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Harmonizing Biomass Co-Firing with the Green Economy Paradigm: A Sustainable Approach for Indonesia's Energy Landscape

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Abstract

Objective. To explore the implementation of Biomass Co-Firing in Indonesia, the objective encompasses an analysis of how policies, practices, and investments in Biomass Co-Firing can support desired sustainable development goals. Design/Methodology/Approach. This research utilizes the Library Research methodology, which examines literature, legal documents, and other textual sources to investigate the integration of Biomass Co-Firing into the Indonesian Green Economy. Results/Discussion. The development of renewable energy using biomass and co-firing in power plants offers significant potential for reducing carbon emissions and addressing challenges in clean energy development in Indonesia. With a strong legal foundation as outlined in Article 2 of Law No. 30 of 2007 concerning Energy, the government has provided a solid basis for renewable energy development. However, implementation still faces challenges in permitting regulations and cross-sector coordination. A significant drawback is the lack of specific incentives from the government for biomass co-firing projects, along with uncertainties regarding biomass certification and standardization. To overcome these challenges, concrete steps are needed, such as providing fiscal and financial incentives for industry players and enhancing coordination among the government, private sector, and other stakeholders. Conclusions. The development of renewable energy with biomass and co-firing in power plants promises a reduction in carbon emissions and supports clean energy development in Indonesia, despite facing challenges in permitting and cross-sector coordination. Originality/Value. The harmonization of Biomass Co-Firing projects with the Green Economy paradigm in Indonesia emphasizes resource efficiency, environmental impact reduction, and sustainable economic growth.

Keywords: *Co-Firing Biomass, Green Economy, Sustainability, Policy*

INTRODUCTION

Indonesia, an archipelagic and densely populated country, faces serious challenges in meeting sustainable energy needs while preserving the environment.(Agung Pambudi et al. 2024) According to data from the BP Statistical Review of World Energy, released in July 2021, Indonesia ranks third as the world's largest coal producer.(Dale and others 2021) In 2020, Indonesia's total coal production reached 562.5 million tons. Despite ranking third, the country still plays a significant role in the coal industry. South Sumatra, South Kalimantan, and East Kalimantan are home to the majority of mining locations.(Erb, Mucek, and Robinson 2021) Indonesia is also a major exporter in the Asian market. Despite negative sentiments regarding environmental impact, coal remains a primary energy source with low costs in Indonesia.

Table 1. National Coal Production and Comparison with Global Production, as well as National Production Target

Year	National Coal Production (million tons)	Domestic Market Obligation (million tons)	Percentage of DMO to Production (%)
2021	611,69	63,47	10
	Global Coal Production Ranking		
	China	3,90 billion	
2020	India	756,5	
	Indonesia	562,5	

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	The National Coal Production Target for 2022		
2022	**Production Target Realization (as of December 10, 2021)**	637 - 664 121,3	88,2

According to data, Indonesia is the world's third-largest coal producer after India, and coal remains the primary energy source, accounting for approximately 42% of the country's total primary energy consumption. This high dependence on fossil energy, especially coal, has led to damaging environmental impacts such as air pollution and deforestation due to coal mining exploitation. Additionally, Indonesia's economy is vulnerable to fluctuations in global commodity prices, including coal prices, which can affect the country's overall economic stability.

The Indonesian government has implemented a sustainable development strategy that centers around four strategic pathways: pro-growth, pro-job, pro-poor, and pro-environment development.(Hadi, Hamdani, and Roziqin 2023) This strategy demonstrates a commitment to balancing economic growth, job creation, poverty alleviation, and environmental protection. However, implementing sustainable development at the national level is a complex challenge, particularly in terms of addressing the need for sustainable economic growth while also considering issues of inequality and equitable development.

Indonesia faces significant challenges in reducing greenhouse gas emissions to meet international climate commitments. Data shows that Indonesia is one of the largest carbon emitters globally, primarily due to deforestation, forest burning for plantations and agriculture, and high fossil energy consumption. Efforts to reduce carbon emissions are crucial, especially in raising awareness about the global climate change impact and collaborative international efforts to mitigate its adverse effects.

The concept of the "Green Economy" has become a focal point in achieving sustainable development goals. This concept, which originated from the 1989 "Green Economy Blueprint" report, aims to integrate environmental aspects into sustainable economic development.(Lin et al. 2024) The Green Economy aligns with the Sustainable Development Goals (SDGs) adopted in 2015, setting 17 goals and 169 targets to end poverty, reduce inequality, and protect the environment.(Ma, Bo, and Wang 2024)

Faced with these challenges, Indonesia urgently needs to transition to clean and sustainable energy sources. This includes developing renewable energy potentials such as biomass, hydroelectric power, and geothermal energy, as well as enhancing energy efficiency in various sectors, including industry and transportation.(Cheng et al. 2024) We expect these measures not only to mitigate the negative environmental impact of fossil energy use, but also to enhance national energy resilience and foster sustainable economic growth.

As global awareness of climate change impacts increases, Indonesia, like many other countries, is moving towards a greener economy.(Bahruddin et al. 2024) The Net Zero Emissions (NZE) policy is a strategic step to reduce carbon emissions and mitigate global warming.(Masudin et al. 2024) As part of this effort, the utilization of biomass co-firing in Thermal Power Plants has been adopted by the State Electricity Company (PLN) as an alternative to reduce carbon emissions.

Biomass co-firing has emerged as a potential solution to reduce dependence on coal, lower carbon emissions, and stimulate economic growth through green economy development.(Singh et al. 2023) Biomass co-firing technology involves using biomass, such as agricultural waste or forest biomass, alongside coal in power plants or other industries.(Du et al. 2024) However, despite its significant potential, the implementation of biomass co-firing in Indonesia faces several challenges.

A primary issue in developing the biomass co-firing industry in Indonesia is the lack of adequate regulatory frameworks and policies.(Lou, Squire, and Hilde 2023) Uncertainties in detailed regulations related to biomass use in co-firing hinder the implementation of Indonesia's renewable energy regulations, including Law No. 30 of 2007 on New and Renewable Energy. For instance, regulations on biomass certification and standardization are not fully clear, causing uncertainty for investors and industry players. This is reflected in Article 12,

Paragraph (1), Letter e of Government Regulation No. 79 of 2014, which emphasizes that biomass methods should be an integral part of the application of Renewable Energy in electricity generation.

Moreover, the lack of government incentives is also a barrier to increasing investment and adopting biomass co-firing technology. Although the government has implemented several general renewable energy incentives, such as subsidized electricity tariffs and tax exemptions, the lack of specific incentives for biomass use in co-firing makes it less attractive to industry players. Furthermore, infrastructure gaps pose a serious problem in supporting the biomass supply chain. Data shows that biomass transportation and storage infrastructure is still limited and inadequate. Transporting biomass over long distances from production sites to power plants often results in high transportation costs and potential losses in biomass quality due to improper processing.

The importance of enforcing clear laws to address uncertainties and accelerate Indonesia's transition to sustainable energy is evident.(Handayani et al. 2017) Laws such as Law No. 12 of 2011 and Presidential Regulation No. 22 of 2017 form the foundation for sustaining renewable energy efforts. Besides regulatory challenges, the lack of awareness and understanding among the public and stakeholders about the benefits and potential of biomass co-firing is a significant obstacle to developing renewable energy in Indonesia.(Najicha and Handayani 2018) A survey conducted by the Katadata Insight Center (KIC) indicates that awareness of renewable energy in Indonesia is relatively low. Only about 30% of respondents have a sufficient understanding of renewable energy concepts, while the majority are confused or lack information. Factors such as the lack of formal education on renewable energy in schools and inadequate media coverage of renewable energy issues are the primary causes of this low awareness.(Guo et al. 2021) Additionally, the lack of effective public campaigns and initiatives from the government and private sectors to socialize the benefits of renewable energy, including biomass co-firing, contributes to this understanding gap.

Therefore, the government and relevant stakeholders need to take concrete steps to address these issues. Clearer regulatory and policy improvements, adequate incentives, and developing sufficient infrastructure are key to boosting investment and adopting biomass co-firing technology in Indonesia.(Nik and Karim 2024) This will expedite the transition to clean and sustainable energy, in line with Indonesia's commitment to reducing carbon emissions and mitigating global climate change impacts.(Jayachandran et al. 2022) In-depth research on the use of biomass co-firing in Indonesia's green economy is critical.(Maulidia et al. 2019) Such research will provide insights into the technical and economic potential of this technology, better understand the obstacles that need to be overcome, and propose solutions to encourage broader adoption.

METHOD

This research uses the Library Research methodology, which examines literature, legal documents, and other textual sources to investigate the integration of Biomass Co-Firing in Indonesia's Green Economy. The legal analysis centers on the Net Zero Emission Policy, which examines the environmental impacts of biomass use through literature on the dangers of deforestation and its long-term impacts. Several legal materials are relevant to implementing Biomass Co-Firing and efforts towards sustainable energy in Indonesia. UU No. 30 of 2009 concerning Electricity stipulates that the main objective of electricity development is sufficient availability, quality, and reasonable prices, as well as regulating electricity needs as part of sustainable Natural Resource management. Government Regulation Number 79 of 2014 and Government Regulation Number 27 of 1999 emphasize the use of biomass as an integral part of implementing New Renewable Energy with a sustainable approach and the need for environmental impact risk analysis. Presidential Regulation Number 112 of 2022 emphasizes accelerating the development of renewable energy with an ambitious target of reducing carbon emissions. The General National Energy Plan and the Electricity Supply Business Plan target increasing the application of renewable energy. The implementation of Law Number 6 of 2023 concerning the Establishment of Government Regulations in Lieu of Law Number 2 of 2022 concerning Job Creation has opened up new momentum for business license holders to improve their business management performance by involving stakeholders and creating opportunities for investment cooperation in forest use.(Najicha and Jaelani 2024) Several regulations also highlight company strategies for supporting Renewable Energy Resources but emphasize the absence of a uniform legal framework. Intergovernmental coordination and community participation are also recognized as keys to realizing an efficient green economy. Therefore, a transparent and

integrated legal framework is key to supporting Indonesia's vision of a Green Economy and sustainable development. Furthermore, this study investigates the implementation of renewable energy policies by detecting and assessing synchronization between government agencies. The aim of this technique is to provide a comprehensive understanding of legal aspects, environmental impacts, and policy integration related to Biomass Co-Firing in Indonesia.

RESULTS AND DISCUSSION

Legal Analysis

The level of electricity generation from biomass and waste worldwide reaches impressive figures, totaling around 638,460,341 GWh annually.(Hai et al. 2023) Amidst the global energy landscape, the People's Republic of China stands out as a leader with a contribution of approximately 118,645 GWh, confirming its position as the largest producer of electricity from biomass sources.(Rudek and Huang 2024) However, in Indonesia, the picture is slightly different as the country faces increasing use of coal in hybrid power generation, although global trends point in the opposite direction. Meanwhile, several countries, such as Norway, New Zealand, Brazil, Colombia, Canada, Sweden, and Portugal, have become pilots in producing renewable electricity, showing great potential in adopting cleaner and more sustainable energy sources.(Ritchie and Roser 2020) Nevertheless, challenges remain, and joint efforts from various parties are needed to encourage a transition to a more environmentally friendly energy system globally. Currently, Indonesia has not fully maximized its biomass potential. Meanwhile, in Sweden, the development of a modern bioenergy sector has become a reality, mainly through the efforts of the Swedish Bioenergy Association, which is supported by 400 members, including 300 companies.(Koytsoumpa et al. 2021) Their mission to increase the use of bioenergy in an environmentally friendly and economically optimal manner has proven successful. Even though Indonesia has abundant biomass resources, its utilization is limited due to the lack of an established biomass ecosystem or industry, a lack of authority and multi-stakeholder coordination, limited biomass mapping, and unharmonized policies. Indonesia's potential to produce energy from biomass is still not fully tapped, and cross-sector coordination measures and policy improvements may be needed to turn this into a reality.

The practical challenges of developing biomass co-firing projects cannot be ignored, especially in terms of complex regulations. Legal aspects play a central role in promoting or hindering the implementation of Biomass Co-Firing, which requires a deep understanding of renewable energy regulations in Indonesia. As highlighted in Article 2 of Law No. 30 of 2007 concerning Energy, principles such as improving community welfare, equitable efficiency, energy management to increase accessibility and economic value, environmental conservation, and integration that considers energy availability and management are the legal basis that encourages sustainability in the energy sector. However, implementing these principles in law is still a challenge, even though Law Number 30 of 2009 concerning Electricity tries to regulate electricity needs as part of sustainable natural resource management by emphasizing main objectives such as adequate availability, quality, reasonable prices, and sustainable development.

PLN has targeted co-firing at 52 Thermal Power Plants by 2025, with a total biomass requirement of 10.2 million tons per year. By the end of last year, 35 Thermal Power Plants's had already implemented co-firing, with an estimated biomass consumption of 450,000 tons per year. To meet this demand from Energy Plantation Forests, the Energy Plantation Forests land area must inevitably be expanded.(Bisnis Indonesia 2021) Referring to Industrial Plantation Forests, where 38% originate from natural forest conversion, there is concern that PLN's co-firing Energy Plantation Forests will trigger deforestation ranging from 625,000 to 2.1 million hectares.

Two Ministerial Regulations of the Ministry of Environment and Forestry facilitate the utilization of natural forests, allowing entrepreneurs to clear natural forests for Energy Plantation Forests under the pretext of supporting energy security. The Ministerial Regulation of the Ministry of Environment and Forestry No. 7 on Forest Planning, Forest Area Conversion, Forest Area Function Change, and Utilization of Forest Areas, as well as Ministerial Regulation No. 8 of 2021 on the Utilization of Protected Forest Areas.

Ministerial Regulation No. 7 provides various conveniences for Energy Plantation Forests, such as easier forest area release permits if intended to support energy security, as stipulated in Article 282 paragraph 7, where the governor's recommendation is optional. Furthermore, Article 369, paragraph 2, provides financial incentives by removing the obligation to pay Non-Tax State Revenue for Forest Area Utilization for activities supporting energy security. Forest utilization permits for Energy Plantation Forests also have a longer duration, up to 20 years, or ten times longer compared to average industrial forest utilization permits, which are a maximum of 2 years. This is outlined in Article 406, paragraph 5. Specific allowances are also made for Energy Plantation Forests, which are permitted to carry out nursery activities in forest areas without waiting for the delineation of forest area utilization boundaries, as seen in Article 404.

Ministerial Regulation No. 8 provides facilities for Forest Management Units for Energy Plantation Forests, as stipulated in Article 23, as well as investment cost reimbursement as stipulated in Article 28. If Energy Plantation Forests comes from clearing natural forests, this becomes a new motive for companies to damage and control forest and land resources. The implementation of Energy Plantation Forests will be similar to Industrial Plantation Forests.(McEwan et al. 2020) Although biomass energy was initially considered adequate because it involves waste management to reduce carbon emissions in the short term, this statement notes that this method can cause long-term adverse effects. In this context, it is important to consider the overall environmental impact of biomass use, including sustainability considerations and long-term effects on carbon emissions.

The implementation of Law No. 6 of 2023 concerning the Stipulation of Government Regulation in Lieu of Law No. 2 of 2022 on Job Creation into Law has created new momentum for business license holders to improve their business management performance by involving stakeholders and creating investment cooperation opportunities in forest utilization. This law provides a clearer and more supportive legal basis for businesses to invest in and develop enterprises in the forest utilization sector. The change in nomenclature from environmental permit to environmental approval in this law has caused several changes, namely that the term environmental permit is no longer used in the 2023 Job Creation Law, and the articles regulating environmental permits have been amended and deleted.

The reform of the 2023 Job Creation Law by replacing the term "Environmental Permit" with "Environmental Approval" has significant implications, especially for the regulation of the renewable energy sector, such as biomass co-firing projects. This change in nomenclature reflects the broader spirit of the law, offering flexibility in responding to changing societal demands and global dynamics. Besides flexibility, the change from environmental permit to environmental approval is also driven by a change in approach, where Law No. 32 of 2009 used a licensing approach while the 2023 Job Creation Law uses a risk-based approach. The regulatory approach that has been in place is considered burdensome for businesses because they are faced with numerous types and amounts of permits that must be met for their business activities to legally proceed.

Article 22, number 1, point 35 of the 2023 Job Creation Law marks a significant shift in the approach to environmental permits in Indonesia. The conceptual shift from "Environmental Permits" to "Environmental Approval" signifies a change in both terminology and essence in environmental regulation. This reflects a new paradigm that emphasizes environmental feasibility and government approval as a more holistic and adaptive step in environmental management. The removal of Article 36 of Law No. 32 of 2009 and related changes in Article 22, Number 14 of the 2023 Job Creation Law aim to simplify the permitting process without diminishing the importance of environmental management. The Environmental Management Efforts and Environmental Monitoring Efforts standards remain to ensure the environmental impact management of a business or activity, while government regulations will further detail technical aspects.

The changes from Article 37 of Law No. 32 of 2009 to Article 22, Number 15 of the 2023 Job Creation Law involve the revocation of Business Licensing. These changes include the replacement of terms and an emphasis on environmental feasibility and responsibility in the licensing process. This reflects an adjustment in terminology and concept in business licensing, along with a push towards efficiency and the use of information technology to communicate environmental decisions to the public.

The changes and removal of these articles imply a shift in regulations related to the revocation, announcement, and authority to grant environmental approvals for projects such as biomass co-firing. This reform emphasizes risk-based decision-making and the use of information technology in the permitting process, aligning with efforts to simplify and modernize regulations. Therefore, uncertainty and ambiguity in environmental permit regulations can impact renewable energy projects, including biomass co-firing, which require environmental approval. Additionally, this terminological shift reflects a paradigm shift from the conventional "licensing" approach to a "risk-based" approach. This approach is considered to facilitate businesses, including those involved in biomass co-firing projects, in meeting licensing requirements, supporting business continuity, and adapting to evolving regulations. Consequently, a deep understanding of environmental approval and adaptation to regulatory changes is crucial for managing renewable energy projects, given the significant impact of the 2023 Job Creation Law reform.

One important aspect of implementing this law is providing incentives for business license holders to make sustainable and responsible investments in forest management. With more flexible provisions and an easier permitting process, businesses can more readily invest in various forest-related activities, such as developing Industrial Plantation Forests, peatland restoration, or sustainable production forest management. Furthermore, the implementation of this law supports collaboration between business license holders, the government, local communities, and other stakeholders in forest management. Through investment cooperation involving various parties, forest management can be carried out more holistically and sustainably, considering the interests of all related parties, including environmental, social, and economic aspects.

Therefore, the implementation of Law No. 11/2020 on Job Creation serves as an important momentum for business license holders to enhance their business management performance by providing opportunities for more sustainable and continuous forest utilization investments, as well as strengthening cooperation with stakeholders to achieve common goals in sustainable forest management.

One solution to the challenges faced in implementing co-firing in Thermal Power Plants's is to adopt a more sustainable approach to managing biomass resources. In line with PLN's target for co-firing in 52 Thermal Power Plants's by 2025, it is important to consider alternative biomass procurement that does not involve excessive deforestation. One step that can be taken is to expand the use of biomass from more sustainable sources, such as agricultural waste or organic waste from the food industry. This approach can help reduce pressure on forest lands vulnerable to conversion into Energy Plantation Forests. Moreover, a review of regulations governing the utilization of natural forests for Energy Plantation Forests development is necessary. Although regulations like Ministerial Regulation No. 7 of the Ministry of Environment and Forestry provide ease of using forest areas for Energy Plantation Forests activities, it is important to evaluate the long-term impacts on ecological balance and environmental sustainability. Stricter enforcement of regulations and greater incentives for the utilization of sustainable biomass sources can help reduce pressure on natural forests and encourage the adoption of more environmentally friendly technologies in biomass energy production.

The government must consider using other renewable energy sources that do not pose the risk of climate change, as co-firing and continuous coal use can lead to deforestation. According to the National Energy Plan, reinforced by PT PLN's Electricity Supply Business Plan policy, the installed capacity of Geothermal Power Plants is targeted to reach 7,000 megawatts by 2025. Geothermal, hydro, mini, and micro-hydro renewable energy, bioenergy, solar, wind, and marine energy accounted for 1.9 percent in 2015. Thus, the increase in renewable energy implementation compared to the targets in the National Energy Plan is 25% by 2025 and 30% by 2050. Renewable energy should be prioritized over co-firing methods, which have significant long-term risks. Additionally, further analysis of potential risks to energy security is needed.

Regarding the basis for renewable energy implementation, the evaluation of Government Regulation No. 79 of 2014 and Presidential Regulation No. 112 of 2022 shows the strategic steps of companies in demonstrating environmental responsibility through the application of Renewable Energy. However, this evaluation also highlights the lack of a legal framework ensuring fair Renewable Energy implementation across all sectors. Disagreements with current regulations create gaps in coal use as an energy source, contributing to increased

carbon emissions. This underscores the urgent need for clear and stringent legislation to ensure Renewable Energy implementation in all sectors in Indonesia.

Awareness of the long-term impacts of biomass use also needs to be increased. Although co-firing was initially considered a sustainable solution because it reduces short-term carbon emissions, it must be acknowledged that Energy Plantation Forests and Industrial Plantation Forests management can cause significant long-term environmental damage.(Giuntoli et al. 2022) Therefore, it is important to conduct comprehensive environmental impact assessments and consider sustainability aspects in decision-making regarding the use of biomass as an energy source. Article 12 paragraph (1) letter e of Government Regulation No. 79 of 2014 asserts that the use of biomass methods must be an integral part of the application of Renewable Energy in power generation. However, uncertainties regarding biomass certification and standardization create challenges for investors and industry players.

Since there are no standard or clear criteria regarding the quality, type, or other aspects of biomass that can be used in Biomass Co-firing projects, this causes uncertainty in project development.(Hiloidhari et al. 2023) Industry players need to ensure that the biomass they use meets certain standards to ensure sustainability, quality, and efficiency. Additionally, the lack of specific incentives from the government for biomass use in Biomass Co-firing also poses a barrier. Although the government has implemented several incentives for renewable energy in general, such as subsidized electricity tariffs and tax exemptions, the lack of incentives specifically aimed at Biomass Co-firing projects makes them less attractive to industry players. Without adequate incentives, industry players may be reluctant to invest in this technology due to the associated risks and costs that may outweigh the expected benefits. Therefore, concrete steps from the government are needed to address this issue. There should be regulatory clarity regarding biomass certification and standardization, as well as more attractive incentives for industry players. This will create a more stable and supportive environment for the development of renewable energy, such as Biomass Co-firing, in Indonesia.

To provide effective incentives for industry players in Biomass Co-firing projects, the government can consider several concrete steps. First, the government can provide fiscal incentives, such as tax exemptions or tax relief, for companies investing in Biomass Co-firing technology development. This will reduce the financial burden on companies and make the projects more economically attractive. Additionally, the government can provide financial incentives in the form of subsidies or direct funding for Biomass Co-firing projects. This can help reduce the high initial capital costs associated with developing the necessary infrastructure and technology for these projects.

Besides fiscal and financial incentives, the government can also provide non-fiscal incentives, such as easier access to permits and licensing, as well as support in technical and managerial capacity development for industry players.(Pambudi and Ulfa 2024) This will help reduce administrative and technical barriers that often hinder the development of renewable energy projects. By providing comprehensive and diverse incentives, the government can create a conducive environment for the development of Biomass Co-firing projects in Indonesia. These incentives will help increase investment attractiveness in renewable energy projects, thus accelerating the transition towards a cleaner and more sustainable energy system.

To address the challenges in formulating a legal framework for New and Renewable Energy, close coordination between the central government, local governments, the private sector, and other stakeholders is crucial.(Masuda et al. 2022) Presidential Regulation No. 22 of 2017 emphasizes the importance of several aspects, such as the preparation of the National Electricity General Plan, the Electricity Supply Business Plan, and the management of the state and regional budgets, in maximizing renewable energy development at both central and local levels. The integration of energy security and independence should also be considered, along with providing incentives, funding allocations, and strict supervision to ensure the efficiency and effectiveness of energy use in accordance with existing regulations.

Strategy Towards a Green Economy

Indonesia has taken strategic steps to support the transformation towards sustainable development, including the implementation of Biomass Co-Firing by the State Electricity Company.(Ibrahim, Hermawan, and Sutiawan

2022) More environmentally friendly production is implemented by incorporating elements of resource efficiency, which is very important in the transition to a green economy. Green economics can be linked to environmentalism, economic theory, and ecological economics.(Loiseau et al. 2016) The application of these two theories in practice produces different concepts and approaches. Environmental economics is closely related to cleaner production and resource efficiency, while ecological economics relies on new concepts such as industrial ecology or the circular economy. One of the new concepts emerging in environmental policy is the concept of nature-based solutions.(Waylen et al. 2024) Implementing nature-based solutions requires designing multifunctional landscapes that contribute to sustainable resource management systems that encourage green economic development.(Hölscher et al. 2024) Nature-based solutions can simultaneously provide many benefits, such as flood control, carbon storage, raw materials, human health, and biodiversity, if the ecosystem is healthy. Therefore, the concept of nature-based solutions is focused on investing in natural resources that increase the supply of multi-benefit ecosystems. It aims at environmental protection through reducing pollution and increasing the stock of natural resources. Therefore, nature-based solutions are the only approach that is in line with solid sustainability. However, it also requires a micro perspective as it is aimed at public and private investors to facilitate nature-based solutions in urban and rural landscapes. A circular economy is an industrial economy designed to be restorative and reflects the active nature of improving and optimizing the systems through which it operates. The circular economy is built on waste prevention and resource efficiency by showing where the most significant benefits can be realized and by emphasizing the need to consider the sustainability of raw material sources and their fate.

Meanwhile, the circular economy approach as a restorative model that reflects nature can be linked to the concept of waste hierarchy in the green economy. Waste prevention and resource efficiency are important elements in achieving green economy goals, with the stages of the waste hierarchy including prevention, reuse, recycling, recovery, and disposal.(Feldman et al. 2024) This concept and approach create a sustainable and environmentally friendly economy. Waste hierarchies can relate to both environmental economics and ecological economics, depending on the extent to which different approaches are applied (down-cycling versus up-cycling).(Yudin et al. 2024) These concepts are based on practical approaches or solutions to achieve green economy goals, namely environmental, economic, and social benefits. Practical solutions for a green economy include a variety of applicable approaches, such as reuse, repair, recovery, or recycling; the implementation of eco-friendly design rules; or the development of industrial symbiosis.(Yadav et al. 2022) This refers to a product approach designed to produce, recover, and reuse without waste, taking into account the environmental impact of a product's life cycle.

Resource efficiency and eco-friendly design aim to increase the use of natural resources in the production value chain, focusing on companies and their behavior by reducing emissions and environmental waste through technological innovation. This is consistent with the assumption of environmental economics that continuous improvements in the rate of substitution of natural resources for artificial or human resources can support the transition to sustainability. The waste hierarchy approach and waste prevention are important elements in the green economy by increasing resource efficiency, reducing the need for raw materials, and aiming to close material flows. The stages of the waste hierarchy are first prevention, then reuse, recycling, recovery, and finally disposal.(Manumayoso et al. 2024) At the bottom of the hierarchy, the amount of additional energy and resources required for waste management, as well as material and energy losses, increases. By preventing waste from occurring, these negative impacts can be avoided. Waste prevention starts with product design and processing. Biomass co-burning is a nature-based solution in terms of energy and the environment. The application of biomass co-firing involves the use of biomass fuel together with fossil fuels in power generation or industrial processes. This strategy can reduce dependence on fossil fuels, reduce carbon emissions, and utilize renewable natural resources.

Biomass co-burning makes a positive contribution to several important aspects of environmental and energy sustainability. First, implementing biomass co-burning effectively reduces the overall carbon footprint by reducing carbon emissions. Biomass, such as wood or organic waste, is a renewable energy source that can replace some fossil fuels, thereby having a positive impact on air quality and the environment. Second, the use of biomass derived from renewable natural resources, such as sustainably managed forests, agricultural waste,

or certain energy crops, supports the responsible use of natural resources. This helps maintain ecosystem balance and supports sustainable practices. Third, biomass co-burning follows the natural carbon cycle, where plants absorb carbon dioxide (CO2) during growth. When biomass is burned, the amount of CO2 released is equivalent to the amount absorbed by plants. This creates a more environmentally friendly carbon cycle. Lastly, managing organic waste through biomass co-firing, such as using rice husks or agricultural waste, provides a solution to reduce the negative impact of organic waste on the environment. Therefore, holistically, biomass co-burning supports sustainable practices by integrating these aspects into energy management. Therefore, biomass co-burning can be considered part of nature-based solutions in the transition towards a more sustainable and environmentally friendly energy system.

Strategic steps to support the transformation towards sustainable development, one of which is the implementation of Biomass Co-Firing by PLN, This step reflects a commitment to implementing cleaner production by including elements of resource efficiency as the key to the transition to a green economy. In this case, green economics is a necessary foundation that can be linked to environmental economic theory and ecological economics.(Tosi et al. 2024) The application of a green economy strengthens sustainability efforts by applying the principles of environmental economic theory. Recognizing that natural resources are limited is fundamental to seeing how we can manage the economy efficiently. In addition, the principle of internalization of environmental costs demands respect for environmental impacts in economic decision-making. Thus, a green economy leads to efficient use of energy and materials, an important step in reducing environmental impact.

Furthermore, the green economy concept integrates the principles of ecological economics. Understanding a product's life cycle, from production to disposal, is critical to identifying potential environmental impacts.(Jaelani, Luthviati, and Octavia 2023) Meanwhile, the emphasis on ecosystem balance ensures that economic activities run efficiently and do not harm the environment in the long term. This initiative also encourages the application of renewable energy as an environmentally friendly alternative and encourages product design innovation that supports recycling. By combining these concepts, the green economy creates economic sustainability and supports overall environmental sustainability.

In this case study, PLN utilizes biomass as a substitute energy source on a fairly large scale and reaches significant amounts over a certain period of time. The implementation of Biomass Co-Firing in Indonesia is a strategic step in efforts to diversify energy sources and increase sustainability. Centralized development is carried out by the State Electricity Company (PLN), which uses biomass as replacement energy in several Thermal Power Plants. Biomass, in the form of wood pellets, sawdust, and palm shells, was significantly integrated and reached high levels during the implementation period. For example, PLN has used 404.5 thousand tons of biomass resources for six months in 2023, with a target usage of 954 tons. The use of biomass as a fuel substitute for Thermal Power Plants is in line with Indonesia's efforts towards net zero emissions in the future. Apart from increasing the contribution of renewable energy to the national energy mix, it has a positive impact on co-firing and the development of the people's economy (circular economy) because it can open up jobs and business opportunities in the biomass sector, especially those based on waste.(Jamin et al. 2023)

Practices like this can be assumed from the perspective that economic growth and sustainable resource use can be achieved simultaneously.(Fernandes and Machado 2022) Porter's hypothesis (Porter and Van der Linde, 1995) deserves special attention because it assumes the existence of a win-win solution for the economy and the environment. Environmental regulations can spur entrepreneurial innovation, improve business performance, and provide benefits in both environmental and economic dimensions. Therefore, the strategy carried out by environmental economics is to set prices correctly (internalization) to provide an accurate assessment of resources, which is done by evaluating natural resources and external impacts. Therefore, the concept of nature-based solutions is focused on investing in natural resources that increase the supply of multi-benefit ecosystems. It aims at environmental protection through reducing pollution and increasing the stock of natural resources. Therefore, nature-based solutions are the only approach that is in line with solid sustainability. However, it also requires a micro perspective as it addresses public and private investors to facilitate nature-

based solutions in urban and rural landscapes. The Relationship between the Green Economy Concept and the Co-Firing Biomass Development Policy:

Energy and Material Efficiency can encourage policies that support investment in energy efficiency technology in biomass power plants. This includes incentives for the adoption of advanced technologies that optimize the use of energy and raw materials.

Renewable Energy can be realized through providing incentives and regulations that support the development of renewable energy sources, including biomass, as the main component in the factory energy mix. This policy support includes favorable electricity tariffs and fiscal incentives.

Encourage the application of environmentally friendly designs in the biomass production process. These policies could include tax incentives for design innovations that reduce environmental impact and encourage recycling.

Incorporate product life cycle analysis into the biomass co-burning project approval process. This policy can ensure that factories consider environmental impacts from biomass procurement to incineration.

Implement public policies that support biomass co-burning, such as setting renewable energy targets and clear regulations for biomass procurement and use. This support creates a conducive policy environment for investment.

Education and awareness are increased through the implementation of policies that support education and awareness programs about the benefits of biomass co-burning for the general public, industry stakeholders, and workers. This could include information campaigns and incentives for new skill training.

Ecosystem balance is achieved by including sustainability clauses in operational permit requirements for biomass co-burning projects to ensure that ecosystem sustainability is considered throughout the biomass supply chain.

By linking the green economy concept with co-firing biomass development policies, sustainable and environmentally friendly infrastructure can be built, achieving energy sustainability goals while minimizing negative impacts on the environment.

Grand Design Sustainable Biomass Supply by PLN. The Grand Plan is to ensure sustainable biomass availability based on geospatial data and a sustainable supply strategy, which is targeted to be achieved by 2025.(Rahayu et al. 2023) Based on this, biomass availability is based on several key aspects. First, PT PLN identifies Industrial Plantation Forests / Energy Plantation Forests land (such as rubber and oil palm), as well as critical land and intercropping land that can be utilized. In addition, they are also considering the use of twigs and log residue, as well as by-products such as sawdust. The sustainable supply strategy involves signing long-term production sharing contracts, developing Green Economic Villages, community-based energy business models, and efforts to simplify contracts through the creation of Regional Aggregators. Meanwhile, to achieve the target in 2025, PT PLN is targeting the signing of an MoU/Contract for Industrial Plantation Forests management with a target area of 41,000 out of a total of 500,000 hectares, the implementation of a Green Economy Village Pilot with a target of 30 villages and a total area of 15,000 hectares, Biomass Ecosystem Development Community Based with a target of being established in 12 locations and involving 100 communities, and the Establishment of a Regional Aggregator involving 3 partners to manage 10 regions. Thus, PT PLN is committed to ensuring sustainable biomass availability, in accordance with environmental and business sustainability principles.

Biomass accessibility includes several important factors. First, infrastructure, from raw materials to Thermal Power Plants boilers is the main consideration, including transportation routes that connect the two. Apart from that, the distance between the biomass production location and the Thermal Power Plants is also a key factor in ensuring transportation efficiency. Modes of transportation, both land and sea, are also a concern to ensure smooth and timely supplies. Within the framework of the Sustainable Supply Strategy, accessibility is emphasized through several measures. Prioritization and synchronization of supplies with Thermal Power Plants readiness is an important strategy, along with the choice of using a single delivery system (Single-Des) for supplies in small quantities, and a multi-des delivery system (Multi-Des) for supplies in large quantities. In

this case, sending small amounts of biomass can be done via truck, while sending large quantities can be done via ship. To achieve the target in 2025, accessibility efforts are focused on building biomass production facilities and adjusting infrastructure at the Thermal Power Plants, such as loading facilities, stockyards, and others. There are plans to build six local production facilities with a capacity of 50 tons per day each, as well as one multidesk production facility in Kendari. In addition, the biomass production design from Industrial Plantation Forest regulated for shipping by ship as part of efforts to increase accessibility and efficiency in the supply chain. Thus, focusing on biomass accessibility is key to supporting PT PLN's goal of ensuring a sustainable energy supply into the future.

In terms of biomass acceptance, several factors are the main considerations. First, the quantity and quality of available biomass play an important role, as do the technology and processes required to utilize it efficiently. Furthermore, the social and environmental impacts of biomass use must also be seriously considered. In order to achieve sustainable acceptance, a Sustainable Supply Strategy has been implemented. This includes the use of diverse biomass sources and processing facilities, as well as joint investment and multi-product production. Stakeholder involvement and efforts to maintain biodiversity are also the focus of this strategy. Towards the 2025 target, efforts to receive biomass will be emphasized at several points. First, establishing Industrial Plantation Forests baselines in several regions, such as South Sumatra/Bangka Belitung, West Kalimantan/South Kalimantan, and Sulawesi/Halmahera. Furthermore, joint investment in Industrial Plantation Forests for Thermal Power Plants and Biomass Power Plant, as well as partnerships with cooperatives or Village-Owned Enterprises are priorities. Apart from that, maintaining biodiversity and the diversity of Industrial Plantation Forests types is also a focus in efforts to achieve optimal biomass production. Thus, biomass acceptance is not only reviewed from technical and economic aspects but also from its social, environmental, and long-term sustainability impacts.

Biomass affordability is seen in several aspects, which are the main factors in the assessment. First, comparing the CIF (Cost, Insurance, and Freight) price of biomass with the price at the point of sale, including the price of raw coal, is an important consideration. Furthermore, competition between buyers also affects the affordability of biomass, as well as price fluctuations in both local and export markets. The strategy to guarantee Sustainable Supply based on biomass affordability is implemented through the use of price aggregation with the principle of cross-subsidy, wholesale sales to retailers and/or regulated businesses, as well as signing long-term contracts and joint investments. Towards the 2025 target, the focus on biomass affordability is strengthened through several steps. First, cross-subsidies through regional aggregaters are the main strategy to maintain biomass affordability. Furthermore, planting and production facility contracts (FasProd) and joint investment contracts in existing areas are priorities. Finally, the signing of long-term contracts and joint investment in Industrial Plantation Forests with an area of 41,000 hectares is also part of efforts to ensure sustainable biomass affordability.

Thus, the aspect of biomass affordability is not only a consideration of price but also about long-term strategies that support economic and operational sustainability. In terms of sustainability, several factors are the main focus of assessment. First, fluctuations in biomass supply are an important consideration, along with the ability and willingness to provide a stable supply. Furthermore, the social and environmental impacts of biomass production and use are also important aspects of evaluating sustainability. Sustainable Supply Strategy. This includes the provision of long-term contracts to guarantee the supply of biomass from Industrial Plantation Forests and Energy Plantation Forests, the connection of energy prices to markets, as well as the involvement of stakeholders and biodiversity. Towards the 2025 target, the focus on sustainability is strengthened through several strategic steps. First, the signing of an MoU or contract for the management of Industrial Plantation Forests with an area of 41,000 out of a total of 500,000 hectares, as well as licensing and DMO mechanisms for Industrial Plantation Forests products and advocacy on biomass prices. Furthermore, partnerships with cooperatives or Village-Owned Enterprises and maintaining biodiversity and the diversity of Industrial Plantation Forests types are also a focus in efforts to achieve sustainable sustainability. Thus, biomass sustainability is not only viewed from the production and supply aspects alone but also in the context of its social, environmental, and long-term sustainability impacts.

Table 2. The analysis of the Sustainable Biomass Supply Grand Design by PT PLN

Aspect		Description
Advantages	Supply Availability Guarantee	The Grand Design ensures the sustainable availability of biomass with targets set until 2025 based on Geospatial Data.
	Planned Supply Strategy	PT PLN identifies biomass sources and develops concrete strategies for sustainable supply.
	Supply Diversification	The Grand Design encompasses supply diversification and joint investments, enhancing long-term sustainability.
Disadvantages	Infrastructure Limitations	There are still challenges related to accessibility and transportation infrastructure that affect biomass transportation.
	Complexity of Biomass Management	Managing diverse biomass sources requires intensive coordination to ensure stable and sustainable supply.
	Social and Environmental Challenges	There are still challenges related to the social and environmental impacts of biomass production and utilization that need to be addressed.
Solutions	Infrastructure Development	Collaboration is needed to accelerate the development of transportation infrastructure and necessary production facilities.
	Stakeholder Inovolvement	More intensive involvement with stakeholders is required to support the implementation of this Grand Design.
	Monitoring and Evaluation	It's important to continuously monitor and evaluate the implementation of this Grand Design and adapt to changing conditions.

The Grand Design Sustainable Biomass Supply by PT PLN promises sustainable biomass availability until 2025. Based on geospatial data and a sustainable supply strategy, this program sets targets to ensure a consistent biomass supply. Concrete steps have been taken, including identification of biomass sources such as Industrial plants, Forest/Energy and energy plants on forest land, and the use of twigs and log residue. The supply strategy includes signing long-term contracts, building Green economy Villages, and establishing regional aggregaters. However, infrastructure and transportation challenges, as well as the complexity of managing biomass sources, remain shortcomings that must be overcome. The proposed solution includes infrastructure development, increased stakeholder involvement, and ongoing monitoring. With this approach, it is hoped that the Grand Design can achieve its goal of ensuring sustainable biomass availability for Indonesia's energy needs.

CONCLUSIONS

The conclusion from the above explanation is that the development of renewable energy using biomass and co-firing in Thermal Power Station offers great potential for reducing carbon emissions and facing challenges in developing clean energy in Indonesia. With the existence of a legal framework that regulates sustainability principles in the energy sector, as regulated in Article 2 of Law No. 30 of 2007 concerning Energy, the government has provided a solid foundation for the development of renewable energy. However, implementation of these principles still faces challenges in licensing arrangements and cross-sector coordination. One significant weakness is the lack of special government incentives for biomass co-firing projects, as well as uncertainty regarding biomass certification and standardization. To overcome this challenge, concrete steps are needed, such as providing fiscal and financial incentives for industry players as well as improving coordination between the government, the private sector, and other stakeholders. In addition, it is important to consider the use of other renewable energy sources that do not pose a climate change risk, such as geothermal, hydro, solar, and wind. This requires careful evaluation of the environmental and sustainability impacts of using biomass as an energy source. The 2023 Job Creation Law reform brings new momentum to forest management and the application of renewable energy, but it also raises new challenges related to changes in terminology and approaches to environmental licensing. Thus, a deep understanding of environmental licensing requirements and adaptation to regulatory changes is crucial in managing renewable energy projects, including biomass co-firing. To overcome the practical challenges of developing biomass co-burning projects, close coordination is needed between the government, the private sector, and other stakeholders in the preparation of a clear and supportive legal framework. This will help create a conducive environment for the development of renewable energy projects, such as biomass co-firing, thereby accelerating the transition to a cleaner and more sustainable energy system.

Indonesia has taken strategic steps, especially in supporting the transformation towards sustainable development by implementing Biomass Co-Firing by the State Electricity Company (PLN). In this case, PLN has taken steps to integrate more environmentally friendly production by including elements of resource efficiency, which is an important step in the transition to a green economy. In this process, concepts such as

environmental economics, ecological economics, nature-based solutions, and the circular economy become the basis for implemented policies and practices. The advantages of this approach include guaranteed sustainable biomass availability, diversification of supply, and a planned supply strategy. However, there are still several challenges that need to be overcome, such as limited infrastructure, the complexity of managing diverse biomass, and social and environmental challenges associated with biomass production and use. To address these challenges, proposed solutions include infrastructure development, increased stakeholder engagement, and ongoing monitoring. With this approach, it is hoped that the goal of ensuring sustainable biomass availability for Indonesia's energy needs can be achieved. Thus, the steps taken by PLN in implementing Biomass Co-Firing can be considered part of a broader effort to support the transformation towards sustainable development in Indonesia.

Conflict of Interest

The author declares that there is no conflict of interest.

Statement of Data Consent

The data generated during the development of this study has been included in the manuscript

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