

Competitiveness of Biomass as Bioenergy in Indonesia

Rista Fitria^{1,3*}, *Meika Syahbana Rusli*^{2,3}, and *Siti Jahroh*¹

¹ The Master of Management and Business Program, School of Business, IPB University, 16128 West Java, Indonesia

² Department of Agroindustrial Technology, Faculty of Agricultural Engineering and technology, IPB University, 16680 West Java, Indonesia

³ Surfactant and Bioenergy Research Center, IPB University, 16129 West Java, Indonesia

Abstract. The energy transition to renewable sources is a strategic step in reducing greenhouse gas (GHG) emissions and addressing global climate change. Biomass, as a renewable energy source, has significant potential to support the decarbonization of the energy sector. This study analyzes the competitiveness of biomass as bioenergy in Indonesia compared to other Asian countries, namely Thailand and India, by considering four key dimensions: (1) biomass availability, (2) biomass contribution to Total Energy Supply (TES), (3) the price of biomass as an energy source, and (4) bioenergy support policies, including the legislative framework, fiscal incentives, and market mechanisms. The analysis shows that although Indonesia has a high diversity of biomass sources, it is still less competitive compared to other Asian countries (Thailand and India), particularly in terms of contribution to TES and policy support. This study recommends reinforcing environmental pricing policies and incentive scheme to enhance the competitiveness of biomass implementation in Indonesia.

1 Introduction

Indonesia is one of the largest biomass producing countries. According to calculations, Indonesia's biomass potential reaches 298 million tons. According to the Ministry of Energy and Mineral Resources states that Indonesia has enormous bioenergy potential from biomass sources, equivalent to 56.97 GW of electricity. However, the utilization of biomass for bioenergy in Indonesia is still not optimal.

Biomass-based bioenergy is a form of renewable energy that converts the energy contained in plants or biological organisms into heat or electrical energy. This is because biomass raw materials derived from plants utilize the process of photosynthesis to capture solar energy by converting carbon dioxide from air and water into carbohydrates, oil compounds, and complex fibers. Carbohydrate, oil, and fiber compounds are energy sources that can be utilized/processed through various reactions, thus enabling them to be used for various types of bioenergy [1].

* Corresponding author: risfit.92@gmail.com

New and renewable energy (NRE) plays a crucial role in improving energy security and decarbonizing the global economy. Government Regulation (PP) No. 79 of 2014 targets the NRE mix to reach 23% by 2025, and 31% by 2050. To support the goal of net-zero emissions by 2060, the use of NRE still needs to be increased. This is due to the NRE energy mix reaching only 13.09% in 2023, compared to a target of 17.87%. Furthermore, the NRE mix will reach only 14.1% in 2024, compared to a target of 19.5%. Based on this data, the NRE contribution to Indonesia's energy mix is still far from the target of 25% in 2025.

In addition, according to the Minister of Energy and Mineral Resources, Indonesia has set an Enhanced-Nationally Determined Contribution (E-NDC) where carbon emission reduction in 2030 is 32% or 912 million tons of CO₂. As for the energy sector, Indonesia's emission reduction target in 2030 is 358 million CO₂ through the development of renewable energy, energy efficiency, low-carbon fuels, and clean coal technology.

The development of new and renewable energy is an alternative to replace fossil fuels, whose availability is decreasing. This is supported by data released by Indonesia Mining Association. Indonesia's fossil energy reserves in 2024 are, respectively, 31.71 billion tons of coal, 4.7 billion barrels of oil, and 54.83 trillion cubic feet of natural gas. Based on the remaining reserves, if used using a conservative scenario, the estimated lifespan of these fossil energy reserves is 28 years for coal, 21 years for oil, and 19 years for natural gas. Therefore, it is necessary to develop other sustainable new and renewable energy alternatives. And biomass is one of the new and renewable energy sources that can be developed and is sustainable in the long term.

One implementation of biomass as a new and renewable energy is the use of cofiring technology in 52 coal-fired power plants in Indonesia. Cofiring technology is a technology used to reduce coal use by substituting coal with biomass at a certain ratio. The implementation of cofiring technology for the PLN Group also played a role in reducing carbon emissions by 429 thousand tons of CO₂ throughout the first semester of 2023. According to the US Department of Energy, cofiring raw materials derived from plants have been successfully proven to replace up to 20% of the coal used in boilers. This is one of the efforts towards an energy transition to achieve sustainable economic growth.

The transition to sustainable economic growth is crucial. Within the concept of a sustainable economy, not only the economic aspect is the primary target but also social and environmental aspects need to be considered. The use of resources without regard for sustainability in linear economic activities causes very significant negative impacts such as climate change, loss of biodiversity, environmental pollution and others. The issue of climate change and sustainability has become a very important issue in current economic activities. According to the United Nations Indonesia, a total of 79 disasters related to hydrometeorological hazards were reported in Asia in 2023, according to the Emergency Events Database. Over 80% of these were related to floods and storms, with over 2,000 deaths and nine million people directly affected. In another source presented by the Ministry of Finance, several other risks of climate change are water scarcity, damage to terrestrial ecosystems, declining health quality, damage to marine ecosystems, and food scarcity. Based on a study conducted by the National Development Planning Agency, it appears that economic losses due to the impact of climate change in Indonesia reached 544 trillion rupiah during 2020-2024. These losses affect the coastal and marine sectors (ship accidents and flooding), agriculture (reduced rice production and water availability), and public health (increased dengue fever cases).

The development of biomass as bioenergy in Indonesia faces significant challenges, despite its enormous potential of up to 50 GW. Previous research has emphasized the importance of strategic planning, a shift in approach towards sustainability, improvements in biomass fuel quality, and policy and financial support to ensure the success of biomass as a renewable energy source [2]. However, as other studies have shown, Indonesia's biomass

policy strategy remains incremental and less integrated than countries like India, which have successfully developed the technology and institutions to effectively support the biomass sector [3].

A case study in India shows that although biomass development in India is not yet optimal, the existence of a targeted strategy in utilizing the potential of agricultural-based biomass, including the management of agricultural residues, can significantly increase biomass availability [4]. In Indonesia, other research identified several major obstacles, such as the lack of integration between developers and producers, minimal human resource expertise, the use of traditional tools, and regulations that are not coordinated between sectors [5]. This hampers the competitiveness of biomass as bioenergy in Indonesia. Therefore, it is necessary to analyze the competitiveness of biomass as bioenergy in Indonesia to understand the position of biomass as bioenergy, especially when compared with countries in the Asian continent that have abundant biomass resources and national conditions that are not much different, such as Thailand and India. This also aims to see how good strategic planning in managing biomass as bioenergy.

2 Method

2.1 Type of data

This research uses secondary data from various institutions such as the Ministry of Agriculture in each country, the Ministry of Energy in each country, the International Energy Agency in the form of annual energy reports and other study reports.

2.2 Method

This research was conducted using descriptive analysis using secondary data. Competitiveness analysis was conducted through a benchmarking approach on representative countries considered to have similarities in terms of large biomass potential and diversity and country conditions that are not much different based on the World Bank classification. The selection of comparison countries was also based on the development of biomass utilization as a fairly advanced bioenergy, namely Thailand and India. Thailand was chosen because the development of biomass utilization as a bioenergy is considered the most significant among countries in Southeast Asia, and India was chosen because it represents a country on the Asian continent that has a good planning strategy in developing technology and institutions to effectively support the biomass sector.

Competitiveness analysis is conducted by comparing the implementation of biomass as bioenergy in Indonesia with Thailand and India against four determined biomass competitiveness parameters. The four competitiveness parameters are biomass availability, the portion of biomass as bioenergy to Total Energy Supply (TES), the price of biomass as bioenergy to the price of fossil fuels as an energy source and policies in supporting biomass development. These parameters refer to previous study mentioning factors that influence economically feasible biomass-based energy systems are the availability of raw materials, market dynamics, capital investment, revenue streams, operational costs and policy incentives [6]. Biomass availability refers to the availability of raw materials. The price of biomass as bioenergy to the price of fossil fuels as an energy source refers to the revenue stream. And policies in supporting biomass development refer to market dynamics, capital investment and policy incentives. The parameter of the portion of biomass as bioenergy to Total Energy Supply (TES) is carried out referring to different research, in measuring renewable energy indicators in 4 countries, namely installed capacity in renewable energy

(GW), the portion of renewable energy in the national energy mix and investment in renewable energy projects. This study will only discuss the portion of renewable energy in the national energy mix and its relationship to Gross Domestic Product (GDP). In this study, GDP is used as a measure of a country's economic development [7].

In the competitiveness analysis, a comparison is made of the biomass potential produced by each country and the diversity of biomass types used. The biomass potential that can be utilized as bioenergy in Thailand refers to the ERIA Research Project Report on Bioenergy Supply Chain Development in AZEC Partner Countries conducted by the Economic Research Institute for ASEAN and East Asia. This report is also used as one of the sources in analyzing biomass-based bioenergy policies in Indonesia and Thailand. The analysis of biomass policies and potential that can be utilized as bioenergy in India refers to the World Bioenergy Association white paper on India: The Next Great Bioenergy Revolution. The biomass calculation approach for Indonesia is carried out with the following calculations.

Oil palm biomass was calculated using the CPO production approach. The ratio of CPO to Fresh Fruit Bunches (FFB) was 24%. The ratio of various types of biomass to FFB was Empty Fruit Bunches (EFB) 21%, Palm kernel Shell 6.1%, and mesocarp fiber 14.4%. Specifically, the calculation of fronds and stems was carried out using productive and unproductive/old/damaged plant conditions. Frond production in productive plant conditions was 1.4 tons/ha, while in unproductive/damaged plants it was 5.20 tons/ha. Meanwhile, stem production was carried out in damaged plant conditions with a value of 56.25 tons/ha.

Sugarcane biomass calculations are based on sugar production data as the primary reference. Sugar production figures are first used to estimate the total mass of harvested sugarcane stalks. This total stalk mass then serves as the basis for calculating the total number of sugarcane plants and the associated biomass fraction. Sugar yield is 8% of stalk weight, while stalk weight accounts for 81% of the total plant weight. Furthermore, sugarcane leaf-top biomass is calculated at 14 percent of the total plant mass, and bagasse is estimated at 35 percent of the total stalk mass.

The calculation of rubber seed shells and rubber seed cake is based on data from rubber plantations. One hectare of rubber plantation is assumed to consist of 476 rubber trees and produce 1,666 kg of rubber seeds. Based on this assumption, the total amount of rubber seeds can be estimated using the following ratios. Rubber seed shells are estimated to constitute 41.6 percent of the total mass of rubber seeds, while rubber kernels constitute 58.4 percent of the total mass of rubber seeds. Furthermore, rubber seed cake is calculated to constitute 37.2 percent of the mass of rubber kernels.

Rice biomass was obtained from rice production data, specifically dry unhulled rice (DUR), which serves as the primary reference for estimating biomass components. DUR data was used to calculate rice husk with a ratio of 25% to DUR. Meanwhile, rice straw was estimated based on harvested dry rice grain data, which requires converting DUR to wet unhulled rice (WUR). The conversion factor for WUR to DUR was 93.18%, and straw was calculated using a ratio of 3/2 to WUR.

The calculation of cassava peel biomass was obtained at a ratio of 15% of cassava production in Indonesia. Coconut fiber and coconut shell biomass calculations are based on Indonesian copra production data. This data was first converted to the number of whole coconuts to determine the proportion of coconut fiber and coconut shell relative to whole coconuts. Coconut fiber biomass is estimated at 25 percent of the total whole coconuts, while coconut shell biomass is calculated at 16 percent of the total whole coconuts.

Corn biomass calculations are based on dry corn kernel production data. This data is used to estimate the number of dry corn cobs harvested and the total fruit mass, which includes kernels and cobs. The resulting values then serve as the basis for calculating the number of husks and stalks. Corn cob biomass was calculated using dry corn kernels produced at 14% moisture content, based on the 2020 Central Java Production and Yield Survey, with a

conversion ratio of harvested dry corn kernels to dry corn kernels of 55.94%. Dry corn kernels are estimated to constitute 31.3% of the total fruit. Furthermore, husk biomass is calculated at 25.65 percent of the total fruit, while stalk biomass is estimated at 3.48 percent of the total fruit.

The assessment analysis is carried out by giving plus points to following parameters. Each parameters will receive score range from 1, 2, 3 point.

- a. Biomass availability parameters are assessed based on biomass quantity and diversity. Higher biomass availability and diversity receive a maximum score.
- b. The biomass contribution to total energy supply (TES) parameter will be assessed based on the proportion of biomass-based bioenergy to TES and the value of biomass-based bioenergy in each country. The greater the proportion and value of biomass-based bioenergy, the higher the points earned, and vice versa.
- c. The parameter of the price of biomass as an energy source is assessed based on how competitive the price of biomass is with the price of coal at a certain calorific value.
- d. The bioenergy support policies parameter is assessed based on the completeness of policies supporting biomass implementation. The more comprehensive the policy, the higher the score.

3 Result

One of the efforts made to reduce greenhouse gas (GHG) emissions is through an energy transition from fossil-based energy to renewable energy. The combustion of fossil fuels is a major contributor to increasing CO₂ gas emissions levels which will result in global climate change. In addition, the use of fossil fuels can also cause substantial biodiversity loss and widespread pollution, thus posing an existential threat to the health and stability of the Earth's ecosystems [8].

Each country's contribution to reducing greenhouse gas emissions is outlined in *its Nationally Determined Contributions* (NDCs). The Paris Agreement stipulates that each country contributes to reducing greenhouse gas (GHG) emissions. Therefore, each country determines its policy direction from using fossil fuels to more environmentally friendly energy, namely renewable energy. Renewable energy is energy derived from renewable sources such as the sun (solar energy), wind (wind power), water (hydroelectric power), geothermal heat (geothermal energy), tides (tidal power), and biomass.

Based on data released by Global Bioenergy Statistics Report, the supply and consumption of renewable energy have increased in the last 20 years, although it is still dominated by fossil fuels. Renewable energy supply data shows that in 2000 it reached 53.7 EJ and in 2020 it reached 88 EJ. Meanwhile, consumption data shows an increase from 46.2 EJ in 2000 to 70.3 EJ in 2020. By continent, the use of renewable energy sources shows that the African continent has the largest portion of both supply and consumption of renewable energy sources compared to the portion of energy sources of each continent.

According to a study, renewable energy sources could control up to two-thirds of the global primary energy supply by 2050, in stark contrast to the 24% contribution predicted by the reference scenario. Pioneers of this energy transition are Denmark and Germany, the European Union countries with the largest energy contributions coming from wind energy. Then in the Asian continent, China and India show very rapid annual growth exceeding 30% in solar and wind sources. The Americas show a diverse contribution to the types of renewable energy sources. In addition, Middle Eastern countries are progressively diversifying their energy portfolios, and while Africa shows potential, the transition is limited by infrastructure challenges [8].

According to the Global Bioenergy Statistics report, renewable energy contributed 15% of the total global primary energy supply in 2021. In 2020, the largest contribution of

renewable energy supply was used for electricity generation, with a 29% share of the total global electricity generation sources, with bioenergy accounting for 9% of all renewable sources. With a similar contribution of 8%, renewable energy contributes to total global heat production. In renewable-based heat production, biomass-based bioenergy contributed 96%. Meanwhile, in the transportation sector, renewable fuels are dominated by biofuels, accounting for 90% of the renewable share in that sector.

One renewable energy source with potential for development is biomass-based energy. The supply of biomass as energy continued to increase from 2000 to 2020, ranging from 41.7 EJ to 57.5 EJ. Biomass sources can come from urban waste, industrial waste, solid biomass, biogas, and liquid biofuels. Of these various biomass sources, solid biomass is the largest source of biomass. In 2020, biomass supply from solid biomass reached 86%, this value includes wood fuel, wood pellets, and wood charcoal. The largest use of solid biomass is in the electricity and heat production sectors with portions reaching 69% and 52%, respectively.

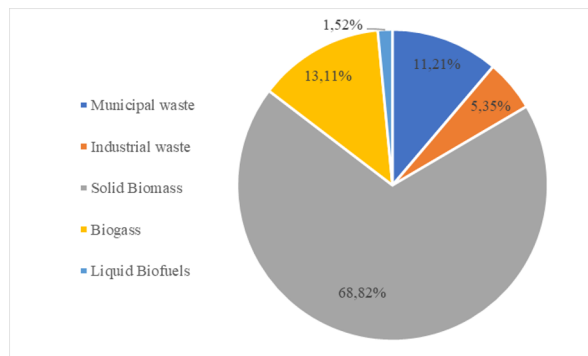


Fig. 1. Biomass-based electrical energy in 2020 according to the Global Bioenergy Statistics report.

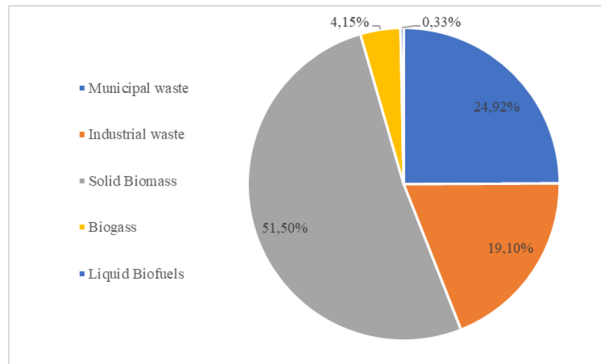


Fig. 2. Biomass-based thermal energy in 2020 according to the Global Bioenergy Statistics report.

If we look at the development of biomass-based bioenergy implementation in Southeast Asia, one of the countries with the greatest development in biomass implementation is Thailand. This is because Thailand had the largest total installed biomass-based capacity in Southeast Asia in 2019 [2].

Based on these data, this study will compare the competitiveness of biomass implementation as bioenergy in Indonesia and several selected countries based on the development of biomass implementation as bioenergy and the country's condition. The countries that are the objects of this study are Indonesia, Thailand, and India. Thailand was chosen because it represents an upper-middle-income country according to the World Bank

classification, with a high Human Development Index. Indonesia is an lower-middle-income country according to the World Bank classification and has a high Human Development Index score. Meanwhile, India was chosen as a representative of a lower-middle-income country with a medium Human Development Index.

Table 1. Conditions of three countries based on the World Bank classification about developing countries.

	Human Development Index (HDI) Tier 2023	Human Development Index (HDI) (2023) (0-1)	World Bank Classification	GNI Per Capita (Atlas) (\$)
Thailand	High	0.80	upper middle income	7190
Indonesia	High	0.73	lower middle income	4810
India	Medium	0.69	lower middle income	2580

Referring to previous research, the Human Development Index (HDI) is one indicator of a country's sustainable development. This means that the better a country's HDI score, the more it will develop a sustainable life through sustainable energy development as well. The HDI is a measure used to assess the level of human well-being and sustainable development in a country, and takes into account three main aspects: health (life expectancy at birth), education (school education, higher education level), and standard of living (per capita income). Countries with a high HDI indicator are usually more able to achieve sustainable development and provide a conducive environment for social, economic, and environmental growth [7].

3.1 Biomass Availability

The availability of biomass resources is one of the keys to the successful development of biomass-based bioenergy in every country. This also relates to the future sustainability of biomass-based bioenergy development. This is crucial because the current use of fossil fuels, with available reserves dwindling and their renewal taking a very long time. Biomass-based bioenergy feedstock is a renewable energy source, but proper management of the feedstock is necessary to ensure future availability.

Indonesia has a large and diverse biomass potential. Data shows that Indonesia's biomass potential reaches 301 million tons, Thailand's biomass potential is 277 million tons, and India's is 229 million tons. The largest biomass potential in Indonesia comes from palm oil waste, especially oil palm trunks and empty fruit bunches. This is in accordance with Indonesian palm oil production. According to data from the Foreign Agricultural Service, USDA, Indonesia is the country that produces the most palm oil in the world with a share of 58% of global production with a total production reaching 46 million tons in 2024/2025. The second largest biomass potential is rice waste derived from rice straw and husks. And the third biomass potential is wood waste from forests. Based on this data, Indonesia has a higher competitiveness in terms of biomass availability compared to the other two countries.

Unlike Indonesia, Thailand's largest biomass potential is sugar production waste in the form of bagasse and sugarcane leaves. This is followed by cassava production waste and forestry waste. Based on data from the USDA's Foreign Agricultural Service, in 2024, Thailand's total sugar production is lower than India's total sugar production, with production values of 10.04 million tons and 28 million tons, respectively. India has a larger share of the world's sugar needs, at 15%, while Thailand only has 6%. However, data shows that biomass used as energy in India is smaller, at only 6.4 million tons. This is because the waste produced

is not entirely used as an energy source but is also used for household needs, animal feed, compost, and other purposes. According to a report by the World Bioenergy Association, only 1/3 of biomass waste, or 230 million tons, is used as an energy source, while the remaining 2/3 of the total biomass is used for household needs, animal feed, compost, and other purposes. In India itself, the largest biomass used as an energy source comes from cotton production waste. This is in accordance with cotton production data released by the Foreign Agricultural Service, USDA, where India is the second largest country contributing to world cotton production with a portion of 20% or worth 24 million bales. The second largest source of biomass in India is waste from rice production. This is also in accordance with India's total rice production, which is the largest in the world, namely 150 million tons and is a contributor to total world production with a portion of 28% of total world production.

Table 2. Biomass potential in Indonesia, Thailand and India (Tons).

Biomass Type	Indonesia (2023)	Thailand (2020)	India (2021)
Sugarcane			
Bagasse	9,774,804	65,526,016	6,400,000
Sugarcane leaf	4,827,063	45,194,485	
Palm Oil			
Empty fruit bunch	41,198,764	196,149	
Fiber	28,250,581	119,077	
Shell	12,555,814	54,103	
Front	20,604,410	357,741	
Trunk	38,595,392	30,155,059	
Rubber			
Cake	824,979		
Shell	1,579,721		
Rice			
Husk	13,495,248	6,354,281	41,700,000
Straw	86,897,928	27,685,247	
Cassava			
Peel	2,514,653		
Pulp		20,512,651	
Rhizome		5,964,933	
Trunk		15,214,725	
Coconut			
Shell	3,081,562	84,308	
Fiber	4,814,941	20,972	
Corn			
Cob	11,636,780	2,165,534	15,200,000
Pulp/husk	12,107,482	2,280,773	
Trunk	1,642,652	14,779,405	
Cotton			
W heat			
Potato			
Pulses			
Oilseed			
Waste			
Municipal waste	2,733,233		
Forest waste			
Wood waste (Forest Products)	9,720,741	40,213,879	
Other			
Total	300,678,101	276,879,338	228,500,000

Based on the data presented above, Indonesia has a high level of competitiveness compared to the other two countries in terms of biomass availability. This is because Indonesia has the largest total biomass with a greater variety than the other two countries, Thailand and India.

3.2 Biomass contribution to total energy supply (TES)

Beyond availability, competitiveness must also consider actual integration into national TES. Biomass contribution to total energy supply is an important indicator that shows progress in integrating bioenergy into national energy systems. This indicator reflects the extent to which countries are shifting to more sustainable energy sources [7].

Based on data released by the Ministry of Energy and Mineral Resources refers to handbook of energy & economic statistics of Indonesia 2023, Indonesia's energy sources are still dominated by coal (39.69%) and petroleum (29.91%), followed by natural gas-based energy (17.11%) and renewable energy (13.29%). The total primary energy supply in 2023 reached 1,853,281,000 BOE. When looking at the supply of solid biomass-based energy in Indonesia according to its raw material sources, in 2023 Indonesia has supplied 20,451,942 BOE as industrial biomass and 16,648,879 BOE as traditional biomass. Biomass can also be seen in other renewable energy, where these other renewable energies show bioenergy-based power plants. Data on the production of biomass-based power plants, biomass-based power plants generated through on-grid in 2023 amounted to 176 GWh and the production of off-grid biomass power plants reached 21,256 GWh. The total production of power plants both on-grid and off-grid is 21,432 GWh or equivalent to 12,611,180 BOE. The total supply of biomass-based energy is 49,712,001 BOE or equivalent to 84,483 GWh. Based on calculations, the potential of biomass in Indonesia reaches 301 million tons or equivalent to 1,252,825 GWh with the assumption that the average calorie used is 15 MJ/kg. If converted to electrical energy with 30% efficiency, the electrical energy generated from biomass potential is approximately 375,848 GWh, while the required biomass supply is 84,483 GWh. This indicates that the biomass requirement to meet biomass-based energy supply is only 22.5% of the existing biomass potential. Thus, there is a significant gap between biomass potential and biomass utilization, requiring significant efforts to optimize the utilization of existing biomass.

According to other sources in International Energy Agency, Indonesia's total energy supply (TES) reached 11.5 million TJ and is the second largest after India when compared to India and Thailand. India's TES reached 45 million TJ and Thailand has the smallest TES value of 5.4 million TJ. This is equivalent to the Gross Domestic Product (GDP) value, where the GDP values of India, Indonesia and Thailand in 2024 according to the World Bank are respectively 3.9 trillion, 1.4 trillion and 0.53 trillion. GDP is an indicator to measure a country's macroeconomic performance which is seen based on a country's economic ability to produce goods and services [7]. This means that the greater a country's GDP, the more industries it has to produce goods and services. The larger the existing industry, the greater the energy required, thus requiring a larger energy supply.

Based on existing data, the magnitude of this TES value is also comparable to the biomass-based energy supply produced, where India produces around 9 million TJ, Indonesia 1.3 million TJ and Thailand 1 million TJ. According to data submitted by the IEA, the biomass-based energy supply in question is biofuel and waste, causing the figure released by the IEA to be larger than the data according to the Ministry of Energy and Mineral Resources, namely 1.3 million TJ or equivalent to 40.5 GW.

Compared to the TES, Indonesia has the lowest biomass-based energy supply at 11%, while India and Thailand have similar figures at 19.77% and 19.17%, respectively. This is certainly a significant step for Indonesia to take to increase the share of biomass-based energy

in its TES. The low energy share is disproportionate to its biomass potential, indicating that the utilization of biomass as bioenergy in Indonesia is still suboptimal and needs to be improved.

According to the Global Bioenergy Statistics report, the use of biomass as bioenergy has the largest contribution in producing heat energy. Looking at renewable energy sources in Indonesia, biomass is the most widely used as energy, especially in biofuels and biomass power plants. Based on existing data, the use of biomass for power generation continues to increase every year. A similar trend is also occurring in Thailand and India. This trend is further strengthened by government policies that continue to increase the target for the use of biomass as energy. For example, in the ERIA Research Project Report, the application of biomass as bioenergy, the development of biomass as energy in Thailand has achieved very good achievements, especially in solid energy and biogas which has increased twofold. Thailand has clear plans and targets with government programs that support the targets that have been set. By 2037, Thailand has a target of implementing biomass power plants of 5790 MW and biomass heat use reaching 23,000 Ktoe. The same thing also occurs in India. The total energy supply in India has doubled in the last two decades and continues to grow where the amount of bioenergy is quite stable at 7-8 million TJ.

Table 3. Portion of biomass to TES in 3 countries.

Parameters	Indonesia	Thailand	India
	Unit in TJ (2023)		
Total Energy Supply (TES)	11,498,283	5,447,610	45,430,619
Biomass-based Energy Supply	1,277,286	1,044,206	8,987,587
% Biomass Portion to TES	11.11	19.17	19.77

Indonesia has the smallest share of TES in the country. This proportion indicates that biomass utilization, despite its vast potential, is still less than optimal. Despite its high potential, biomass development in Indonesia faces challenges. These challenges include weak institutional coordination, limited skilled human resources, reliance on traditional tools, and fragmented policies.

3.3 The price of biomass as an energy source

Biomass pricing is highly complex, as it depends on the varying prices of raw materials and the processing technology used to produce biomass as a fuel. Furthermore, the use of biomass as an energy source also requires consideration of supply chain logistics costs. Consequently, biomass prices are higher than those of coal.

Table 4. Price of biomass in Indonesia.

	Calorific value (Kcal/kg)	Price (Rp)	Conflicting uses
Rice Husk	3000 - 3400	290/kg	Tile, brick and cement production, fertilizer, poultry feed
Sawdust	3000 - 3500	350 – 600/kg (+- 2,450 Kcal/kg NCV)	Chicken bedding, insect repellent
Woodchip	3000 - 3500	829 – 922/kg	Paper and pulp

Wood pellet	3940 - 4400	1300/kg (>4100 Kcal/kg NCV)	Export
Palm kernel shell	3500 - 4200	825 – 960/kg (>3500 Kcal/kg NCV)	Export
EFB	-	45 – 68/kg	Internal use, fertilizer, paper and pulp
EFB pellet	3600 - 4000	NA	Internal use, fertilizer, paper and pulp

source : ERIA Research Project Report

Biomass pricing is crucial because if biomass prices are too low, it will make it less attractive to raw material producers. Meanwhile, if biomass prices are too high, it will cause energy raw material prices to rise, resulting in expensive energy production. This makes the transition from fossil fuels to biomass energy less attractive, so efforts are needed to make biomass as an energy raw material more competitive. Another study analyzed the cost of electricity generated from biomass in the form of imported wood pellets from the Southern US under price support mechanisms such as Renewable Obligation Certification (ROC) and Levy Exemption Certificates (LEC) and the cost of electricity generated from coal in England. When compared to coal-based electricity, the results showed a 30% higher cost of electricity using wood pellets (22.23 cents/kWh) without price support and a 16% lower cost (14.29 cents/kWh) under price support conditions. Other studies have also been conducted in various locations, such as Virginia, USA, which showed lower electricity prices with incentives (Renewable Energy Certificates (RECs)) for the use of more environmentally friendly raw materials. From this study, providing similar incentives such as REC, ROC, LEC, and carbon tax is very important to make biomass-generated electricity more competitive [9,10].

Table 5. Price of wood pellets and coal in 3 countries

	Wood pellets (Rp/kg) (4100 Kcal/kg)	Coal (Rp/kg) (4100 Kcal/kg)
Indonesia	1300	837
Thailand	1860 [11]	1565
India	1819	368

The above values are processed using an exchange rate of 1 USD = Rp. 16,162 in 2024, the Indian exchange rate in May 2024 was 1 Indian Rupee = Rp. 194.6 and the Thai exchange rate in 2020 was 1 Bath = Rp. 449.80

Comparative data on the price of wood pellets and coal shows that India has the highest price ratio, with wood pellets being 4.94 times higher than coal of the same calorie content. Indonesia has the second highest price ratio at 1.55 times, and Thailand at 1.19 times. Looking at the price difference between biomass and coal, Thailand's biomass price is the smallest, with biomass being 18.8% higher than coal, while Indonesia's is 55.3% higher than coal, and India's is 394% higher than coal. This price ratio indicates Thailand's price competitiveness compared to Indonesia and India. Thailand, with minimal policy support such as subsidies, carbon taxes, and green incentives, can compete with coal. Indonesia's significant price gap necessitates strong incentives for a successful energy transition. India, for example, sees a significant price gap between wood pellets and coal, making it difficult to compete on a price basis. However, several Indian government policies have been implemented that encourage the use of biomass, even if it is uneconomical.

3.4 Bioenergy support policies

To accelerate the energy transition from fossil fuels to renewable energy, a set of policies is needed to support this transition. These policies can include government policies, legislative policies, and fiscal policies.

The policy for the energy transition to renewable energy is formulated into three major policies, namely: legislative and regulatory frameworks, financial and tax incentives, and market mechanisms and the implementation of environmental pricing [12]. The legislative and regulatory framework in question consists of establishing mandatory laws for the purchase of renewable energy and establishing minimum quotas for clean energy in the national energy mix [13]. The four main incentive strategies of the Chinese government that can accelerate the energy transition in promoting the renewable energy power generation (REPG) are research and development incentives, fiscal and tax incentives, grid connection and tariff incentives, and market development incentives. Preferential tax policies include value-added tax (VAT), income tax, and import duties. Fiscal and tax incentives are provided when taxes and duties on imports of renewable energy equipment are exempted [14]. Other fiscal policies are pricing laws, quota requirements, production incentives, tax credits, and trading systems. Of these policies, the Feed-in Tariff (FIT) policy and the renewable portfolio standard (RPS) are the main policies to encourage the development of renewable energy for power generation. FIT is a pricing policy that guarantees a fixed price to renewable energy generators for the electricity they produce [15]. Market mechanism policies and the implementation of environmental pricing are seen in the existence of a system for trading carbon emissions or clean energy certificates that require industrial facilities to purchase emission rights. This will increase the cost of fossil fuels compared to the use of isotopic renewable energy. This mechanism creates price competition between fossil fuels and renewable energy.

This study will compare the implementation of legislative and regulatory policies, financial and tax incentives, market mechanisms, and environmental pricing in Indonesia, compared with Thailand and India. The following presents government policies regarding the implementation of biomass as bioenergy.

Table 6. Government policy on the implementation of biomass as bioenergy.

	Indonesia	Thailand	India
Legislative	<ul style="list-style-type: none"> National Energy Policy (PP No. 79/2024) is related to the renewable energy target of 23% in 2025 and 31% in 2050 where bioenergy is projected to reach 10% of the energy mix. National Energy General Plan 2017 related to the projection of bioenergy generation reaching 5.5 GW (12.2%) of the renewable electricity capacity of 45.2 GW in 2025. The Green Electricity Supply Business Plan 	<ul style="list-style-type: none"> The Renewable and Alternative Energy Development Plan (2018–2037) is a target of 30% renewable energy from total final energy consumption in 2037 and specifically for biomass, it is a target of 5,790 MW of electricity capacity and 23,000 ktoe of heat production. SPP & VSPP Schemes, in the 	<ul style="list-style-type: none"> The National Bioenergy Program in 2021 through the Biomass Program and waste to energy program sub-programs. The SAMARTH policy in 2021 serves as a mandate for biomass use and as a basis for establishing a biomass supply chain ecosystem. Environmental guidelines according to the Central Pollution

	Indonesia	Thailand	India
	<p>2021-2030 has designated 18,895 MW of coal-fired power plants, with a target biomass requirement for cofiring of 10.2 million tons/year by 2030.</p> <ul style="list-style-type: none"> • Presidential Decree No. 112/2022 prohibits the construction of new coal-fired power plants, except those already designated, requires a roadmap to accelerate the cessation of coal-fired power plants, and establishes a benchmark price for the purchase of renewable energy electricity, including biomass. • The Ministry of Energy and Mineral Resources Regulation No. 12/2023 relates to the regulation of biomass cofiring in existing coal-fired power plants and emphasizes the involvement of local communities in the provision of biomass (people's economy). 	<p>form of a legal framework since 1992 & 2006 and supports electricity from biomass, biogas, and solid waste through an adder mechanism (additional electricity tariff for RE).</p> <ul style="list-style-type: none"> • Community-based Renewable Power Plants Programme (2019) with a capacity limit scheme of ≤ 3 MW (biomass) and ≤ 6 MW (biogas). Communities can own up to 40% of the shares. Target: 150 MW total capacity • Energy Policy & Planning Office (EPEC, 2023) in the form of additional approval for the purchase of electricity from industrial waste & biomass within the framework of PDP2018 Rev.1 	<p>Control Board, Ministry of Environment, Forest and Climate Change</p>
Fiscal incentives and tax	<ul style="list-style-type: none"> • Presidential Decree No. 112/2022, the government may grant incentives to business entities developing renewable power plants • There is no specific funding policy for biomass programs. 	<ul style="list-style-type: none"> • FiT Applicable to biomass & WtE projects since 2012 (replaces adder). • ENCON Fund: Subsidies up to 30% for biomass collectors, pellet/briquette producers, and industrial users. • BOI Incentives: Tax holiday, zero import duty; non-tax incentives (work permits, land ownership); priority for biomass projects reducing 	<ul style="list-style-type: none"> • CFA: Provides capital and loan interest support for biomass and WtE projects (pellet, briquette, WtE). • Regional subsidies: Special schemes for pellet plants in high-pollution areas. • Price benchmarks: Stabilize and lower pellet raw material costs.

	Indonesia	Thailand	India
		GHG & using agricultural waste.	
Market mechanisms	<ul style="list-style-type: none"> • Presidential Decree No. 112/2022 in determining the biomass price benchmark where the maximum tariff for biomass electricity purchases by PLN is determined. • PPA (Power Purchase Agreement) scheme, namely direct negotiations between PLN and IPP with prices referring to the benchmark tariff. • Mandatory cofiring (Electricity Supply Business Plan & the Ministry of Energy and Mineral Resources Regulation 12/2023), PLN is required to implement cofiring of 10 – 70% depending on the boiler type) and encourage market demand for solid biomass on a large scale (10 million tons/year) 	<ul style="list-style-type: none"> • FiT (Biomass & WtE): ≤3 MW tariff ฿4.8482/kWh, >3 MW tariff ฿4.2636/kWh (20 yrs); +฿0.50/kWh in certain provinces. • SPP/VSPP: EGAT must purchase electricity from small biomass producers. • Community Power Plants: Market access for small-scale community biomass projects. • WtE Procurement: EGAT & ERC prioritize municipal solid waste-based electricity projects. 	<ul style="list-style-type: none"> • Cofiring mandate: Coal plants must mix 5–7% biomass pellets. • WtE deployment: 90 active projects (2023) converting municipal & industrial waste to electrical/thermal energy. • Supply chain digitalization: Biofuel Circle, Biofuel Junction. • EU CBAM: Boosts competitiveness of low-carbon export products.

Legislatively, Indonesia has a relatively comprehensive regulatory framework, ranging from Government Regulation No. 79/2024, which targets a renewable energy mix of 23% by 2025 and 31% by 2050, to the 2017 National Energy Regulation, which sets a 5.5 GW bioenergy projection by 2025. This policy is reinforced by the Electricity Supply Business Plan 2021–2030, which allocates cofiring at 52 coal-fired power plants with a biomass requirement of 10.2 million tons per year, and Presidential Regulation 112/2022, which prohibits the construction of new coal-fired power plants, mandates a roadmap for coal-fired power plant retirement, and establishes a benchmark price for renewable electricity. Furthermore, the Ministry of Energy and Mineral Resources Regulation 12/2023 regulates biomass cofiring by involving local communities as raw material providers, thus creating a people-oriented economic dimension. In terms of fiscal and tax incentives, regulations remain limited. Presidential Regulation 112/2022 does provide incentives for renewable energy developers, but there is no specific funding scheme specifically supporting biomass. This is a weakness compared to other countries that already have direct funding support. Regarding market mechanisms, Indonesia uses a reference price scheme for biomass electricity purchases by PLN and a Power Purchase Agreement (PPA) mechanism based on price negotiations with IPPs. Furthermore, cofiring is mandatory, with a target biomass mix of 10–70% depending on boiler type. This drives significant demand for biomass, despite the risk of supply constraints and price stability at the community level.

Thailand has established a biomass energy policy direction through the 2018–2037 AEDP, with a target of 30% renewable energy by 2037, including 5,790 MW of electricity and 23,000 ktoe of heat from biomass. Thailand has long had the Small Power Producer (SPP) and Very Small Power Producer (VSPP) schemes, which have been in place since 1992 and 2006, respectively, providing a legal framework for purchasing electricity from biomass and waste. This policy is complemented by the Community-Based Power Plant Program (2019), which allows communities to own up to 40% of the shares in small-scale power plants. In terms of fiscal and tax incentives, Thailand is relatively superior, with the Investment Promotion Guide (BOI) providing tax holidays, duty-free imports of machinery and raw materials, and easy permits for foreign workers. Furthermore, the ENCON Fund (Energy Conservation Promotion Fund) provides subsidies of up to 30% of investment costs for biomass raw material collection, pellet/briquette production, and biomass utilization in industry. These incentives make Thailand more attractive to biomass investors than Indonesia. The market mechanism is regulated through the Fiscal Transactions (FiT) for biomass and WtE, with different tariffs for capacities ≤ 3 MW (4.8482/kWh) and > 3 MW (4.2636/kWh), valid for 20 years. The Electricity Generating Authority of Thailand (EGAT) is required to purchase electricity from small biomass producers, ensuring a stable market. Furthermore, community programs provide market access for smallholder biomass businesses, while prioritizing municipal waste-based electricity projects. This scheme demonstrates a balance between large-scale projects and community participation.

India is establishing a biomass policy framework through the National Bioenergy Program (NBP) 2021 and the Sustainable Agrarian Mission on use of Agri-Residue in Thermal Power Plants (SAMARTH) 2021 policy, which mandate biomass use and foster a supply chain ecosystem. These policies are reinforced by environmental guidelines from the Central Pollution Control Board (CPCB) to ensure biomass utilization complies with environmental standards. For fiscal and tax incentives, India has a progressive Central Financial Assistance (CFA) scheme, which provides investment support and loan interest subsidies for pellet, briquette, and waste-to-energy projects. The government also provides special regional subsidies for pellet plant construction in high-pollution areas and sets benchmark pellet prices to ensure stability and affordability. This combination provides a more comprehensive financial support model than Indonesia and Thailand. In terms of market mechanisms, India has implemented a co-firing mandate for coal-fired power plants requiring a blend of 5–7% biomass pellets. Furthermore, there were more than 90 active WtE projects by 2023, demonstrating widespread adoption. India is also promoting supply chain digitalization through platforms such as biofuel circles and biofuel junctions to improve distribution efficiency. India is even leveraging external policies such as the EU Carbon Border Adjustment Mechanism to increase the competitiveness of low-carbon product exports. Overall, India appears to be integrating domestic policies with global market opportunities.

Overall, Indonesia excels in its commitment to the energy transition through progressive regulations, but is weak in financial incentives and supply readiness. Thailand places greater emphasis on price certainty and investor incentives, despite its limited biomass project capacity. India appears to be the most comprehensive, as it, in addition to establishing a national mandate, also provides will have substantial financial support, supply chain digitalization, and integration with global market policies. Biomass competitiveness as bioenergy in Indonesia compare to India and Thailand.

3.5 Biomass competitiveness as bioenergy in Indonesia compare to India and Thailand

The following are the results of the assessment of biomass competitiveness as bioenergy in Indonesia compared to India and Thailand based on secondary data that has been obtained.

Table 7. Results of the assessment of the competitiveness of biomass as bioenergy in 3 countries

Element	Indonesia	Thailand	India
Biomass availability	+++	++	+
Biomass contribution to total energy supply (TES)	+	++	+++
The price of biomass as an energy source	++	+++	+
Bioenergy supports policies, including the legislative framework, fiscal incentives, and market mechanisms	+	++	+++

Based on the analysis of four parameters, Indonesia excels in biomass availability, but its contribution to the national energy supply (TES), policy support, and biomass prices are still less competitive than the other two countries. Thailand stands out in more competitive biomass prices and relatively strong policy support through FiT, SPP/VSP, and fiscal incentives, although the availability of biomass sources is not as large as Indonesia. Meanwhile, India has an advantage in its high biomass contribution to TES and comprehensive policy support through national programs, investment incentives, and mandatory cofiring, although challenges remain due to limited availability and less competitive biomass prices. Thus, Indonesia still lags behind Thailand and India in terms of implementation and competitiveness of biomass as a renewable energy, despite its enormous resource potential.

4 Conclusion

Indonesia has abundant biomass resources, with a potential of up to 301 million tons. Indonesia's largest biomass potential comes from palm oil, rice, and forestry waste. Indonesia's vast biomass potential is not matched by its utilization, with the current biomass energy supply only accounting for around 22.5% of the potential. This large gap between biomass potential and biomass utilization requires significant efforts to optimally utilize Indonesia's biomass. Furthermore, the significant price gap between biomass and coal requires strong incentives for a successful energy transition.

The analysis shows that although Indonesia leads in biomass potential, its competitiveness remains limited by policy incentives and TES contribution. This study recommends strengthening environmental pricing policies, increasing the economic value of biomass, and optimizing the incentive framework as key strategies to enhance the competitiveness of biomass implementation in Indonesia.

References

1. L. Kindberg. An Introduction to Bioenergy: Feedstock, Processes and Products. National Sustainable Agriculture Information Service. The ATTRA National Sustainable Agriculture Information Service. IP359 (2010). <https://attra.ncat.org/publication/an-introduction-to-bioenergy-feedstocks-processes-and-products/>
2. MM Tun, D. Juchelkova, MM Win, AM Thu, T. Puchor. Biomass Energy: An Overview of Biomass Sources, Energy Potential, and Management in Southeast Asian Countries. MDPI Resources. **8(2)** , 81. (2019). <https://www.mdpi.com/2079-9276/8/2/81>
3. R. Singh, AD Setiawan Biomass energy policies and strategies: Harvesting potential in India and Indonesia. Renewable and Sustainable Energy Reviews. **22** , 332-345. (2013). <http://dx.doi.org/10.1016/j.rser.2013.01.043>
4. H. Negi, DC Suyal, R. Soni, K. Giri, R. Goel. Indian Scenario of Biomass Availability and Its Bioenergy-Conversion Potential. Energies. MDPI. **16 (15)** , 5805. (2023). <https://doi.org/10.3390/en16155805>
5. Kasmaniar, S. Yana, Nelly, Fitriliana, Susanti, F. Hanum, A. Rahmatullah. 2023. Development of Renewable Biomass Energy from Agricultural, Plantation, and Forest Product Sources: A Study of Development and Constraints. Jurnal Serambi Engineering. **3(1)**, 4957 – 4964. (2023). <https://www.scribd.com/document/673424425/2b>
6. F. Ali, A. Dawood, A. Hussain, MH Alnasir, MA Khan, TM Butt, NK Janjua, A. Hamid. Fueling the future: biomass applications for green and sustainable energy. Discover Sustainability. **5(156)**. (2024). <https://link.springer.com/article/10.1007/s43621-024-00309-z>.
7. NK Ganawi, SJ Shaaibith. The Impact of Renewable Energy Policies on Sustainable Economic Growth: Applied Study in China, India, Brazil, and Mexico. Indonesian Journal of Economics and Development. **3(3)**. (2025). <https://journal.areai.or.id/index.php/jepi/article/view/1554>.
8. Q. Hassan, P. Viktor, TJ Al-Musawi, BM Ali, S. Algburi, HM Alzoubi, AK Al-Jiboory, AZ Sameen, HM Salman, M. Jaszczur. The role of renewable energy in the global energy transformations. **48**. (2024). <https://www.sciencedirect.com/science/article/abs/pii/S1755008424000097>
9. H. Nandimandalam, VG Gude1. Renewable wood residue sources as potential alternative for fossil fuel dominated electricity mix for regions in Mississippi: A techno-economic analysis. Renewable Energy. **200**, 1105 – 1119. (2022). <https://www.sciencedirect.com/science/article/abs/pii/S0960148122015038>
10. P. Dwivedi, E. Johnson, D. Greene, S. Baker, Tracking Economic and Environmental Indicators of Exported Wood Pellets to the United Kingdom from the Southern United States: Lessons for Policy?, BioEnergy Res. **9** , 907–916 . (2016). <https://doi.org/10.1007/s12155-016-9749-8>
11. P. Saosee, B. Sajjakulnukit and SH Gheewala. Environmental and socio-economic assessment of wood pellet production from fast growing trees in Thailand. IOP Conference Series: Earth and Environmental Science. 463 012049. (2020). <https://iopscience.iop.org/article/10.1088/1755-1315/463/1/012049>
12. S. Kumar, P. Sharma. Policy mechanisms for renewable energy. Journal of Energy Policy. **48 (2)**, 120–135. (2021).
13. L. Cheng, et al. Green jobs and economic growth. Journal of Sustainable Development. **15 (4)**, 670–690. (2021).

14. Z .Y. Zhao, YL Chen, RD Chang. How to stimulate renewable energy power generation effectively? – China's incentive approaches and lessons. *Renewable Energy*. **92** , 47-156. (2016).
<https://www.sciencedirect.com/science/article/abs/pii/S0960148116301021?via%3Dihub>.
15. J. Lipp. Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. *Energy Policy* . **35** (11), 5481-5495. (2007).
<https://doi.org/10.1016/j.enpol.2007.05.015>