPG for generating heat in the cyclone burner during the tea drying process (Table 3).

Table 3. Fuel cost savings

Material	Fuel (kg)	Price ($.kg^{-1})	Value ($)
Saw dust	19.175	0,13	2.493
LPG	7.856	1,20	9.427
Savings			6.934

4. CONCLUSION

The innovation of using a sawdust-fueled cyclone burner for drying tea leaves shows promising prospects due to its efficiency, effectiveness, and environmentally friendly nature, contributing significantly to reducing global warming. The growth of Indonesia's roundwood and wood processing industries ensures a steady supply of sawdust to meet the long-term needs of the tea drying sector. By 2040, the projected potential of sawdust biomass is expected to reach 10.15 million tons, with an annual growth rate of 8.19%. This innovation, using cyclone burners powered by sawdust waste, offers great potential for tea producers, as it can reduce energy costs by $6,934 per month, or 73.56%, compared to traditional fuel types.

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