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NET ZERO

# Techno-Economic Environment Assessment of Carbon Capture Storage when Retrofitting Coal-Fired Power Plants in Indonesia

The implementation of Carbon Capture and Storage (CCS) in coal-fired power plants offers a viable solution for reducing greenhouse gas emissions. CCS captures carbon dioxide (CO2) emissions, transporting them to storage sites underground or for industrial use. Despite challenges like high costs and suitable storage requirements, CCS is crucial for meeting climate targets. This study assesses CCS implementation in fossil fuel power plants, focusing on the Indonesia Government State Owned Electricity Company, PT. PLN (Persero). Using the Integrated Environmental Control Model (IECM), it evaluates feasibility, efficiency, and environmental impact. The research investigates energy requirements, costs, and carbon capture efficiency, considering retrofitting CCS technologies. Through detailed analysis, it evaluates the increased cost of electricity in plants with CCS, factoring in infrastructure investments.

*Keywords:*
*Carbon capture storage, Indonesia coal-fired powerplant, amine, ammonia.*

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## INTRODUCTION

Indonesia contributed about 1.7% of global carbon emissions in 2023. The vast majority of CO2 emissions in the energy sector come from the burning of fossil fuels such as coal, oil and natural gas for power generation accounts for 32% of the total CO2 emissions, as shown in Fig. 1. Figure 2 illustrates that coal provides 61% of electricity in Indonesia.

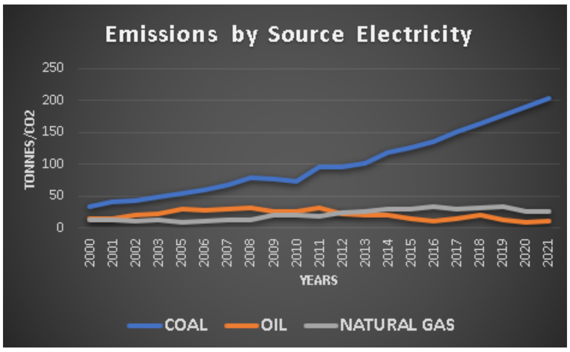


Fig. 1. Total emission in electricity [1].

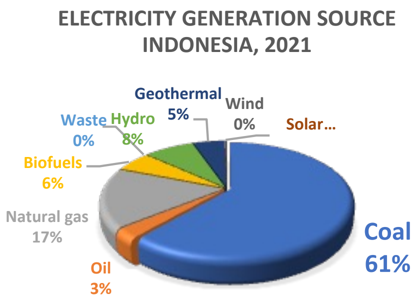


Fig. 2. Electricity generation source [1].

Indonesia's government intends to implement fuel switching from oil to gas, diesel to mixed biofuel, diesel to gas and to roll out the use of more efficient and low carbon technology [2]. However, this dependence raises environmental concerns, particularly regarding carbon dioxide (CO2) emissions. Retrofitting existing fossil fuel power plants with carbon capture and storage (CCS) technology emerges as a promising strategy to address these concerns.

Post-combustion, pre-combustion, and oxyfuel are three key carbon capture and storage (CCS) technologies with distinct advantages and limitations. Post-combustion capture involves removing CO2 from the flue gas after combustion, making it suitable for retrofitting existing power plants [3]. Pre-combustion capture, on the other hand, involves converting fossil fuels into syngas before combustion, enabling CO2 separation and capture prior to power generation [4]. Oxyfuel combustion, utilizing oxygen instead of air during combustion, produces a flue gas stream with a higher CO2 concentration, facilitating easier capture and storage [4]. Each technology offers unique opportunities for reducing emissions from fossil fuel power plants, with factors such as energy efficiency, cost-effectiveness, and scalability influencing their suitability for different applications as shown in Table 1.

| Oxy Combustion | Pre Combustion | Post Combustion |
|---|---|---|
| | *Advantages* | |
| Produces high efficiency steam cycle | Lower energy requirement than other | Applicable for existing and new coal fired power plant |
| Low level pollutants emissions | Requires less amount of water than other | Most commonly used technology in ccs |
| | *Disadvantages* | |
| High energy penalty | Significant loss energy than post combustion | Low co2 partial pressure at ambient pressure |
| High overall cost | High equipment cost | Need more water than other |

Table 1. Strengths and weaknesses of CCS methods [5].

Post-combustion capture technologies vary in their efficiency, energy requirements, and cost-effectiveness. Common techniques include aqueous amine scrubbing, pressure swing adsorption, and membrane separation, each with its advantages and limitations [3, 4]. Aqueous amine scrubbing, for example, involves passing the flue gas through a liquid solvent, such as monoethanolamine (MEA) and ammonia, which selectively absorbs CO2 molecules. The solvent is then regenerated through heating to release the captured CO2 for compression and storage (Fig. 3).

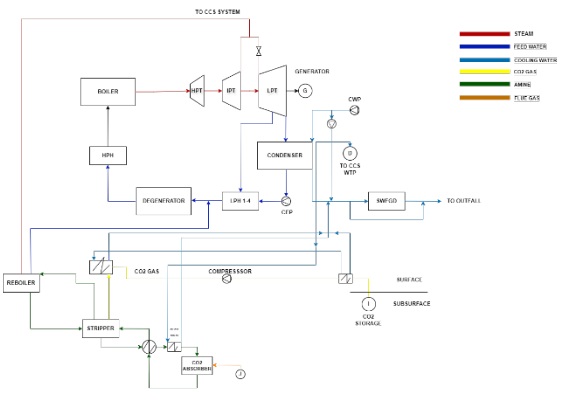


Fig. 3. Illustration of typical CFPP with a CCUS System.

The performance and cost-effectiveness of post-combustion capture technologies depend on factors such as the concentration and composition of CO2 in the flue gas, the availability and cost of capture solvents, and the energy penalties associated with capture and regeneration processes [3, 4]. Techno-economic assessments utilizing simulation tools like Integral Environment Control Mode (IECM) enable researchers to evaluate the feasibility of post-combustion capture retrofitting in specific case studies, considering factors such as plant size, fuel type, and operational conditions [6]. By incorporating detailed engineering models, economic parameters, and environmental considerations.

## MATERIALS AND METHODS

*Input Data IECM*
The methodology employed for modeling coal-fired power plant capacity in Indonesia involves compiling data on existing power plants, including their names, capacities, and fuel types. Each power plant is assigned a unique identifier, and relevant information such as capacity and fuel classification is recorded systematically. Additionally, the total capacity of all coal-fired power plants is calculated to provide an overview of the cumulative generation capacity in the country.

The modeling process requires meticulous data collection from reliable sources such as government agencies, energy companies, and industry reports to ensure accuracy and completeness. The classification of fuel types, categorized into different classes, enables the characterization of the coal used for power generation, considering factors such as calorific value and sulfur content. This classification informs decisions regarding fuel procurement, emissions control, and environmental compliance. Additionally, the average capacity of coal-fired power plants is calculated to provide insights into the typical size and scale of operations in the industry. shown in Table 2 below.

| Items | Value | References |
|---|---|---|
| Gross electrical output (MWh) | 2500 MWh | [9] |
| Type generation | Sub-critical | [7] |
| Capacity factor (%) | 64% | [8] |
| Plant location | Indonesia | |
| Fuel cost (USD/Ton) | 36.9 | [9] |
| Coal properties | Class 2 | [7] |
| Coal rank | Sub Bituminous | [7] |
| Carbon storage type | EOR | [10] |
| Pipeline distance | 134 | [10] |
| Emission rate (Kg/kWh) | 0.62 | [11] |
| Cost of electricity (USED/MWH) | 75.05 | [8] |

Table 2. IECM technical data.


Fig. 4. CFPP and CCS schemes in Indonesia.

## RESULTS

The results in Fig. 5 demonstrate significant variations in net electrical output and energy penalties among different CCS technologies compared to the scenario without CCS implementation. In the scenario without CCS, the net electrical output is the highest at 2266 MW. However, with the introduction of CCS technologies utilizing amine and ammonia, there are notable reductions in net electrical output. Specifically, the amine-based CCS technology achieves a net electrical output of 2020 MW, while the ammonia-based CCS technology yields a slightly lower output of 1903 MW. This reduction in net electrical output can be attributed to the energy penalties associated with CCS implementation. The amine-based CCS technology incurs an energy penalty of 156 MW, while the ammonia-based CCS technology experiences a higher penalty of 562 MW. These energy penalties reflect the additional energy requirements for the capture and separation of CO2 from flue gas streams.

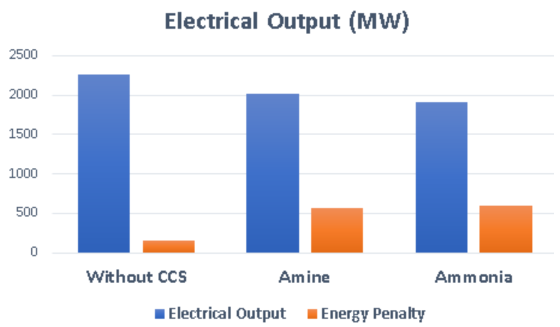


Fig. 5. Electrical output.

The results in Fig. 6 reveal significant differences in the total levelized annual cost and associated costs for CO2 capture, transport, and storage among various carbon capture and storage (CCS) technologies compared to the scenario without CCS implementation. In the scenario without CCS, the total levelized annual cost is the lowest at 531.6 M$/yr. However, with the integration of CCS technologies utilizing amine and ammonia, there are notable increases in total levelized annual costs. Specifically, the amine-based CCS technology incurs the highest total levelized annual cost of 588.6 M$/yr, followed closely by the ammonia-based CCS technology at 553.4 M$/yr.

This increase in costs is primarily attributed to the expenses associated with CO2 capture, transport, and storage. Interestingly, while the amine-based CCS technology has a higher total levelized annual cost, it requires lower expenses for CO2 capture, transport, and storage compared to the ammonia-based CCS technology. This discrepancy highlights the varying cost structures and operational requirements of different CCS technologies. Overall, the results underscore the importance of evaluating not only the net electrical output but also the total economic implications.

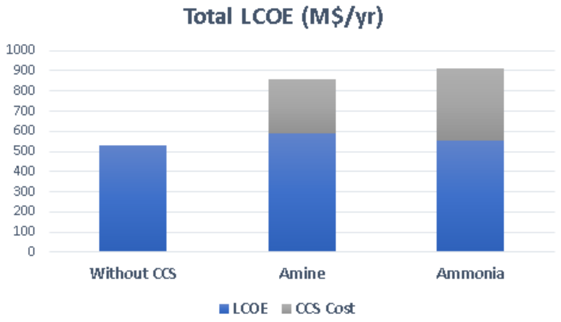


Fig. 6 Total LCOE.

The results in Fig. 7 illustrate substantial reductions in carbon dioxide (CO2) emissions with the implementation of carbon capture and storage (CCS) technologies compared to the scenario without CCS. In the scenario without CCS, CO2 emissions are highest, totaling 7.34E+04 metric megatonnes. However, with the integration of CCS technologies utilizing amine and ammonia, there are significant reductions in CO2 emissions. Specifically, the amine-based CCS technology achieves a notable decrease in CO2 emissions, with only 8554 metric tons emitted annually. Similarly, the ammonia-based CCS technology also demonstrates substantial CO2 emission reductions, with emissions totaling 8324 metric tons annually. These reductions underscore the effectiveness of CCS technologies in mitigating CO2 emissions from fossil fuel power plants. The results highlight the potential of CCS to contribute significantly to greenhouse gas reduction efforts, aligning with global climate goals and emphasizing the importance of integrating CCS into energy transition strategies for a sustainable future.

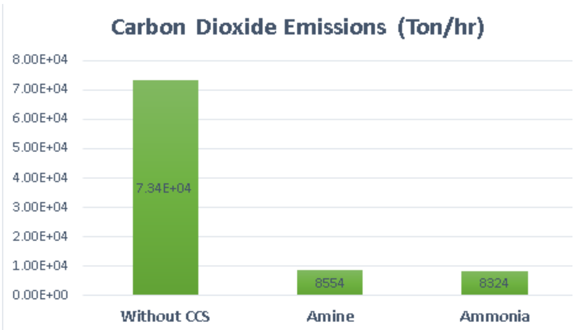


Fig. 7. CO2 emissions.

## DISCUSSION

The substantial reductions in carbon dioxide (CO2) emissions achieved through the implementation of carbon capture and storage (CCS) technologies, as evidenced by the significant differences in emissions between the scenarios with and without CCS, align with findings from previous research emphasizing the role of CCS in mitigating greenhouse gas emissions from fossil fuel power plants. The observed variations in net electrical output, total levelized annual cost, and associated CO2 capture expenses among different CCS technologies further highlight the importance of considering not only technical performance but also economic feasibility and operational requirements when evaluating CCS deployment options.

From the perspective of working hypotheses, the findings corroborate the hypothesis that CCS technologies can effectively reduce CO2 emissions from coal-fired power plants while also providing insights into the trade-offs involved, such as the impact on net electrical output and associated costs. These results underscore the complexity of CCS implementation and emphasize the need for comprehensive techno-economic assessments to inform decision-making processes.

In the broader context, the implications of the findings extend to global climate change mitigation efforts, emphasizing the potential of CCS to contribute significantly to reducing greenhouse gas emissions from the power generation sector. However, challenges such as high implementation costs and energy penalties underscore the importance of continued research and innovation to optimize CCS technologies and enhance their cost-effectiveness and efficiency.

Future research directions may focus on addressing key knowledge gaps and uncertainties surrounding CCS, including advancing capture technologies, optimizing CO2 transport and storage infrastructure, and exploring policy mechanisms and incentives to facilitate CCS deployment. Moreover, interdisciplinary collaboration and stakeholder engagement are essential for overcoming barriers and accelerating the transition to a low-carbon energy future.

## CONCLUSIONS

The results of this study underscore the significant potential of carbon capture and storage (CCS) technologies to mitigate carbon dioxide (CO2) emissions from fossil fuel power plants. The substantial reductions in CO2 emissions achieved through the implementation of CCS, as evidenced by the comparison with the scenario without CCS, highlight the effectiveness of these technologies in addressing climate change concerns. However, the observed variations in net electrical output, total levelized annual cost, and associated CO2 capture expenses among different CCS technologies emphasize the importance of conducting comprehensive techno-economic assessments to inform decision-making processes.

***Conflicts of Interest***
*The authors declare no conflict of interest.*

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