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BIOMASS CO-FIRING FOR ELECTRICITY IN INDONESIA: A SYSTEM THINKING APPROACH

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ABSTRACT

Indonesia's heavy reliance on coal for electricity generation poses significant environmental challenges, necessitating a transition toward more sustainable energy sources. Biomass co-firing, which involves blending biomass with coal in existing power plants, offers a practical solution to reduce carbon emissions while utilizing the country's abundant biomass resources. However, its large-scale implementation is influenced by multiple interdependent factors, including fuel availability, economic feasibility, technological readiness, and policy support. The study utilizes qualitative data analysis which is collected on interview sessions with energy and electricity stakeholders, including government, national electricity producers, and biomass suppliers. The study found 44 factors influence the system of biomass co-firing for electricity, which derived from seven categories, including biomass related factors, economic feasibility, government, institutional characteristics, technical practicality, and new renewable energy/bioenergy. The interrelationships within the factors were analyzed using causal loop diagrams, which include three major drivers, which are technical practicality, institutional characteristic, and economic feasibility. The findings emphasize the need for coordinated policies, investment in biomass supply chains, and stakeholder collaboration to enhance co-firing effectiveness. This study contributes to the understanding of biomass integration in the electricity sector and offers strategic recommendations to accelerate Indonesia's sustainable energy transition

KEYWORDS *Biomass co-firing, electricity, renewable energy, system thinking, causal loop diagram*

INTRODUCTION

Indonesia has set an ambitious target to achieve Net Zero Emissions (NZE) by 2060 as part of its commitment to global climate action and sustainable energy development. This commitment aligns with the country's pledge under the Paris Agreement to reduce greenhouse gas (GHG) emissions through various policy measures and technological advancements. Indonesia's latest National Determined Contribution (NDC) commits to a higher GHG reduction target of 31.89% (unconditional) and 43.2% (conditional) as compared to 29% and 41% respectively in the previous version. As part of this roadmap, the Indonesian government aims to increase the share of New and Renewable Energy (NRE) in the national energy mix to at least 23% by 2025 and 31% by 2050, which are outlined on the Government Regulation No. 79/2014 on National Energy Policy (*Kebijakan Energi Nasional*/KEN). Additionally, the government issued Presidential Regulation No. 22/2017 on the National Energy General Plan

(*Rencana Umum Energi Nasional*/RUEN), which calls for a 1% annual reduction in energy intensity and a target of 23% NRE in the national energy mix by 2025. Furthermore, the regulations also supported by the Electricity Supply Business Plan (*Rencana Usaha Penyediaan Tenaga Listrik*, RUPTL) that prioritizes development of NRE (Green RUPTL), which is initiated by the National Electricity Company (*Perusahaan Listrik Negara*/PLN).

As of 2023, based on the data from the Ministry of Energy and Mineral Resources, the use of renewable energy in achieving the national energy mix only reach 13.29%. In fact, Indonesia possesses significant renewable energy potential, including solar, wind, geothermal, hydro, and bioenergy sources. Among these, bioenergy stands out as a promising contributor to the renewable energy mix due to the country's vast agricultural and forestry resources. Compared to other renewable energy sources, bioenergy offers unique advantages, particularly its ability to provide a stable and continuous power supply. Given Indonesia's abundance of biomass feedstocks such as palm oil residues, wood chips, and agricultural waste, bioenergy can play a vital role in achieving the country's renewable energy targets (Pasek et al., 2024). Biomass energy, particularly in the form of co-firing with coal, presents a practical and scalable transition pathway towards decarbonization while utilizing existing power plant infrastructure. Biomass co-firing refers to the simultaneous combustion of biomass and coal in existing power plants, leveraging the infrastructure of coal-based energy systems while reducing carbon emissions. Overall, the National Electricity Company, PLN, owned 114 Coal-Fired Power Plants (CFPPs) that have potential for biomass co-firing, with a total capacity of 18.1 gigawatts (GW), demonstrated a potential demand of approximately 4 to 9 million tons of biomass annually (IEEFA, 2021). While this represents a significant opportunity for biomass suppliers and the circular economy, challenges such as biomass quality standardization, logistical constraints, and economic competitiveness with coal persist (Palupi et al., 2023). Furthermore, its implementation also remains limited due to concerns over fuel supply chain stability, regulatory challenges, and economic feasibility (Sulistiowati & Akbar, 2023).

Therefore, since the role of biomass co-firing could be potentially effective in achieving the energy mix target, this research aims to understand the following objectives: to analyze the current implementation of biomass co-firing in Indonesia's electricity sector; to identify and analyze the key factors that influence the success of biomass co-firing in Indonesia's power plants; and to identify the key recommendations that can be implemented to address the challenges in scaling up the biomass co-firing in Indonesia's electricity sector.

RESEARCH METHOD

The research design of this study involved several stages. It begins with Pre-Study, Literature Study, and Non-Participant Observation as part to observe current media and writing updates, regulations, and literature review about biomass co-firing for electricity sector as well as system thinking approach. The research continues to the interview stage with several stakeholders as the primary data from related actors of the biomass co-firing for electricity sector system. It also has objective to validate previous literature research and acknowledge the structure of the system, including the activities involved in, the actors, and their links. The transcript of the interview data then is being analyzed by qualitative data analysis using NVivo software to categorize the factors and analyze the number of each factor mentioned. Several codes were formulated based on its occurrences and categorized based on the issues raised by each stakeholder. After finding the factors that involved in the system, the interrelationships between each factor were analyzed using causal loop diagram. Several causal loop diagrams are built to understand the key drivers of the system. Below is the list of respondents in the interview sessions.

Table 1. List of Interview Respondents

Interview No.	Respondent's Initial	Category	Relevant Experience
I1	S1	Electricity Producer	20+ years
I2	S2	Policymaker	20+ years
I3	S3*	Biomass Supplier	9+ years
	S4*		10+ years
I4	S5	Coal-Fired Power Plant 1	7+ years
I5	S6	Coal-Fired Power Plant 2	10+ years

*Respondent is interviewed in the same interview session.

RESULT AND DISCUSSION

Current State of Biomass Co-Firing in Indonesia's Electricity Sector

1. Actors Involved

Biomass co-firing for electricity generation in Indonesia involves various stakeholders, each of whom has a different role in the development and implementation of this initiative. In general, the implementation of biomass co-firing is inseparable from the actors that play a role in achieving the target of renewable electricity production. In general, Figure 1 provides information regarding the main stakeholders of the electricity sector (Sunitiyoso et al., 2020). For further details, the key actors that play direct roles in the biomass co-firing process are listed in the Table 1 below.

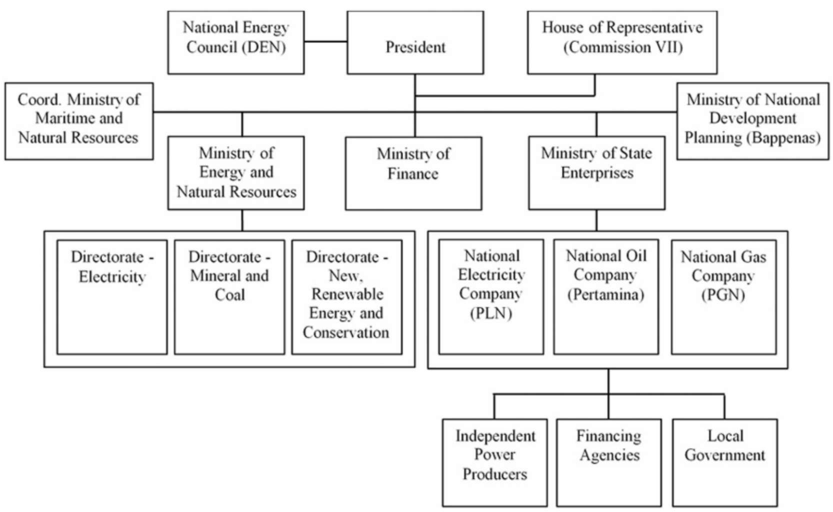

Figure 1. Electricity Sector Key Stakeholders
(Sunitiyoso et al., 2020)

Table 2. Actors and their Roles in Biomass Co-firing

Actor	Role
Ministry of Energy and Mineral Resources (MEMR)	Develops and promotes policies to integrate biomass cofiring into the national energy strategy, aiming to increase the share of renewable energy in the power sector.
Ministry of Finance (MoF)	Provides financial incentives, subsidies, and tax reliefs to encourage investments in biomass production and infrastructure. Facilitates funding mechanisms for renewable energy projects, including biomass cofiring.
Ministry of Environment and Forestry (MoEF)	Regulates the sustainable use of biomass sources, ensuring that biomass production does not lead to deforestation or environmental degradation. Overseas environmental impact assessments and promotes sustainable forest management practices.
Ministry of State-Owned Enterprises (MSOE)	Oversees state-owned companies, including PLN, ensuring the implementation of biomass cofiring initiatives. Encourages SOEs to collaborate with private sectors and regional stakeholders to enhance biomass utilization.
PT Perusahaan Listrik Negara (PLN)	Implements biomass cofiring in existing coal-fired power plants, conducting trials and expanding the program to multiple facilities to enhance renewable energy generation.
Biomass Producers	Supply the necessary biomass materials, such as wood pellets and chips, to support cofiring operations in power plants.
Local Governments	Facilitate the development of biomass supply chains by providing support and infrastructure at the regional level.
Private Sector Investors	Invest in biomass production facilities and related infrastructure to support the supply chain for cofiring initiatives.
Independent Power Producers (IPP)	As a private sector (non-state-owned CFPPs), implements biomass cofiring in existing coal-fired power plants, conducting trials and expanding the program to multiple facilities to enhance renewable energy generation.
Delivery Drivers (Logistics Providers/ Individual Operators)	Transport biomass materials from suppliers to power plants, ensuring timely and efficient delivery. Handle the logistics of biomass supply chains, including route optimization, storage, and unloading processes at the power plant.

2. Supply Chain Mechanism

The flowchart in Figure 2 illustrates the biomass supply chain and its integration into biomass cofiring for NRE electricity generation in Indonesia. The process begins with biomass feedstock, which includes raw materials such as agricultural residues, wood pellets, or other organic waste. This feedstock is then transported through the biomass delivery stage, facilitated by delivery transportation drivers. These drivers play a critical role in ensuring that the biomass reaches the next step efficiently. The biomass is mainly sourced from farmers and small-scale biomass producers, who act as key suppliers in the supply chain. These suppliers provide raw or processed biomass to biomass suppliers, who aggregate and distribute the materials to end users.

The biomass then reaches various buyers to begin the process of biomass co-firing, including CFPPs under national electricity company, Independent Power Producers (IPPs), and international buyers for export activities. Finally, through biomass cofiring, the biomass contributes to the generation of NRE electricity, supporting Indonesia's goal of increasing renewable energy adoption while reducing dependency on fossil fuels. This structured supply chain involves various stakeholders that working collaboratively to enhance the efficiency and sustainability of biomass-based energy production in Indonesia.

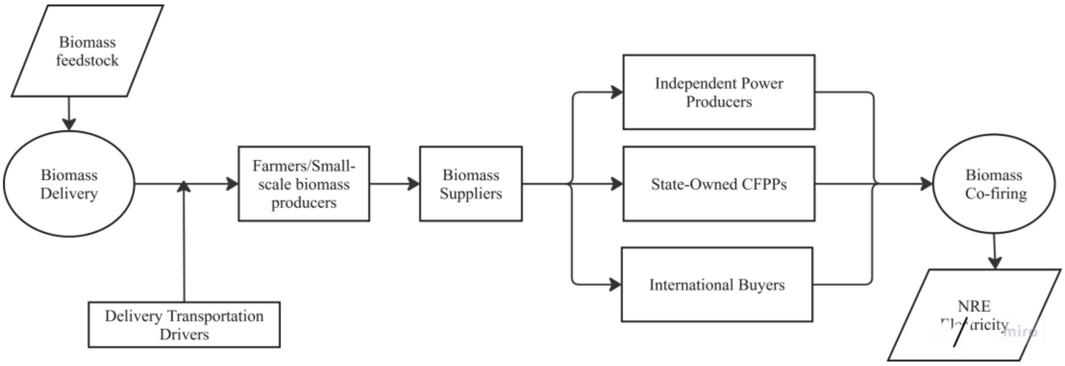

Figure 2. Supply Chain Mechanism of Biomass Co-firing

Key Factors that Influence the Success of Biomass Co-Firing in Indonesia's Electricity Sector

Table 3 presents the key factors derived from open coding based on the interview sessions by adapting the framework from Kim et al., (2019) and Nita et al., (2023) with the same methodology. The analysis of interview transcripts reveals 44 factors that influence the implementation of biomass co-firing program. The interviewee's frequency of mentioning each factor is shown by the code occurrences, which are subsequently interpreted as the factors' assessed relevance (Melgoza et al., 2020) (Lohle & Terrel, 2017). These occurrences provide a quantitative perspective within the qualitative framework. However, the coding process did not assign weights or capture every possible instance exhaustively. The identified factors are systematically grouped into seven categories, outlined below.

Table 3. Factors and Occurrences

Categories and Factors		Occurrences in Interviews					Total Occurrence
		I1	I2	I3	I4	I5	
Biomass		**24**	**38**	**18**	**23**	**14**	**117**
B1	Biomass Availability	4	4		3	1	12
B2	Biomass Co-firing Achievement	2	3	2	1	3	11
B3	Biomass Co-firing Goals	3	3	2			8
B4	Biomass Co-firing Target	5	5	2	2		14
B5	Biomass Demand		3	3	3	2	11

B6	Biomass Price	2	7	2	1	1	13
B7	Biomass Production	2			1		3
B8	Biomass Quality	1	4	5	7	4	21
B9	Biomass Quantity		2	2	1	2	7
B10	Biomass Resource Potential	5	7		4	1	17
Economic Feasibility		**17**	**8**	**8**	**5**	**8**	**46**
EF1	Coal Price	2	2			1	5
EF2	Complexity of Cost Mechanism	6	1				7
EF3	Cost Saving	2					2
EF4	Economic Benefits		1	5		3	9
EF5	Electricity Price		1			1	2
EF6	Social Welfare	4	1	3	4	3	15
EF7	Subsidy	1	1				2
EF8	Transportation Cost	2	1		1		4
Environmental Impact		**3**	**7**	**2**		**2**	**14**
EI1	Emission	3	4				7
EI2	Natural Barriers			2		2	4
EI3	Sustainable Resource		3				3
Government		**6**	**8**	**2**	**4**	**2**	**22**
G1	Central Government Support	1	2	1		1	5
G2	Regional Government Support	3	1		3	1	8
G3	Regulation and Bureaucracy Barrier	2	5	1	1		9
Institutional Characteristics		**10**	**26**	**18**	**11**	**16**	**81**
IC1	Collaboration/Coordination	4	7	6	3	6	26
IC2	Competition Among Suppliers			1		3	4
IC3	Electricity Supply Business Plan (RUPTL) Target	2	1				3
IC4	Information Barriers		2				2
IC5	Organization Commitment	2	6	7	3	5	23
IC6	Organization Limitations		8	1	2	1	12
IC7	Stakeholders Awareness	2	2	3	3	1	11
NRE and Bioenergy		**3**	**8**				**11**
NB1	Bioenergy Implementation Achievement		2				2
NB2	NRE Implementation Achievement		3				3
NB3	NRE Potential	2	2				4
NB4	NRE Target	1	1				2
Technical Practicality		**14**	**19**	**17**	**22**	**19**	**91**
TP1	Delivery System Compliance			4	3	3	10
TP2	Domestic Market Competition	2			1	1	4
TP3	Export Activities	3	2	3	1	1	10
TP4	Infrastructure/System Barriers	3	3	2	3	7	18

TP5	International Market Competition	1	6	1	1		9
TP6	Logistical Barriers	1	1		2		4
TP7	Monitoring and Evaluation	1	2	1	4	1	9
TP8	Standardization	3	5	4	7	5	24
TP9	Technological Investment			2		1	3

Analysis of the Factors Involved

1. Biomass Related Factors

The availability of biomass is one of the primary determinants of the feasibility of biomass co-firing. A consistent and sustainable biomass supply is essential for maintaining operational stability in power plants. Based on expert interviews, biomass availability must be actively sourced and developed rather than solely relying on industrial residue waste (waste-oriented approach). In this regard, a production-oriented approach is crucial, where biomass should be specifically cultivated to meet energy demands. *Biomass co-firing achievement* also plays an important role. Based on interviews with experts, all agreed that currently, biomass co-firing achievements are still quite far from the set targets. The realization of biomass co-firing in power plants has only reached 1.6 million tons, far from the 2025 target. On average, biomass co-firing accounts for only 2% of coal use, though this varies by power plant. One of the key challenges is finding biomass at prices that comply with MEMR Regulation No. 12 of 2023. Governments and organizations set *biomass co-firing goals* as part of renewable energy and carbon reduction strategies. Indonesia has set a *target* to increase the share of renewable energy to 23% by 2025 (as stated in KEN), where biomass co-firing plays a critical role by implementing the effort to do coal and biomass combustion in the existing coal-fired power plants. Its principle is similar to biodiesel, where only the fuel changes while the existing system remains intact. Additionally, co-firing helps manage industrial waste, preventing fire hazards, decomposition, and odour pollution.

Demand for biomass as an energy source directly influences its pricing and availability. *Biomass pricing* is also a crucial economic factor that determines the competitiveness of co-firing with coal. Electricity producers face challenges in securing biomass supply for co-firing due to price regulations that equate biomass costs with the domestic coal price, which is capped at 70 USD per ton under the Domestic Market Obligation (DMO). This makes biomass unattractive for several suppliers. As biomass targets increase, relying solely on waste is insufficient, so biomass must be deliberately produced to meet demand. The efficiency and sustainability of *biomass production* influence long-term supply chains for co-firing. Many regions rely on agricultural residues, forestry waste, or energy crops to sustain biomass production (Nurariffudin et al., 2018). Compliance with six Indonesian National Standards (SNI) and Ministerial Regulation No. 12 of 2023 ensures *biomass quality,* but enforcement remains difficult. *The biomass quantity* required for co-firing is also substantial, and scaling up co-firing necessitates a robust biomass supply chain. A study in Indonesia estimated that 9 million tons of biomass per year would be needed to sustain widespread biomass co-firing (Sugiyono et al., 2022). Managing logistics and infrastructure for collection, processing, and transport remains a key challenge. The *potential of biomass resources* is also a key enabler for adoption of co-firing, which includes wood and furniture waste, and plantation forests, followed by the collaboration between electricity producers, regional governments, and private sectors.

2. Economic Feasibility

The *complexity of cost mechanism* in providing biomass as a co-firing fuel in power plants has become a challenge. The pricing mechanism has shifted to account for logistical challenges in sourcing biomass, since CFPPs were not initially designed for biomass, so necessitating *transportation cost* from distant sources. The logistics of biomass supply for CFPPs present cost challenges due to varying distances between power plants and biomass sources. Some CFPPs are near mine-mouths, lowering supply costs, but not necessarily close to biomass sources, increasing transport expenses.

Co-firing is also categorized as an energy source that supports *cost savings,* because co-firing is considered to have a low cost of production compared with other types of renewable energy (hydropower, solar power, wind power), and at the beginning of its implementation in 2021, the cost of production carried out is only 85% so that there is no additional investment for power plants. Study found that cofiring biomass can reduce long-term operational costs by lowering coal consumption and emissions-related expenses. However, initial investments in retrofitting power plants may be significant (Arifin et al., 2023). The cost of electricity production is a key determinant of feasibility in *electricity price*. Biomass cofiring impacts the levelized cost of electricity (LCOE), often increasing it compared to coal-only plants. A study found that biomass cofiring increased LCOE but was still within an acceptable range for Indonesia's energy market (Rahmanta et al., 2024). The implementation of the co-firing program depends on revising Minister of Finance Regulation No. 174/2019, which currently excludes biomass from government-*subsidized* fuels. The Ministry of Finance plays a key role in adjusting regulations to include biomass as a subsidized fuel.

Although co-firing slightly increases electricity prices, the impact remains reasonable considering its *economic benefits* by creating jobs, increasing local incomes, and supporting community welfare. Higher biomass demand boosts job absorption, strengthening local economies and funding corporate social responsibility (CSR) initiatives for essential goods and infrastructure, which can also improve *social welfare*. Previous study also shows that biomass co-firing creates economic opportunities by utilizing agricultural waste and generating employment in biomass supply chains that can improve rural economies and energy security (Primadita et al., 2020). Additionally, it can improve air quality by reducing coal combustion emissions, benefiting public health (Palupi et al., 2023).

3. Environmental Impact

Based on the interviews, the co-firing implementation is a key emission reduction strategy. Emission reductions from co-firing are monitored by the Ministry of Environment and Forestry, ensuring national progress across industries. Moreover, weather conditions as part of *natural barriers* also significantly impact biomass quality, as moisture levels from rain and humidity affect its calorific value, potentially causing delivery delays and lack of quantity. However, it is also stated in the interview that in the rainy season, there is no significant decrease in quantity of biomass that meet the specification (monitored at one of the CFPPs). It also should be concerned that biomass supply comes from *sustainable resources*, emphasizing that it does not originate from deforestation.

4. Government

   Government regulations and policies also play an important role in the development and utilization of biomass. *Central government support* is mostly carried out by the Ministry of Energy and Mineral Resources. *Regional government support* (provincial level) also comes in the form of authority over biomass fuel provision, but their role is limited compared to upstream regulatory bodies. Other than that, there are also several *regulatory and bureaucracy barriers*. Pricing disparities between domestic and international markets create barriers to competitiveness.

5. Institutional Characteristics

   The national electricity producer must ensure *RUPTL target* commitments are met while balancing economic and operational feasibility. The existence of set targets causes *stakeholders awareness* to arise from related institutions. *Organization commitment* is one of the institutional characteristics that influence the biomass co-firing implantation. Suppliers also need to meet the specification of biomass that is supplied to the CFPPs. Based on that commitment, *collaboration/coordination* between relevant stakeholders certainly plays an important role in the sustainability of biomass co-firing implementation. However, there are several challenges that are also faced due to regulatory and bureaucratic barriers, which lead to *organizational limitations*. The organizational limitations also lead to *information barriers*. *Competition among suppliers* also influences the implementation of biomass co-firing. Biomass suppliers compete based on quality, quantity, and supply chain efficiency. Some of the suppliers have received foreign interest in biomass exports but some of theme also have a desire to prioritize supporting domestic co-firing program.

6. NRE and Bioenergy

   Indonesia's renewable energy transition places a strong emphasis on *bioenergy.* Other than biomass, efforts to replace fossil fuels include biofuel substituting conventional fuel and biogas replacing natural gas. In terms of *NRE implementation achievement*, Indonesia reached 13.3% NRE penetration in 2023, still falling short of the 23% *NRE target* set for 2025, highlighting the urgency for accelerated efforts. The country holds an estimated total *NRE potential* of nearly 3700 GW, yet bioenergy utilization remains at only 3400 MW as of Q3 2024, illustrating the vast untapped resources (MEMR, 2024). Achieving the target requires stronger policy support, active industry participation, and comprehensive technical-economic assessments to optimize renewable energy utilization and ensure a more sustainable energy future.

7. Technical Practicality

   Infrastructure/system barriers also influence the implementation of biomass co-firing. CFPPs were originally designed for 100% coal combustion. This requires modifications to accommodate biomass co-firing that involve the mixture of two materials, which are coal and biomass, which have different specifications, including the caloric value. The adaptation process is slow due to the specifications of the existing boilers in CFPPs. Storage issues further complicate operations, as biomass with high moisture content leads to reduced calorific value, affecting combustion efficiency. This indicates that future *technological investments* in preprocessing facilities and at the CFPP itself are also required for biomass quality enhancement.

Besides that, *logistical barriers* also affect the implementation of biomass co-firing. Transporting biomass is a major logistical challenge, as biomass has a lower density than coal, making sea transportation inefficient and increasing reliance on land-based delivery. Large power plants are creating traffic congestion and transportation shortages, including including delays, increased transportation costs, and limited truck availability. The varying distances between biomass sources and CFPPs further exacerbate the problem, making delivery costs uneven across different locations.

To overcome these barriers, *standardization* should be applied to the whole operational activities. National electricity producer and the Ministry of Energy and Mineral Resources have introduced six Indonesian National Standards (SNI) for biomass. These standards specify calorific values, moisture limits, and size requirements, but many suppliers still struggle to meet them. The existence of standardization requires *monitoring and evaluation* in all operational activities, ensuring *delivery system compliance* with biomass quality and contract terms. There are also both *domestic* and *international market competitions* in securing biomass supply, since there is also biomass supply needed for *export activities*, where the price is much higher than the domestic market.

Major Concerns of Factors: Driving Grouping Loops

A causal loop diagram shown in Figure 3 illustrates the connections between various factors, where arrows indicate cause-and-effect relationships. The difference of colors shows different categories of factors. The plus and minus signs represent the nature of the change, where a plus signifies a change in the same direction, while a minus denotes an opposite change. There would be either reinforcing (R) or balancing (B) the initial change in the full loop. Three main categories have been identified as critical concerns, which are technical practicality, institutional characteristics, and economic feasibility, highlighting the influence of these factors in shaping the system. These categories are further examined through relational loops, which illustrate the interactions among factors within each category and their connections to factors in other categories. To reduce complexity, unrelated loops and factors are excluded from the diagram.

Figure 3. Causal Loop Diagram of Biomass Co-firing for Indonesia's Electricity System

1. Technical Practicality

The technical practicality component, shown in Figure 4, is the first group of loops that significantly affects the biomass co-firing. There are infrastructure/system and logistical barriers as external factors. This is because initially, power plants are basically set up for 100% coal combustion, while in the co-firing, the coal must be mixed with biomass, which have different specification with coal, particularly in the caloric value. In addition, the distance between the power plant and the biomass source is also a challenge, because basically the location of power plant only considers the distance to the coal mining area. These barriers have led to the formation of many standardizations in the system. The existence of complex standardization causes the need for high monitoring/evaluation for stakeholders, especially for the CFPP as the implementer of the co-firing process. The higher the level of monitoring/evaluation carried out, of course, will have an impact on the high suitability of the biomass delivery system in the supply chain, which then has an impact on increasing the biomass co-firing results that meet specifications.

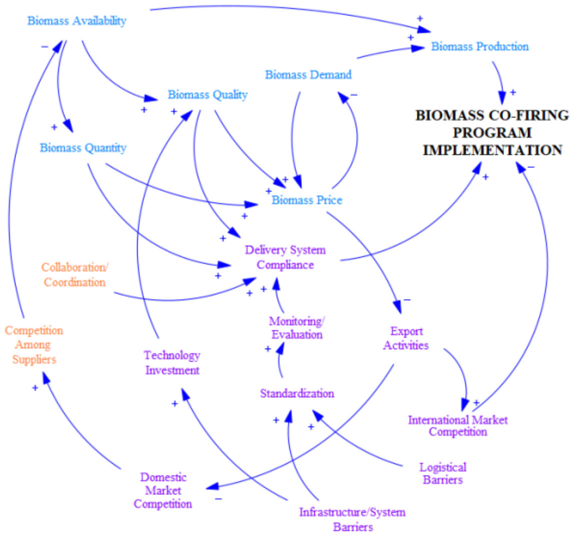

Figure 4. CLD of Technical Practicality Drivers

2. Institutional Characteristic

The second group of loops that effectively influence the implementation of biomass co-firing is the institutional characteristics factor, as presented in Figure 5. The NRE mix target that has been set forms the biomass co-firing target which also triggers the formation of the RUPTL target as one of the commitments that must be implemented by the national electricity company. The existence of this RUPTL increases the awareness of relevant stakeholders to take their respective roles according to their capacity and responsibility. This then encourages the formation of organizational commitment which also has an impact on increasing collaboration/coordination between stakeholders. Increased collaboration/coordination between actors will certainly increase the achievement of delivery system compliance when biomass enters the CFPPs, including the quality and quantity of biomass. The higher the achievement of delivery system compliance, it will support the increase in the implementation of biomass co-firing with quality according to specifications.

In addition, there are also external factors in the form of government support that determine the barriers between regulation and bureaucracy. The higher the regulatory and bureaucratic barriers, the higher the organizational limitations. This limitation can also be in the form of information disclosure which then has an impact on constraints in the collaboration/coordination process. The lower the collaboration between related organizations, the impact will be on the mismatch of delivery system achievements which can then have an impact on reducing the implementation of biomass co-firing in accordance with specifications. Therefore, in the process of collaboration/coordination, although organizations have limitations, it is important to consider their respective commitments that have also been established in order to achieve the target achievement of biomass co-firing implementation

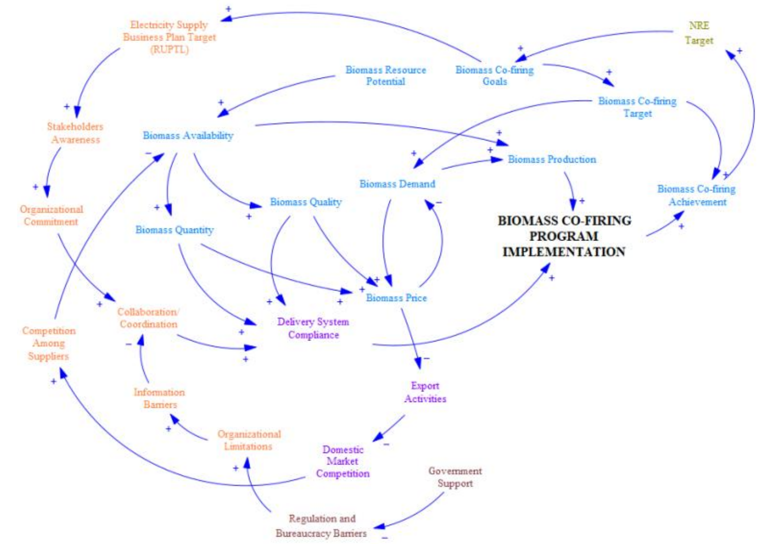

Figure 5. CLD of Institutional Characteristic Drivers

3. Economic Feasibility

According to Figure 6, economic feasibility factors are the third group of loops that significantly influence the use of biomass co-firing. The price of biomass is influenced by the quality and quantity of the biomass itself. In addition, the price of biomass is also influenced by the price of coal, in this case the prevailing price in the domestic market according to the applicable regulations, which is also influenced by the level of subsidies. The higher the subsidy level, the higher the cost savings will be, leading to increased economic benefits and social welfare. Furthermore, the price of biomass will have an impact on the price of electricity, which if the price of electricity is lower will certainly have an impact on improving people's welfare.

An external technical factor that also influences economic factors is logistical barriers. The greater the distance between the power plant and the biomass source, the higher the transportation costs. This can have an impact on increasing the complexity of the cost mechanism, because the distance travelled for the biomass distribution varies. The biomass capacity required by each power plant is also different, as is the availability of biomass potential in one region from another. This determines the number of delivery trucks needed which also has an impact on transportation costs, thus affecting the complexity of the cost mechanism. The more complex the cost mechanism is, the more it will reduce economic benefits, which in turn will reduce social welfare.

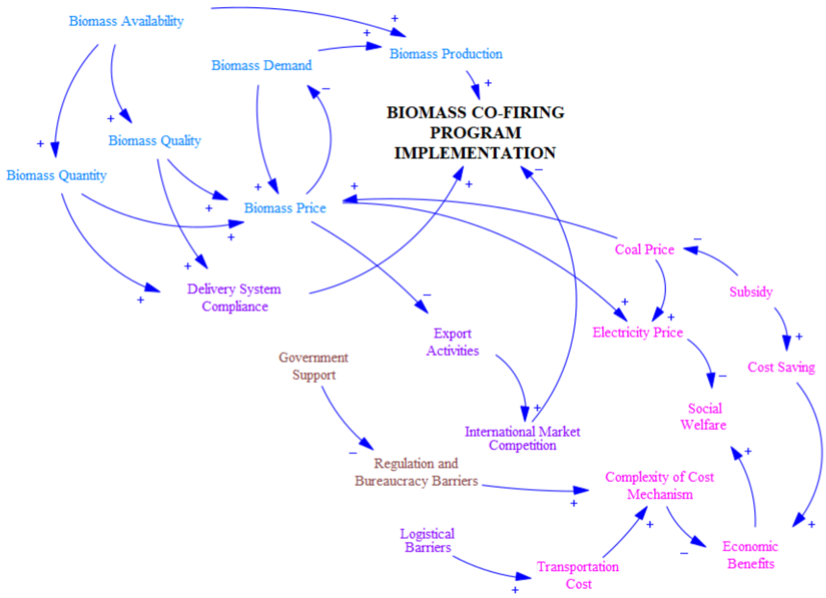

Figure 6. CLD of Economic Feasibility Drivers

CONCLUSION

Current implementation of biomass co-firing in electricity sector in Indonesia involves several stakeholders, including government, national electricity company, biomass supplier, independent power producers, industries that build their own power plant, and local community in regional areas. The successful implementation of biomass cofiring for electricity generation in Indonesia requires addressing multiple challenges across biomass related factors, including biomass resource potential and availability, biomass co-firing achievement, goals, and target, biomass demand, price, and production, as well as its quality and quantity. Other than that, economic feasibility also holds important role in managing economic benefits and social welfare. Furthermore, the quality of nature should also be maintained by considering environmental impact factors. Government support and policies, institutional coordination, and technical practicality should be done properly with high awareness and collaborations within all relevant stakeholders. This will affect the achievement of renewable energy integration targets.

While Indonesia has abundant biomass resources, their utilization remains suboptimal due to logistical inefficiencies, cost constraints, regulatory barriers, and technical challenges. Key barriers such as inconsistent biomass supply, high transportation costs, standardization compliance, and minimal technological investment hinder large-scale adoption. Additionally, complexity of pricing between coal and biomass prices also remains a challenge. However, strategic business solutions, including biomass supply chain optimization, financial incentives, infrastructure investment, technology advancement, and regulatory streamlining, can accelerate biomass adoption while ensuring economic and environmental sustainability. By strengthening collaboration among stakeholders, including the big players such as government, electricity producers, private investors, and biomass suppliers, Indonesia can leverage its biomass potential to meet renewable energy targets, reduce dependence on fossil fuels, and promote a low-carbon economy.

The detailed recommendations to overcome the challenges are listed below.

1. Strengthening Biomass Supply Chains
   Ensuring a consistent and high-quality biomass supply is crucial. The government should develop regional biomass collection hubs near power plants to aggregate and process raw biomass. Contract farming agreements with farmers and plantation owners can ensure long-term supply stability. Unused or degraded land should be allocated for dedicated energy crop cultivation. To maintain biomass quality consistency, a national biomass certification system should regulate moisture content, calorific value, and ash content. Transparent biomass pricing mechanisms should also be introduced.
2. Enhancing Economic Feasibility and Financial Incentives
   Biomass cofiring is often less cost-competitive than coal due to high production and logistics costs. Introducing a carbon tax or emissions trading system would make coal less attractive and encourage biomass adoption. The government should offer low-interest loans, tax exemptions, and grants to support biomass infrastructure and power plant retrofitting. Public-private partnerships should be encouraged to attract investment in biomass supply chains and technology. A biomass carbon credit trading scheme would also allow industries to offset emissions by investing in biomass projects.
3. Improving Policy and Regulatory Frameworks
   Regulatory uncertainty and bureaucratic inefficiencies slow down biomass cofiring adoption. A dedicated biomass energy task force should be established to coordinate policies across ministries and streamline licensing processes. Regional governments should develop biomass master plans tailored to their specific resource potential. Export control policies should be implemented to prioritize domestic biomass supply for power generation and prevent excessive exports from disrupting the local energy market.
4. Advancing Technological Innovations and Infrastructure Development
   Existing coal-fired power plants require modifications to accommodate biomass, and advanced processing technologies are lacking. The government should incentivize retrofitting power plants with biomass-compatible boilers and combustion systems through grants and soft loans. Investment in R&D should focus on biomass gasification, carbon capture, and torrefaction technologies. Partnerships with several countries that leading in this sector can also accelerate technology transfer. Improving transportation infrastructure, such as rail and inland waterway systems, will reduce biomass transportation costs.
5. Strengthening Stakeholder Collaboration and Public Awareness
   Better coordination between government, electricity producers, biomass suppliers, and policymakers is needed. A biomass stakeholder forum should be created for knowledge-sharing and problem-solving. Public awareness campaigns should highlight the economic and environmental benefits of biomass energy. Technical training programs should be introduced for farmers, suppliers, and power plant operators to improve biomass handling and combustion efficiency. Community engagement programs should also be promoted to increase local job opportunities in biomass supply chains

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