Barriers and drivers of biomass renewable energy as co-firing in industrial supply chain with bibliometric analysis

Sawarni Hasibuan[1], Choesnul Jaqin[2], Hermawan[3], Ika Yunita[4], Bayu Nugroho[5]
[1,2,4,5]Master of Industrial Engineering Program, Universitas Mercu Buana, Jakarta, Indonesia
[3]Computer Science Department, Universitas Pakuan, Bogor, Indonesia
Corresponding author: sawarni02@mercubuana.ac.id

Abstract

The urgent need for reductions in greenhouse gas (GHG) emissions continues to grow. Countries worldwide, including Indonesia, have started investing large amounts of resources into new renewable energy sources. Biomass co-firing can play an important role in achieving these new renewable energy objectives. It has the potential to reduce the potential environmental impacts associated with fossil fuel combustion. In the co-firing process, it is possible to reduce GHG emissions by replacing some coal with biomass during the combustion process. This article aims to identify barriers and drivers in implementing biomass worldwide through a literature review with a bibliometric analysis approach. In addition, this article will investigate the existing co-firing plants in Indonesia with the availability of available biomass resources in the country associated with the barriers that have been successfully identified. This article is very important for the development and utilization of biomass energy to generate recommendations and future strategies for biomass utilization. It is also useful for researchers to select future areas of research.

Keywords
Barrier, Biomass, Driver, Co-firing, Supply chain.

1. Introduction
Indonesia is the largest country in ASEAN, with energy consumption in 2019 of 989.9 million BOE (Barrel Oil Equivalent) (BPPT, 2021). The energy demand is projected to increase until 2050 with an average growth of 3.5% per year and is still dominated by BBM with an average growth of 2.8% (BPPT, 2021). In the 2015 Paris Agreement, Indonesia has committed to reducing greenhouse gas emissions by 26% until 2025. It has been ratified through Law no. 16/2016 concerning Ratification of the Paris Agreement to The United Nations Framework Convention On Climate Change. In the national energy mix, it is proclaimed that by 2025 23% of national energy sources will come from renewable energy. Indonesia will gradually shift to sustainable and cleaner energy; power generation will switch to domestic energy sources. It is crucial because Indonesia is a net importer of energy (oil, fuel, LPG) (BPPT, 2021) which means that Indonesia's energy security depends on other countries.

In early 2020, the Ministry of Energy and Mineral Resources (Ministry of Energy and Mineral Resources) and PLN (the National Electricity Company) announced plans to implement co-firing for PLTU (Steam Fired Power Plant (Coal)) Indonesia. Co-firing is a process of adding biomass as a partial substitution of coal or coal mixture for PLTU to increase the renewable energy mix (Adhiguna, 2021). As of June 2021, PLN has successfully implemented co-firing on 17 PLTUs (Kementrian ESDM, 2021). Biomass can be obtained from plantation waste, wood, agriculture, and garbage (Adhiguna, 2021; Hermanto & Swastika, 2017). Sources of biomass come from energy plants grown on dry land or cultivated in Energy Plantation Forest areas such as Kaliandra, Gamal, and Lamtoro trees. The co-firing project, PLN, has produced green energy equivalent to a generating capacity of 189 Mega Watt (MW) (PLN, 2021). Of the 17 PLTUs that use biomass commercially, around 12 PLTUs are spread across Java and 5 locations outside Java and are managed by two PLN subsidiaries, namely PT Indonesia Power (PT IP) and PT Pembangkitan Jawa Bali (PT PJB). In the implementation of co-firing, the two companies utilize waste, including sawdust, wood chips, and solid recovered fuel (SRF) from waste. In 2021, PLN estimates that the need for biomass for power generation will reach 570,000 tons. PLN targets the co-firing program to be carried out at 52 PLTU locations with a total capacity of 18,154 MW consisting of 16 PLTUs located in Jamali (Java-Madura-Bali) and 36 PLTUs outside Jamali.

However, power generation involving the biomass sector has many challenges, both in the economic field and in securing the supply of raw materials, to the technical aspect. This article will identify the challenges and drivers of implementing biomass for co-firing. The purpose of this paper is to summarize state-of-the-art research related to biomass as a renewable energy source and identify the barriers and drivers for the sustainability of biomass as co-firing of renewable energy in supply chains at the global level and real conditions in Indonesia.

3. Research Methodology

The approach used in this research is through a systematic literature review, a comprehensive analysis of the literature, and a quantitative bibliometric analysis is applied to complete the analysis results. Article searches were carried out in the last ten years, namely, 2011-2021, using the keywords "Feedstock" AND "Biomass" AND "Solid" AND "Power Energy" AND "Driver," "Barrier" AND "Dry Biomass" AND "Co-Firing" OR "Co Firing," which is used in the title, abstract and keywords to perform searches on the ScienceDirect (www.sciencedirect.com) and Scopus.com databases with an option to search for articles in English, and sorted by relevance. In the initial stage, 507 articles were obtained, then selected for content and relevance checks. The final result was 20 selected articles, which will be reviewed in detail.

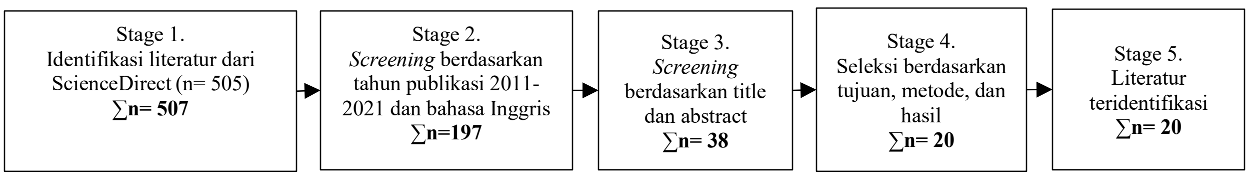

Figure 1. Research Framework

4. Results and Discussion

4.1 Bibliometric Analysis

Vosviewer Software was first developed by Nees Jan van Eck and Ludo Waltman in 2010, with the primary function as a bibliographic map visualization (see http://www.vosviewer.com). VOSviewer performs classification based on different keywords and groupings. The data is taken in RIS file format to display the graphic visualization with Vosviewer software. Co-occurrence on keywords is taken as a data analysis option with the full counting method. The minimum number of occurrences of the keyword can be set to meet the threshold requirement. From 38 articles (stage 3), bibliometric analysis was carried out on keyword linkages between articles that have been screened. The results of bibliometric visualization can be seen in Figure 2, while the trend of topics by year is presented in Figure 3.

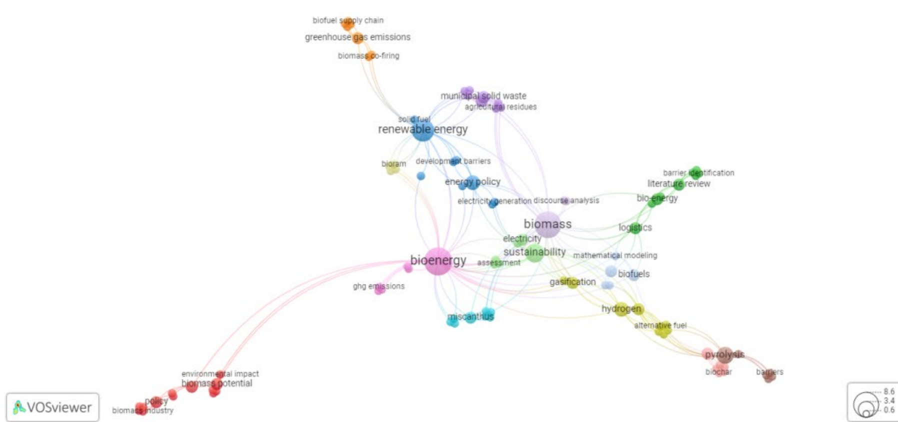

Figure 2. Occurrence Analysis with VosViewer

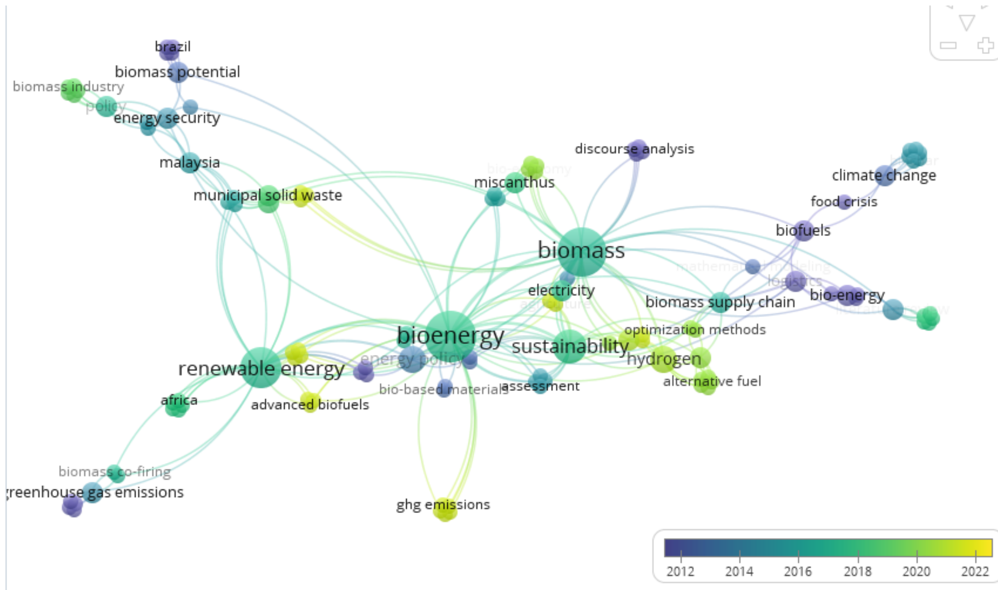

Figure 3. Trend Topic Analysis with VosViewer

Based on Figure 2, it can be seen that there are 16 clusters based on the level of relationship between keywords. Of the 16 clusters, it is clear that there are three main clusters (largest nodes), namely: "bioenergy," "biomass," and "renewable energy." The "bioenergy" cluster has a strong relationship with other main nodes. In this cluster, the ones that appear the most are related to "sustainability," "energy security," and "miscanthus." The "biomass" cluster has the second strong relationship between keywords after the "bioenergy" cluster. In the second cluster, the most common ones are related to "sustainability," "biofuels," "municipal solid waste," "discourse analysis," "miscanthus," and "logistics." But interestingly, the topics of "biomass supply chain," "electricity," "food crisis," and "agriculture" also emerged. The "renewable energy" cluster has the third strongest relationship between keywords. In the 3rd cluster, the most common ones are related to "greenhouse gas emission" and "municipal solid waste." But what is interesting is the topic of "advanced biofuels" and "biomass co-firing." If seen in Figure 3, the topic trends are based on the period. The topic trends that are currently being discussed a lot (judging by the color of the yellow-green-yellow nodes) include "advanced biofuels”, "municipal solid waste”, "ghg emission," and "agriculture." Meanwhile, the focus of research in this article on "barriers" and "drivers" in the "biomass supply chain" has not been discussed long enough, namely around 2018 (Figure 4).

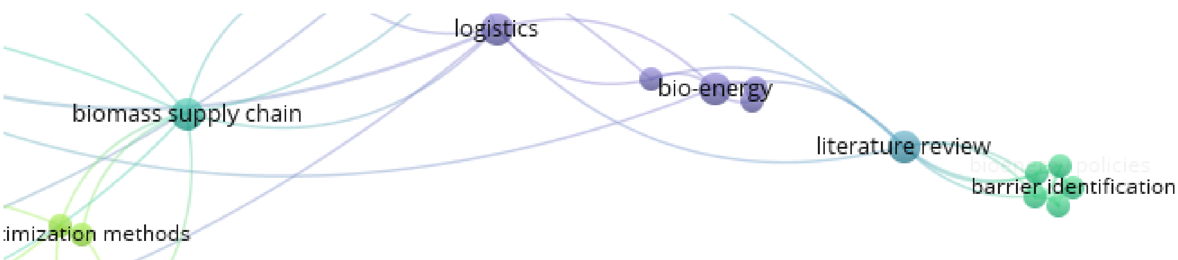

Figure 4. Barrier Identification Node

4.2 Descriptive Analysis

Based on the evaluation results of published articles, based on keywords, 20 articles from publications from 2011 to 2021 were obtained according to the keywords determined in the research method. The literature that has been collected is then analyzed quantitatively. Descriptions related to where the article was published and the distribution of the year of publication can be seen in Figure 5. From Figure 5, it can be seen that many articles related to biomass were published in Q1 and Q2 journals, meaning that articles discussing biomass associated with its potential as a renewable energy source became an interesting topic in reputable international journals.

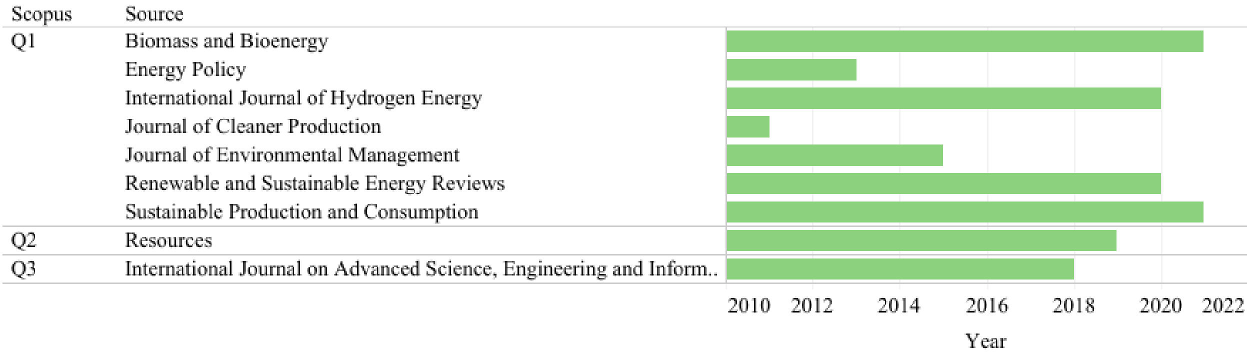

Figure 5. Distribution of Journal Index, Journal Name, and Publication Year

4.3 Identification of Barriers and Drivers

The barriers that have been collected in this paper can be divided into various dimensions, namely economic, social, technical, and institutional, and policy. The description of various aspects related to the barriers in the biomass supply chain collected can be seen in Table 1. While the barriers to implementing the biomass supply chain are presented in Table 2.

Table 1. Summary of Social, Technical, Economic, and Institutional Barriers to Biomass Supply Chain

Dimension	Sub-Dimension	Description	Reference
Economy	Feed stock Procurement	Cost of collecting, storing, and transporting feed stock before processing.	(Gold & Seuring, 2011; Gwenzi, Chaukura, Mukome, Machado, & Nyamasoka, 2015; Hasibuan, Adiyatna, Widowati, & Kandasamy, 2020; How et al., 2019; Junginger et al., 2011; Ludlow et al., 2021; Sinclair, Cohen, Hansen, Basson, & Clift, 2015; Upadhyay, Shahi, Leitch, & Pulkki, 2012; Visser, Hoefnagels, & Junginger, 2020)
		Feedstock cost	(Hoefnagels, Banse, Dornburg, & Faaij, 2013; Visser et al., 2020)
		Tariffs and non-tariff trade barriers	(Junginger et al., 2011; Popp, Lakner, Harangi-Rákos, & Fári, 2014)
		The unwillingness of suppliers for a long-term commitment	(How et al., 2019)
		Storage risks	(Gold & Seuring, 2011)
	Production process	Production cost; The operating and set-up costs; High cost of electricity generation from renewables; Operation and maintenance costs	(Hasibuan et al., 2020; Osmani, Zhang, Gonela, & Awudu, 2013; Sharma, Ingalls, Jones, & Khanchi, 2013; Thomson, Kwong, Ahmad, & Nigam, 2020; Upadhyay et al., 2012; Visser et al., 2020)
	Lack of competitiveness	The price of biomass feed stock is still high	(Junginger et al., 2011; Ludlow et al., 2021; Sinclair et al., 2015)
	Investment cost & Low investment attractiveness	The cost of capital is very high	(Ludlow et al., 2021)
		Funding limitations	(Giwa, Alabi, Yusuf, & Olukan, 2017; Sinclair et al., 2015)
	Lack of domestic market	Biomass generated for export	(How et al., 2019; Ludlow et al., 2021)

Dimension	Sub-Dimension	Description	Reference
Social	Skills and knowledge	Lack of technical expertise	(Gwenzi et al., 2015; How et al., 2019; Ludlow et al., 2021; Mäki, Saastamoinen, Melin, Matschegg, & Pihkola, 2021; Tun, Juchelkova, Win, Thu, & Puchor, 2019)
Technical	Technology	Awareness of technology	(Gwenzi et al., 2015; Hoefnagels et al., 2013; Ludlow et al., 2021)
		Absence of biomass monitoring and tracking system	(How et al., 2019)
		Obsolete and insufficient operational equipment	(Giwa et al., 2017; Sinclair et al., 2015)
	Production	Production capacity of biomass	(Mäki et al., 2021; Thomson et al., 2020)
		Biomass supply issue (lack of supplier, seasonal); Sufficiency of biomass resource	(How et al., 2019; Mäki et al., 2021; Roni et al., 2017)
		The debate over food versus fuel (sugarcane, soybeans, and corn)	(Zahraee, Shiwakoti, & Stasinopoulos, 2020)
		Specification of quality	(Giwa et al., 2017; Gold & Seuring, 2011; Junginger et al., 2011; Thomson et al., 2020)
		Characteristics of biomass impacting its harvest, collection, and handling	(Gold & Seuring, 2011)
		Pre-treatment techniques	(Gold & Seuring, 2011)
	Logistic	Logistics infrastructure; Transport to pellet to plant	(Gold & Seuring, 2011; How et al., 2019; Ludlow et al., 2021; Visser et al., 2020)
Institutions and policies	Institutions	Limited cross-sectoral collaboration (e.g. lack of a national strategy between different Ministries)	(Ludlow et al., 2021; Tun et al., 2019)
	Policies	Limited policy support	(Ludlow et al., 2021; Tun et al., 2019)
		Lack of clear strategies	(Giwa et al., 2017)
		The political nature	(Galik, Benedum, Kauffman, & Becker, 2021)

Table 2. Driver Summary in Biomass Supply Chain Implementation

Dimension	Description	Reference
Economy	Solutions to boost bio-economy and circular economy	(Mäki et al., 2021)
Social	Social responsibility	(How et al., 2019)
Environment	Paris Agreement 2015	
	Law no. 16/2016	
Institutions	Collaboration among user/Producers and (Local) Government	(Tun et al., 2019)
	Cooperation of private sectors	(Tun et al., 2019)
	Involvement of stakeholders	(Tun et al., 2019)
	Waste institutions	(Giwa et al., 2017)

4.4 Indonesia co-firing

To meet the national energy mix target of 26% sourced from new and renewable energy (EBT) in 2025, as stated in the National Energy Policy (KEN), the government issues strategies and policies in the development of bioenergy, including 1) increasing the installed capacity of PLT Bio; 2) utilization of biomass; 3) implementation of biofuels; 4) sustainable biogas development (Kementrian ESDM, 2020a; Moristanto, 2021). Indonesia's bioenergy potential is around 32.6 GW, with a new implementation of 1.9 GW (Moristanto, 2021).

Co-firing is the process of burning two different materials simultaneously. By using co-firing, emissions from burning fossil fuels can be reduced. Co-firing is an alternative method for converting biomass into electric power, namely by partially substituting coal with biomass into a generating unit (Roni et al., 2017). Biomass is known as zero CO2 emissions (Hasibuan, Adiyatna, & Hidayati, 2021; Hasibuan et al., 2020; Yang, Wei, Hou, Li, & Wang, 2019) or has the potential to reduce CO2 accumulation in the atmosphere, besides that biomass also produces less sulfur gas emission when compared to coal. Therefore, co-firing of coal and biomass can support the reduction of CO2 emissions and the emission of NOx and SOx pollutants from fossil fuels.

In Indonesia, there are currently two types of raw materials that are most dominantly used as co-firing of coal fuel at PLTU in Indonesia, namely, waste and forest waste/products in the form of wood. According to Kementrian ESDM (2020b), the potential for waste as raw material for pellets is currently 20,925 tons per day which are concentrated in 15 municipal waste management sites, namely DKI Jakarta (7,000 tons/day), Bekasi City (1,500 tons/day), Bekasi Regency. (450 tons/day), Batam (760 tons/day), Semarang (950 tons/day), Surabaya (1,700 tons/day) Tangerang City (1,200 tons/day), Denpasar and Bandung (1,155 tons/day), Depok , Bogor City and Regencies (1,500 tons/day), Makassar (1,000 tons/day), Bandung (1,630 tons/day), Surakarta (550 tons/day), Malang (800 tons/day), Regional Jogja (440 tons/day) day) and Balikpapan (290 tons/day) with the calorific value of waste processing produced around 2,900 - 3,400 Cal/gr. Furthermore, for wood-type forest products, if it is equivalent to the amount of electricity produced, the total potential for the wood to be made into wood pellets is 1,335 Mega Watt electrical (MWe). The potential is spread across Sumatra (1,212 MWe), Kalimantan (44 MWe), Java, Madura and Bali (14 MWe), West Nusa Tenggara and East Nusa Tenggara (19 MWe), Sulawesi (21 MWe), Maluku (4 MWe) and Papua (21 MWe) with a calorific value of 3,300 - 4,400 Cal/gr.

Although the potential of biomass as a co-firing fuel is tremendous in Indonesia, there are various challenges in its implementation, which are described below (Adhiguna, 2021):

1) Biomass Supply
Challenges in biomass supply include the price of high quality biomass, supply stability, and distribution of resources vs demand centers.

2) Biomass Industry
Challenges that occur in the biomass industry include, among others, that the existing biomass industry is largely built for export markets at premium prices; bank ability challenge to achieve viable commercial RDF & biomass supply model, investment security co-firing fuel flexibility likely require long-term commitment from Government & PLN to assure large scale investments.

3) Power Plant
Challenges that occur in power plants include technical challenges for PLN power plants such as: low calorific value and high moisture content potentially reducing efficiency and increasing operation complexity; slagging & fouling-increased ash deposition in the boiler; accelerated boiler corrosion potential; negative impact escalates with lower quality biomass and greater mixture; tighter constraints for PC boilers fuel properties.

5. Conclusion
Biomass is one of the alternative renewable fuels and is included in the national energy mix to reduce CO2 emissions by 26% by 2021. Based on the literature review results, there are several barriers and drivers related to the sustainability of biomass as co-firing in the power plant supply chain. Drivers of biomass sustainability as co-firing can be grouped into economic, social, technical, and institutional dimensions. At the same time, the drivers of biomass sustainability as co-firing are also related to economic, social, and institutional dimensions in addition to environmental considerations. In the case of Indonesia, the largest biomass potential comes from municipal waste and sawdust, but only 2% of the biomass potential has been utilized. The biggest challenges are related to the sustainability of the quality and quantity of supply of biomass raw materials, the model of stakeholder partnerships and funding that supports the commitment to the sustainability of the co-firing biomass supply chain, and technical challenges in the field.

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Biographies

Sawarni Hasibuan is an associate professor in the Industrial Engineering Department at Universitas Mercu Buana, Jakarta, Indonesia. She completed his Masters in Industrial Engineering at the Bandung Institute of Technology and obtained a Doctorate in Agro-industrial Technology, Bogor Agricultural University. She has carried out several research and publications in operational management, green & sustainable manufacturing, supply chain management, and renewable energy.

Hermawan is a lecturer in the Computer Science Department at Universitas Pakuan, Bogor, Indonesia. He completed his Masters and Doctorate at Bogor Agricultural University. He has carried out several research and publications in industrial management systems, food, energy sustainability, etc.

Choesnul Jaqin is a lecturer in the Industrial Engineering Department at Universitas Mercu Buana, Jakarta, Indonesia. He completed his Masters and Doctorate at Kagoshima University, Japan. He has carried out several research and publications in productivity, quality, and renewable energy.

Ika Yunita is a postgraduate student in Industrial Engineering at Universitas Mercu Buana, Jakarta, Indonesia. She is interested in supply chain management, supply chain sustainability, and agility. She is working as a supply chain management consultant in the supply chain department in one of Indonesia agroindustry located in Jakarta, Indonesia, to manage supply chain integrated information system.

Bayu Nugroho is a postgraduate student in Industrial Engineering at Universitas Mercu Buana, Jakarta, Indonesia. He is interested in industrial management, productivity and quality, and supply chain management. As a risk analyst, he is working as a supervisor in the Department of Engineering in a reinsurance firm located in Jakarta, Indonesia.