| RESEARCH ARTICLE

THE DEVELOPMENT OF BIOMASS REGULATION THROUGH IDN-FARMCO IMPLEMENTATION AS THE IMPLEMENTATON OF INDONESIA'S COMMITMENT TO ZERO EMISSION

Fatina Rizka Sahila [1], Harmono [2], Anis Khoerunnisa [3]
[1] *Universitas Swadaya Gunung Jati, Law, Cirebon*
[2] *Universitas Swadaya Gunung Jati, Law, Cirebon*
[3] *Universitas Swadaya Gunung Jati, Law, Cirebon*
Corresponding Author: Fatina Rizka Sahila, **E-mail**: Fatina.sahila002@gmail.com

| ABSTRACT
Global Carbon research since 2013-2022 found that Indonesia is known as a country that produce the second largest emission over the world. In this situation, Indonesian government showed the support to the revitalization through Regulation of Minister of Energy and Mineral Resources or Energi dan Sumber Daya Mineral (ESDM) number 12 of 2023 about fuel transition program and demonstrated its commitment to realizing the Zero Emission plan. Unfortunately, the nature materials for co-firing are not available to fulfill electricity needs. The reason is that those materials are continuously exported to other countries. The regulation should be implemented as well following for the purpose, that is to support Indonesia stop the coal burning. This research used a juridical method to see how the regulation impact in the reserve of biomass commodity and combined to research and the development method through IDN-FarmCo as biomass farmer collection commodity, in hope to supply the co-firing program. This research proposed some steps to reduce pollution which may help both regulation and innovation to successfully implement the zero-emission plan.

| KEYWORDS
Biomass; Co-firing; Innovation; Regulation

| ARTICLE DOI:

I. INTRODUCTION

One of the causes of huge carbon dioxide emissions (CO2) in Indonesia is because the coal mines are an important role in economic growth and national development. The coal mine also often causes pulmonary diseases to the people in Indonesia. The induced air flow produced by coal transportation is one of the leading causes of dust at the transfer point after the carbon fell, and the surrounding air will move along with carbon materials. Dust in the middle was deposited by negative pressure and diffusion into the surrounding air [1].

In Indonesia, the industry which uses coal burning is steam-electric power plant or known as PLTU. This PLTU generate many controversies regarding the adverse effects of health. This is because the burning of coal in PLTU produce several pollutants such as (NOx) and sulfur oxide (SOx) into the air which is the main contributor in the formation of acid and dust of PM 2.5 (particulates of dust float). These pollutants cause damages to building materials, plants and health disorders. The coal combustion process will produce emissions or commonly referred as air pollutants that come out from the chimney of the factory, and at least the resulting emissions contributed 10% to 15% of pollution in Indonesia [2].

Indonesia needs immediate action to address these ongoing environmental challenges, which have serious impacts. Under the Global Blended Finance (GBF) alliance, Indonesia has also reaffirmed its commitment to achieving Net Zero Emissions by 2060 or sooner. In June 2020, Indonesia successfully reduced emissions by 63 million tons of CO2 from the targeted 67.5 million tons. The country aims to cut emissions by 198.27 million tons by 2025 and reach 314 million tons by 2030.

The Indonesian government is accelerating the achievement of its Net Zero Emissions (NZE) target by 2060 through various initiatives. One key step is the issuance of Presidential Regulation Number 112 of 2022 on September 13, 2022, which focuses on accelerating renewable energy development for electricity provision. This regulation covers business plan preparations for electricity supply, roadmaps for ending the operational period of Steam-Electric Power Plants (PLTU), implementation of electric power purchases, and government support for renewable energy development.

Through the Net Zero Emissions (NZE) program, industrialized and developed countries are required to achieve net zero emissions by 2050. This initiative has prompted the introduction of new regulations in several countries concerning electricity generation. Conventional power plants, such as Steam-Electric Power Plants (PLTU) that use coal, are the primary focus of these new policies. This is due to the CO2 emissions produced by PLTUs, as well as their role in providing the base load that still dominates the electrical systems in several countries, especially Indonesia.

Other efforts should be prepared to find solutions that can reduce emissions. One of the solutions is taking the action to replace the fuel uses. This innovation has also been applied by several PLTUs through the Co-Firing scheme implementation as a commitment to pursuing the NZE target. Several PLTUs, especially those in Indonesia have implemented a Co-Firing scheme including the PLTU Paiton (2 x 400 MW) that use a 1% biomass fuel ratio from coal energy supply. Then PLTU Jeranjang, which uses organic waste pellets and other biomass waste for the Co-Firing mixture of 3% from the coal fuel supply. Based on the results of the development carried out by PLTU Paiton and PLTU Jeranjang, National Electricity Company or Perusahaan Listrik Negara (PLN) plans to implement the Co-Firing scheme in 52 other PLTU units with a total capacity of reaching 18,184 MW [3].

The benefits of Co-Firing technology and programs include preserving environmental functions and mitigating carbon dioxide emissions. This is because Co-Firing can reduce emissions, particularly those from the exploration and exploitation of fossil fuels and coal in PLTU. Additionally, Co-Firing utilizes biomass as an alternative fuel, which increases energy efficiency, reduces costs, and helps minimize environmental waste.

In the implementation of the Co-Firing program, PLTU needs several types of biomass materials such a pellet wood, garbage, palm oil shell and sawdust. Biomass materials mixed with other materials will be referred to as Co-Firing process. However, to run the Co-Firing program, PLTU requires a large amount of biomass materials. Unfortunately, this is a major obstacle for why Co-Firing has not been able to be optimally managed. Some of the challenges stem from the unstable supply of biomass materials, which cannot fully meet the needs of PLTU. In addition, the long growth period of trees and the suboptimal availability of biomass materials, such as palm oil shells, are exacerbated by the fact that these materials are still being exported by foreign farmers.

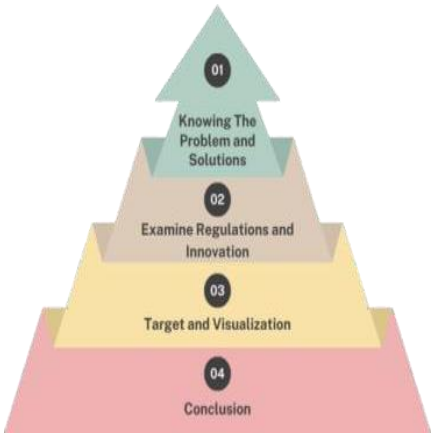
New regulations regarding the availability of biomass materials are outlined in the Regulation of the ESDM Minister Number 12 of 2023, which governs the use of biomass as a fuel mix in PLTUs to support the Co-Firing NZE program. This research aims to examine the implementation of these government regulations in addressing environmental issues, specifically the massive carbon dioxide emissions in Indonesia. Additionally, by leveraging technological advancements, the research proposes the creation of the IDN-Farm Co website, which will track biomass materials and simplify the process for farmers to sell their supply to the government.

II. METHODOLOGY

The research method used in this study is a development research method. This method is a type of research method that focuses on producing certain products and testing its effectiveness or as renewable innovations that can benefit various sectors [4].

In this context, support for the Net Zero Emissions (NZE) goal is demonstrated through various efforts, one of which is the Co-Firing program. The initiative to replace coal with biomass in Steam-Electric Power Plants (PLTU) requires significant cooperation among multiple parties due to the limited local production of biomass. Therefore, in addition to facilitating biomass supplies through the IDN-FarmCo website, which connects farmers from various regions in Indonesia to meet the PLTU's needs, a normative juridical research method is also employed. This research examines Minister of ESDM Regulation Number 12 of 2023 as the legal framework for ensuring the availability of biomass materials. Using data from the Indonesian Central Statistics Agency (BPS), the

development of the website assistance will be evaluated in relation to the targets set for the Net Zero Emissions program. These steps will help ensure that the research aligns with the optimal outcomes of the program, as outlined in the following scheme.



Graph 1. Research Step Scheme

III. RESULTS AND DISCUSSION

Environmental health is currently one of the most critical issues that needs to be addressed urgently. This is due to the growing demands of human development, climate change, and industrial activities across various sectors, many of which negatively impact environmental quality. These activities contribute to the deterioration of essential resources such as clean air and nutritious food, which in turn harm public health. In response, the United Nations Framework Convention on Climate Change (UNFCCC) has been coordinating global efforts through an international agreement aimed at reducing carbon emissions and combating climate change. This agreement, known as the Paris Agreement, was signed on April 23, 2016, in Paris, France, by 195 UN member countries, including Indonesia, committing all parties to reduce Greenhouse Gas emissions.

The Paris Climate Agreement was also signed by the Minister of Environment and Forestry, representing the President of the Republic of Indonesia. In line with the goals of the Paris Agreement, the Indonesian government has demonstrated its support through the publication of Law No. 16 of 2016. As part of the Paris Agreement, Indonesia committed to reducing its greenhouse gas (GHG) emissions by 29% by 2030. Based on GHG emissions data from 2010, Indonesia is also working toward independently reducing emissions by 41% if supported by other countries. The government affirms this commitment through its Nationally Determined Contributions (NDC) [5].

According to implementing 97 paragraphs rules in the Glasgow Climate Pact, there four main points that can be drawn regarding the direction of international cooperation in climate change mitigation are adaptation, mitigation, funding, and collaboration. In terms of climate funding, COP 26 encourages participating countries to increase their climate change mitigation budget according to each country's Nationally Determined Contribution (NDC). The climate change budget in Indonesia is one of the highlights because it continues to decrease annually. The national climate change budget was recorded as IDR 132.47 trillion in 2018. This amount dropped significantly in 2019 to IDR 97.66 trillion and only reached IDR 77.81 trillion in 2022. The cost was shown that Indonesia should be active in many programs to provide the Net Zero Emission Commitment [6].

Net-Zero Emissions (NZE) is a situation where the amount of carbon released into the atmosphere does not exceed what the earth is absorbing. To achieve this program, the transition from the energy system nowadays into a cleaner energy system is necessary to achieve a balance between human activity and natural balance. One of its considerations is to reduce carbon or gas emissions produced by various human activities during a certain period of time known as a carbon footprint. The carbon emission that human produce gives the negative impacts our lives on this planet, among others, droughts, the blow of clean water sources, extreme weather, changes in food chain production and many other natural disasters [7].

Some of the activities carried out to support the Net Zero Emissions commitment are to apply a reduction program including the Emission Reduction, Climate Mitigation, Electric Vehicle (EV), Carbon Pricing, Carbon Trading and Co-Firing. Indonesia is one of the countries that has started implementing the Co-Firing program in several PLTUs that actively operate to reduce quite high emissions production. This action was taken because, according to data released by the World Resource Institute (WRI) in 2014,

Indonesia ranks first among Southeast Asian nations in terms of carbon emissions production, accounting for 1.981 billion tons annually, placing it in the large sixth position overall.

Co-Firing is an initiative in Indonesia aimed at lowering emissions in coal-fired power stations. Co-firing is a method that substitutes fuel from renewable sources with coal based on a certain composition while maintaining the necessary fuel quality. A more prevalent Co-Firing to use biomass material for Steam-Electric Power Plant (PLTU) burning indicates Zero Emissions' commitment to lowering emissions. [8].

Through the existence of Co-Firing technological innovation, there is one of the problem will solved because this program is one of the techniques to reduce the use of fossil fuels from power plants is to modify the coal Steam-Electric Power Plant (PLTU) with the concept of joint combustion or commonly referred to as alternative methods by substitute coal-recomb able fuel for the fuel needs, it can reduce the emission of coal products or the flue gas. Co-Firing is considered the most promising-term approach to reducing CO2, with emissions mitigation using biomass alternative fuel can come from wood, the ruins of certain types of energy plants, certain types of waste, or garbage have been processed.

Co-firing is essentially the process of adding another fuel to a base fuel. There are multiple ways to treat the biomass resources with varying percentages of permits in this program. On the other hand, the indirect technique can reduce emissions during combustion and has a good environmental impact. Biomass included rice husk, wood, garbage, forest tree wood pallet, olive core, maize stalk, wheat straw, and molding biomass [9].

The purpose of Co-Firing is to reduce the use of coal with renewable energy fuel in a certain comparison by considering the quality of fuel according to the needs. In addition, it is expected that the implementation of Co-Firing in several PLTUs, the emissions produced by plants can be lowered so that it is more environmentally friendly. Another goal of Co-Firing also for waste management and reduced emissions to support the national energy mix target [10].

The success of the clean energy transition program is also supported by biomass as the largest source to reduce emission production rates, especially in Indonesia. With biomass, the use of fossil's raw material sources will slowly be replaced to prove Indonesia's commitment to Net Zero Emission, so that many health risks and living environment will also decrease.

The term "biomass" refers to the organic matter that is created by photosynthetic processes and can take the form of either waste or products. Bushes, grass, yams, agricultural waste, wooded area trash, excrement, and farm animal manure are a few examples of biomass. Biomass can be used as a source of electricity (gas) in addition to being the main source of fiber, food, animal feed, vegetable oils, and building materials. There are many advantages of using biomass energy sources. One of them is the availability of sustainable energy supplies through renewable energy resources. Biomass is an essential natural resource in Indonesia, producing a wide range of high-quality goods such as food, fiber, wood, and oil. These biomass products are then utilized to meet domestic demands or exported per customer request [11].

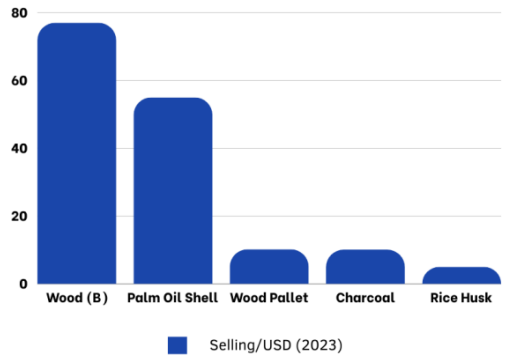
The amount of biomass used for Steam-Electric Power Plants (PLTU) varies depending on the type of power plant and the method applied. For instance, to meet the 1% co-firing requirement in a PLTU, approximately 17,470 tons of biomass are needed per day, or 5 million tons of wood pellets per year. For a Pulverized Coal (PC) type PLTU that requires a 5% biomass mixture, 10,207.20 tons of biomass are needed per day. In a Circulating Fluidized Bed (CFB) type PLTU, which also requires a 5% biomass mixture, 2,175.60 tons of biomass are needed per day. Finally, for a Stoker-type PLTU that uses 100% biomass, 5,088 tons of biomass are needed per day. Indonesia has abundant biomass resources that can serve as substitutes for coal in Steam-Electric Power Plants, offering a potential solution for more environmentally friendly electricity generation.

The key feature of biomass is that its products are classified as sustainable energy sources because the CO2 released during combustion or thermal conversion does not raise the atmospheric concentration of CO2. Because biomass is an organic material derived from plants developing through processes like photosynthesis, it has emerged as a potential sustainable energy solution. In essence, as part of a closed cycle, plants absorb CO2 that is released into the atmosphere because of other plants' decomposition processes. The only result of using biomass for energy is the release of CO2 into the atmosphere, which plants utilize to produce more biomass [12].

The energy transition program, especially energy sourced from biomass is currently becomes a solution that is widely developed in several countries over the world. This is because there are so many alternative sources of renewable energy from the results of the use of biomass materials. In terms of biomass can be tangible in liquid, solid and gas and biomass sources can be found from agricultural products, plantations, and forest results [13].

Even while biomass energy sources have a lot of promise to replace fossil fuels, certain nations, like Indonesia, continue to use biomass for industrial purposes, which makes it impossible for this program to function as efficiently as it could. Although there are plenty of natural resources and biomass sources, they are insufficient to meet the demands of replacing fossil fuels. This is because many biomass materials are derived from agricultural goods, such as food sources like rice, sweet potatoes, coconut, corn, and others, which are utilized as foodstuffs, satisfy the demands of the food industry, and are still being sold overseas (exports).

Based on data collected through the Central Statistics Agency or known as Badan Pusat Statistik (BPS) sources processed to find the amount of sales of biomass overseas materials in 2023 that described from the diagram as follows;



Graph 2. Data on Biomass Raw Material Export Activities in 2023 (Source BPS data)

Government support for the availability of biomass materials is also proven through the Regulation of the ESDM Minister No. 12 of 2023 which is published in consideration as follows; [14]

a. That to accelerate the achievement of renewable energy targets in the national energy mix, lowering greenhouse gas emissions in accordance with national energy policy, and encouraging the development of the community through the role of the community in providing biomass as fuel in steam power plants, it is necessary to regulate the utilization of biomass fuel as a mixture of steam power plants;

b. That based on the consideration as referred to in letters, it is necessary to establish Regulation of the Minister of Energy and Mineral (Permen ESDM) Resources about the Utilization of Biomass Fuel as a Fuel Mixture in Steam Power Plants (PLTU).

Previous research into the challenges faced in providing biomass has been written in written work which the titled is "The Development of Renewable Energy of Biomass from the Source of Agriculture, Plantation and Forest Products: The Study of Development and Constraints" by Kasmaniar in 2023 explains that the government's support for the availability of biomass materials through regulation, but also must help with supply several biomass energy to succeed the transition programs, one of them is Co-Firing.

According to the biomass availability issues that can fulfill Co-Firing needs, government should be open to use technology for help this urgent of situation. As we know from the diagram shown that Indonesian farmer still active in exporting biomass materials product into overseas each year. The regulation must be completed with digital program to collect the biomass material for Steam-Electric Plant (PLTU) project and support the Net Zero Emission commitment.

IDN-FarmCo is a website designed to collect biomass materials in Indonesia to meet the supply needs of PLTUs. This program is aimed at fulfilling the biomass targets for each PLTU in Indonesia. Farmers can easily use the website to view prices for their biomass products and submit their offerings. Through this program, the government will be able to monitor export activities by farmers, as the energy transition in Indonesia is a key priority. Following the completion of the Co-Firing project, IDN-FarmCo could provide a sustainable solution for ensuring the availability of biomass.

Image 1. IDN-FarmCo Logos

By 2025, the goal of the fossil fuel to renewable energy transition program is to reach 23%. 52 power plants with a combined generation capacity of 19 GWe have adopted a biomass co-firing program at the Steam Electric Power Plant (PLTU) in Indonesia, which is owned by PT PLN (Persero) ("Kaleidoskop 2022, Implementation of Co-Firing at PLN Generates 575.4 GWh of Clean Electricity"). With a total capacity of over 18,000 MWe, the Indonesian government plans to implement cofiring methods in coal-fired power plants (CFPP) by 2025, assisted by the state-owned company PLN. It is estimated that the average cofiring ratio will be 10%, which translates to a yearly biomass consumption of 9 million tons [15].

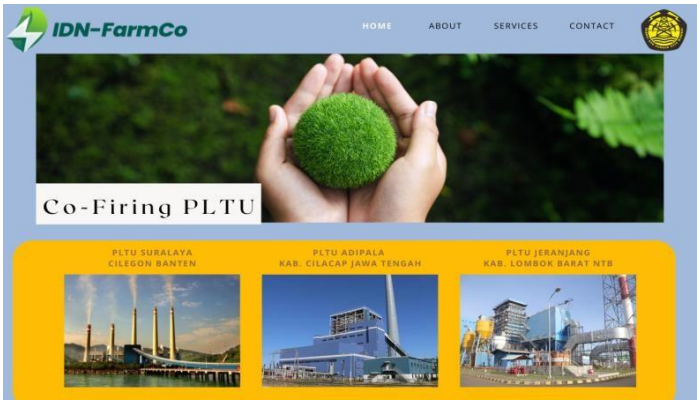


Image 2. IDN-FarmCo Main Display Visualization

The homepage of the IDN-FarmCo website displays a list of Steam-Electric Power Plants (PLTU) in Indonesia that have active Co-Firing projects requiring biomass material supplies from farmers or agricultural organizations. Users can search for or follow the biomass material requirements for each PLTU. The primary function of the IDN-FarmCo website is to support the Net Zero Emission (NZE) commitment, particularly in Indonesia. This technology aims to meet the biomass availability targets for the Co-Firing program through a biomass collection feature. IDN-FarmCo connects Indonesian farmers with PLTU, helping supply biomass products. In line with the Minister of Energy and Mineral Resources Regulation Number 12 of 2023, this website aims to reduce the export of biomass materials, ensuring sufficient supply for Indonesia's Co-Firing program.

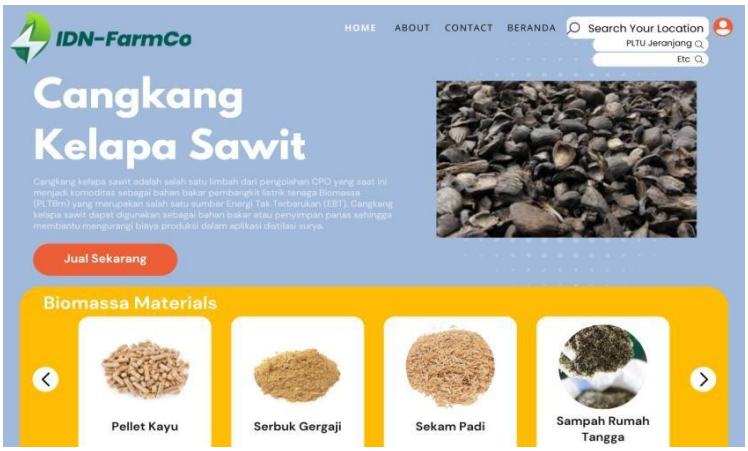


Image 3. Visualization of IDN-FarmCo Blog and Sales Page Display

The second page of IDN-FarmCo outlines the types of biomass materials used in the Co-Firing Program for Steam-Electric Power Plants (PLTU) near the sellers or farmers. This page highlights the functions, benefits, and commodities of the biomass materials to educate farmers on how to prioritize national needs when supplying their products. In addition to supporting the Net Zero Emission (NZE) commitment, both regulations and technology will be utilized to advance the program, aiming for a healthier environment in the future. The final page includes a feature that allows farmers to sell their biomass materials to the nearest PLTU. This website serves to support the Co-Firing program by helping to achieve emission reduction targets in Indonesia while providing a platform for monitoring biomass material usage.

This research examines the implementation of the Minister of Energy and Mineral Resources Regulation Number 12 of 2023, which supports biomass availability for the Co-Firing program, as part of Indonesia's commitment to the Net Zero Emission project. Innovation is also fostered through the development of the IDN-FarmCo website, which connects farmers as suppliers of biomass

materials to nearby Steam-Electric Power Plants (PLTU). The target of reducing emissions is progressing smoothly, supported by both regulatory measures and technological innovation.

IV. CONCLUSION

This research highlights the significant negative effects of environmental health, particularly in Indonesia, where coal mining plays a crucial role in economic development. One of the companies responsible for these effects is the Steam-Electric Power Plant (PLTU), which has been at the center of controversy due to the adverse health impacts associated with coal burning. The combustion of coal in PLTU emits pollutants such as nitrogen oxides (NOx) and sulfur oxides (SOx) into the air. In response, the Indonesian government has taken swift action by committing to the Paris Agreement and pledging to reduce greenhouse gas (GHG) emissions by 29% by 2030. National regulations also support this commitment, notably through Presidential Regulation Number 112 of 2022, which accelerates the development of renewable energy for electricity provision. This regulation focuses on the preparation of business plans, the implementation of roadmaps to phase out the operation of PLTU, the purchase of electric power, and government support to help achieve the Net Zero Emissions (NZE) target by 2060.

One of the programs supported by the Indonesian government is the clean energy transition program, known as Co-Firing. This program aims to replace fossil fuels with biomass materials to reduce emissions and support Indonesia's commitment to achieving Net Zero Emissions (NZE). Co-Firing is a method of supplementing a primary fuel with an alternative fuel, and it offers various methods to process biomass materials with different allowable percentages. The indirect method, in particular, has a positive environmental impact by minimizing emissions during combustion. The types of biomasses used include wheat straw, corn stalk, molding biomass, rice husk, wood waste, forest tree wood pellets, and olive cores. The goal of this program is to successfully replace fossil fuels with renewable biomass materials.

Unfortunately, the Co-Firing program faces challenges because some countries, including Indonesia, still rely on biomass materials for industrial purposes. While Indonesia has abundant natural biomass resources, they are insufficient to fully replace fossil fuels. This is because most biomass materials come from agricultural products, such as rice, sweet potatoes, coconuts, and corn, which are primarily used for food production and meet the needs of the food industry. Additionally, many of these materials are still being exported abroad, further limiting their availability for energy production.

The Indonesian government is supporting biomass availability for the Co-Firing program through the establishment of the Minister of ESDM Regulation Number 12 of 2023. After examining the regulation, the authors propose solutions to ensure its smooth implementation, helping to achieve the Net Zero Emissions (NZE) target. One such solution is the IDN-FarmCo technology, which is designed to facilitate collaboration between farmers and the government in supplying biomass for the Co-Firing program. The website features tools that help farmers sell their biomass materials to nearby power plants, as well as an educational page to inform users about which products can be submitted as biomass materials to replace fossil fuels.

REFERENCES

[1] A. Irfansyah and Susilawati, "RISIKO KESEHATAN PAPARAN KERJA TERHADAP BAHAN KIMIA BERACUN DI TEMPAT KERJA TAMBANG BATUBARA," *ZAHRA: JOURNAL OF HEALTH AND MEDICAL RESEARCH*, vol. 5, no. 2, pp. 287–297, 2023, [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK558907/

[2] M. Berliandaldo and T. Hendrix, "Dampak Pltu Terhadap Kondisi Ekonomi, Sosial, Dan Kesehatan Masyarakat Dalam Lingkungan Hidup Di Kecamatan Jenu," *Vitruvian: Jurnal Arsitektur, Bangunan dan Lingkungan*, vol. 11, no. 3, p. 261, 2022, doi: 10.22441/vitruvian.2022.v11i3.008.

[3] R. M. Ariefianto and R. A. Aprilianto, "Peluang Dan Tantangan Menuju Net Zero Emission (NZE) Menggunakan Variable Renewable Energy (VRE) Pada Sistem Ketenagalistrikan Di Indonesia," *Jurnal Paradigma*, vol. 2, no. 2, pp. 1–13, 2021, [Online]. Available: https://www.researchgate.net/publication/357448042

[4] S. Purnama, "Metode Penelitian Dan Pengembangan (Pengenalan Untuk Mengembangkan Produk Pembelajaran Bahasa Arab),"*LITERASI (Jurnal Ilmu Pendidikan)*, vol. 4, no. 1, p. 19, 2016, doi: 10.21927/literasi.2013.4(1).19-32.

[5] J. Matheus, N. Delicia, Frisca, and Rasji, "Implementation of the Carbon Tax Policy in Indonesia: Concepts and Challanges Towards Net Zero Emission 2060," *Jurnal Ilmu Hukum*, vol. 7, no. 1, pp. 91–114, 2023, [Online]. Available: https://e-jurnal.lppmunsera.org/index.php/ajudikasi/article/view/6464/2597

[6] I. Wahyuni, R. F. Harris, and E. Sujatmoko, "Road to Net-Zero Emission in Indonesia: Legal Loopholes in National Carbon Tax Scheme," *Media Iuris*, vol. 6, no. 3, pp. 399–416, 2023, doi: 10.20473/mi.v6i3.48537.

[7] M. G. W. Yudha, "Teknologi Terbarukan Menuju Jejak Hijau: Strategi Inovatif Untuk Mewujudkan Net Zero Emisi Di Masa Depan," *Jurnal Inovasi Teknologi Manufaktur, Energi, dan Otomotif*, vol. 2, no. 2, pp. 84–89, 2024, [Online]. Available: https://jurnal.poliwangi.ac.id/index.php/jinggo/

[8] A. P. NURYADI *et al.*, "Simulasi CFD Pengurangan CO2 pada Co-firing Batubara dan Tandan Kosong Kelapa Sawit Menggunakan Model Pembakaran Non-Premixed," *Jurnal Teknologi Lingkungan*, vol. 24, no. 2, pp. 283–291, 2023, doi: 10.55981/jtl.2023.725.

[9] Z. Arifin, V. F. S. Insani, M. Idris, K. R. Hadiyati, Z. Anugia, and D. Irianto, "Techno-Economic Analysis of Co-firing for Pulverized Coal Boilers Power Plant in Indonesia," *International Journal of Renewable Energy Development*, vol. 12, no. 2, pp. 261–269, 2023, doi: 10.14710/ijred.2023.48102.

[10] A. Dwi Ariyanto and L. Mustakim, "Analisis Pengujian Co-Firing Biomassa Pada Pltu Batubara Dengan Beberapa Bahan Bakar Alternatif Sebagai Upaya Bauran Energi Baru Terbarukan," *MARTABE: Jurnal Pengabdian Masyarakat*, vol. 6, pp. 08–104, 2023.

[11] N. Adi Sasongko, N. Gunadi Putra, and M. L. Donna Wardani, "Review of types of biomass as a fuel-combustion feedstock and their characteristics," *Advances in Food Science, Sustainable Agriculture and Agroindustrial Engineering*, vol. 6, no. 2, pp. 170– 184, 2023, doi: 10.21776/ub.afssaae.2023.006.02.8.

[12] K. Sivabalan, S. Hassan, H. Ya, and J. Pasupuleti, "A review on the characteristic of biomass and classification of bioenergy through direct combustion and gasification as an alternative power supply," *Journal of Physics: Conference Series*, vol. 1831, no. 1, 2021, doi: 10.1088/1742-6596/1831/1/012033.

[13] M. R. Z. Passarini, A. W. F. Duarte, L. H. Rosa, V. M. de Oliveira, and J. R. Ottoni, "Extremofuels: production of biofuels by extremophile microbes as an alternative to avoid climate change effects," *Science Direct*, pp. 237–256, 2022, doi: https://doi.org/10.1016/B978-0-323-90571-8.00010-9.

[14] Kementrian ESDM, *Peraturan Menteri ESDM Nomor 12 Tahun 2023 Tentang Pemanfaatan Bahan Bakar Biomassa Sebagai Campuran Bahan Bakar Pada Pembangkit Listrik Tenaga Uap*. Jakarta, 2023. [Online]. Available: https://jdih.esdm.go.id/storage/document/Permen ESDM Nomor 12 Tahun 2023.pdf

[15] N. Cahyo *et al.*, "A techno-economic and environmental analysis of co-firing implementation using coal and wood bark blend at circulating fluidized bed boiler," *International Journal of Renewable Energy Development*, vol. 13, no. 4, pp. 726–735, 2024, doi: 10.61435/IJRED.2024.60234.