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Implementation of CCUS Technology in the Development of Steam Power Plants: Challenges and Opportunities in the Era of Energy Transition

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A B S T R A C T

Climate change and rising CO_2 emissions from coal-fired power plants pose significant challenges to the sustainable energy transition. Carbon Capture, Utilization, and Storage (CCUS) offers a solution by capturing up to 95% of CO_2 emissions from industries and power plants. This study evaluates the opportunities and challenges of CCUS implementation in Indonesia from technical, economic, and policy perspectives using qualitative (literature review) and quantitative (emission reduction and economic impact analysis) methods. The results indicate that CCUS can reduce coal power plant emissions by 203.3 million tons of CO_2 per year, but it faces challenges such as high costs, potentially increasing electricity prices by up to 91%. Additionally, Indonesia's carbon tax policy has not been fully implemented, limiting the economic benefits of CCUS. In conclusion, while CCUS has great potential to support the sustainable energy transition, its success depends on stronger policy support, investment incentives, and infrastructure readiness. A collaborative strategy between the government, industry, and research institutions is essential to develop regulations that promote CCUS implementation at a lower cost.

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INTRODUCTION

Climate change is one of the biggest challenges faced by humanity today, with rising global temperatures caused by increasing concentrations of greenhouse gases in the atmosphere. The power generation sector, especially Steam Power Plants, is one of the main contributors to carbon dioxide (CO2) emissions, which trigger global warming and worsen environmental conditions (Agus Pamuji Wibowo et al., 2023).

In an effort to reduce these negative impacts, Carbon Capture, Utilization, and Storage (CCUS) technology is emerging as a potential solution. CCUS technology focuses on collecting CO2 emissions from industrial sources and power plants, and reusing or storing them in a safe and stable form underground (Firlina, 2016). In general, the workings of CCUS are divided into three processes ranging from CO2 capture, CO2 transportation and CO2 storage in geological formations (Sugihardjo, 2022).

The use of CCUS must be considered more since there is a new plan from the government that will stop the use of PLTU early. Especially in the Accelerated Renewable Energy with Coal Phase Down scenario where the PLTU can still operate until the contract period expires but provided that the PLTU must use CCUS technology in its facilities (Verda Nano Setiawan, 2023).

The potential of CCUS in reducing carbon emissions can be up to 95% in capturing CO2, but its implementation requires technological support, policies, and significant investment (Firlina, 2016). Along with the urgent need to achieve sustainable energy targets, the role of CCUS becomes crucial in supporting steam power plants to remain operational and to move towards a more sustainable future (Firlina, 2016).

The price of electricity produced by PLTU is Rp. 737.52 per Kwh, which is still cheaper when compared to PLTS, PLTG and PLTD. On the other hand, PLTU is very suitable to be used as a baseline for electricity in Indonesia (Adi Ahdiat, 2023a). Therefore, if the PLTU must be closed, it can potentially increase the price of electricity and also worry the community.

This research aims to identify the main opportunities and challenges in the implementation of CCUS technology in steam power plants. These challenges include technical, economic, and regulatory aspects that often become barriers to the adoption of this technology. In addition, this study also aims to evaluate the opportunities that can result from the implementation of CCUS technology in the context of sustainability such as how much carbon can be absorbed by the CCSU. Therefore, the author will use the title “Implementation of CCUS Technology in Steam Power Plant Development: Challenges and Opportunities in the Energy Transition Era”.

By reviewing various case studies and available data, this research will explore the potential economic and environmental benefits of CCUS, including the reduction of carbon emissions and its contribution to global climate policy. Furthermore, it aims to determine effective strategies to optimize the use of CCUS in sustainable power plant development.

THEORETICAL REVIEW

PLTU

Steam Power Plant (PLTU) is a power plant that utilizes heat energy from steam used to rotate turbines in order to generate electrical energy through generators, mainly coal, petroleum, or natural gas, to produce high-pressure water vapor (Pambudi et al., 2023). This steam is then used to drive a turbine connected to a generator to produce electrical energy (Tri Amandani Siregar et al., 2023).PLTU plays a significant role in the global electricity system, especially in developing countries such as Indonesia, which still depends on coal as the main energy source (Pahlevi et al., 2024).

The main advantage of PLTU lies in its capacity to produce large amounts of electricity at relatively lower production costs compared to renewable energy (Pontoh et al., 2021). Such as solar power plants (PLTS) and wind power plants (PLTB). In 2022, the price of electricity produced by PLTU in Indonesia is around IDR 737.52 per kWh, which is still cheaper than other renewable energy technologies. In addition, PLTU has a strategic role in maintaining the stability of the national electricity supply as a baseload plant that can operate continuously without depending on weather conditions or the availability of intermittent resources (Fahmi et al., 2022).

However, the use of coal-based power plants poses a major challenge to environmental sustainability. The process of burning coal produces very high amounts of carbon dioxide (CO_2) emissions, contributing to global warming and climate change. In 2022, coal-fired power plants in Indonesia accounted for about 67.21% of total national electricity production and produced carbon emissions of 214 million tons of CO_2 per year (Nugroho et al., 2023). Given the environmental impact, there is an urgent need to implement carbon emission mitigation strategies, one of which is through the application of Carbon Capture, Utilization, and Storage (CCUS) technology.

CCUS

Carbon Capture, Utilization, and Storage (CCUS) technology is an innovation designed to capture, utilize, and store carbon emissions generated by the industrial and power generation sectors (Prasetyo & Windarta, 2022). This technology plays a key role in climate change mitigation strategies, especially in the context of the energy transition to a more sustainable system. CCUS consists of three main stages, namely:

Carbon Capture

In this stage, CO_2 generated from the combustion of fossil fuels is separated from the flue gas before it is released into the atmosphere. There are several main methods in this process, namely post-combustion capture, pre-combustion capture, and oxy-fuel combustion (Prasetyo & Windarta, 2022). Of the three methods, the post-combustion approach is most commonly applied in power plants because it allows modifications to existing power plants without the need to fundamentally change the combustion process.

Carbon Utilization

Captured carbon can be utilized in a variety of industrial applications, including the production of synthetic fuels, fertilizers, low-carbon concrete, and use in Enhanced Oil Recovery (EOR) processes to increase petroleum production from fields that are already in decline (Vishal et al., n.d.). With proper utilization, these technologies not only contribute to emission reduction, but can also create additional economic value.

Carbon Storage

CO_2 that cannot be economically utilized is stored in secure geological formations, such as saline aquifers or depleted oil and gas reservoirs. This underground storage is designed to ensure that the captured carbon does not return to the atmosphere in the long term (Firlina, 2016).

Based on research, the implementation of CCUS technology in PLTUs can capture up to 95% of CO_2 emissions generated, which theoretically could reduce carbon emissions by 203.3 million tons of CO_2 per year if implemented in all PLTUs in Indonesia (Firlina, 2016). Despite its great potential in climate change mitigation, CCUS implementation still faces significant obstacles, mainly related to high investment and operational costs. Studies show that implementing CCUS can increase electricity prices by up to 91% of the initial price, which can impact energy costs for consumers (Putri et al., 2024).

Power Plant (PLTU) Policy

Energy policy in Indonesia in recent years has undergone significant changes to support a cleaner and more sustainable energy transition (Al Huda, 2023). One of the main policies related to PLTU is the Accelerated Renewable Energy with Coal Phase Down scenario, which regulates that PLTU can still operate until the end of its contract period, but on condition that it must adopt low-carbon technologies, such as CCUS (Meilani, 2024). This policy aims to ensure the sustainability of the national electricity supply while still meeting carbon emission reduction commitments in accordance with the Nationally Determined Contribution (NDC) in the Paris Agreement (Ariefianto & Aprilianto, 2021).

In addition, the Indonesian government has also adopted a carbon tax policy as an economic instrument to reduce greenhouse gas emissions. The carbon tax is regulated in Law No. 7 of 2021, which stipulates that a tax will be imposed on carbon emissions that have a negative impact on the environment (Pratama et al., 2022). However, the implementation of the carbon tax in Indonesia has been delayed and will only be fully implemented in 2025.

This delay affects the attractiveness of investment in CCUS technology. One of the key incentives for CCUS deployment is the potential for carbon tax reductions as well as carbon certificate trading, which has yet to be widely implemented in Indonesia (Adiwardhana, 2023). Therefore, stronger policy support is needed to encourage the adoption of CCUS technology, including fiscal incentives, research and development funding, and cooperation with the private sector in financing low-carbon infrastructure projects.

METHODOLOGY

This research uses a combined approach of qualitative and quantitative methods to gain a comprehensive understanding of the implementation of Carbon Capture, Utilization, and Storage (CCUS) technology. The qualitative approach focuses on in-depth analysis through literature studies related to the research theme, while the quantitative approach is used to analyze the data obtained to evaluate the results of the amount of carbon that can be absorbed and its economic value. This approach was chosen to provide a holistic view of the challenges and opportunities in the implementation of CCUS, as well as to devise effective strategies for its implementation.

RESEARCH RESULT

Potential CO2 that can be absorbed by CCUS

Indonesia is a country that still relies on steam power plants that burn coal, recorded in 2022 the percentage of electricity used in Indonesia is still dominated by coal power plants, which is 67.21% (Putri Aulia Mutiara Hatia, 2023). On the other hand, in the same year Indonesia produced 214 million tons of CO2 from steam power plants that use coal as fuel (Adi Ahdiat, 2023b).

Responding to this problem, CCUS can be a solution where its utilization can capture CO2 as much as 95 from each industrial activity, in this case the steam power plant industry that uses coal (Firlina, 2016). Referring to this data, if every steam power plant uses CCUS technology, then:

$$Co2\ that\ are\ minimized = 214 Million\ Tons\ \times\ 95\% = 203{,}3\ Tons$$

From the data above, it can be concluded that the potential CO2 that can be captured by CCUS is 203.3 tons of CO2. And there are still 10.7 million tons of CO2 that are not absorbed.

Challenges in CCUS Implementation

Despite its advantages in capturing 95% of every CO2 produced by the Steam Electricity generation industry. CCUS has large investment and maintenance costs, where the installation of CCUS in steam power plants can potentially increase the price of existing electricity production by as much as 91% of the initial price (Firlina, 2016).

In 2024, the price of electricity in Indonesia ranges from Rp. 1,352 to Rp. 1,700 per Kwh (Arnani mela, 2024). If we use the highest electricity price as a reference then:

$$Electricity\ Price = 1{,}700 + 91\% = Rp. 3247$$

From the above calculation, it can be seen that electricity will increase to a price of IDR 3,247 / Kwh.

Carbon Tax Related Policies

The carbon tax policy in Indonesia is one of the strategic steps taken by the government to reduce greenhouse gas (GHG) emissions and support Indonesia's commitment to achieving emission reduction targets in accordance with the Nationally Determined Contribution (NDC) in the Paris Agreement. In this regard, Indonesia has regulated it in Law No. 7 of 2021, especially in Chapter 6 Article 13 where carbon tax is imposed on carbon emissions that have a negative impact on the environment.

Although the carbon tax policy has been established and is planned to be implemented, its implementation in Indonesia is still in the process of development and is not yet widely applicable. The government continues to review and prepare the necessary steps so that the carbon tax can be effective in reducing carbon emissions without disrupting economic growth. The imposition of the tax in Indonesia has been postponed until 2025 pending further decisions from stakeholders (Muliawati Firda Dwi, 2024).

Since the carbon tax is still not in effect, the utilization of CCUS is still less economical in the process, because the benefits obtained from the utilization of CCUS come from the reduction of applicable carbon taxes from a country and carbon reduction effort certificates that can be traded both domestically and abroad.

CONCLUSION

From some of the above discussion it can be concluded that:

1. CCUS has the potential to capture carbon emissions generated from the Steam Power plant process up to 98% which if accumulated, the carbon emissions that can be absorbed are 203.3 tons of CO2 per year from the Steam Power Plant.
2. With the utilization of CCUS, it can potentially cause an increase in electricity prices to a price of Rp 3,247 / Kwh.
3. Policies related to Carbon Tax in Indonesia are still not enforced which causes the utilization of CCUS to still not produce economic benefits.
4. Therefore, although the utilization of CCUS can reduce the amount of carbon value, its utilization can affect the price of electricity due to expensive investment and unsupportive policies.

RECOMMENDATION

Policy Strengthening and Government Support

1. Accelerate the full implementation of the carbon tax to provide economic incentives for CCUS adoption.
2. Develop clear regulations and roadmaps for CCUS deployment in Indonesia, including legal frameworks for carbon storage.
3. Strengthen coordination between government agencies, industries, and research institutions to facilitate CCUS research and development.

Investment Incentives and Financial Mechanisms

1. Provide financial support such as tax incentives, subsidies, and low-interest loans to encourage power plants to adopt CCUS technology.
2. Establish public-private partnerships (PPP) to share investment risks and costs in CCUS projects.

Explore international funding opportunities, including carbon credit markets and climate finance initiatives, to support CCUS deployment.

Technological Development and Infrastructure Readiness

1. Enhance research and development (R&D) efforts in CCUS technology to improve cost efficiency and effectiveness.
2. Invest in infrastructure for CO_2 transportation and storage, ensuring safe and long-term carbon sequestration.
3. Promote pilot projects to test and optimize CCUS implementation in Indonesian power plants.

Economic Feasibility and Public Awareness

1. Conduct further studies on cost-reduction strategies to make CCUS more economically viable.
2. Implement public education campaigns to increase awareness of CCUS benefits and dispel misconceptions about its risks.
3. Develop business models that integrate CCUS with carbon utilization (e.g., synthetic fuels, industrial applications) to create additional revenue streams.

Integration with Renewable Energy Transition

1. Align CCUS adoption with Indonesia's long-term energy transition strategy by ensuring its role in bridging the shift to renewable energy.
2. Encourage the integration of CCUS in hybrid energy systems, combining coal-fired power plants with renewables to minimize emissions.
3. Develop long-term strategies for phasing out coal while maximizing CCUS as a transitional solution for energy security and sustainability.

By implementing these recommendations, Indonesia can optimize the potential of CCUS technology to support its energy transition goals while mitigating the economic and environmental challenges associated with coal-fired power plants.

FURTHER STUDY

Future studies should explore advanced CCUS technologies that can reduce investment and operational costs while maintaining high carbon capture efficiency. Additionally, comparative studies with countries that have successfully implemented CCUS can provide insights into cost-effective strategies.

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