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Modeling and Simulation of a Natural Gas and Alternative Fuels Combined Cycle Power Plant with Amine-Based CO_2 capture in Peru

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Abstract – This study evaluates alternative scenarios for reducing carbon dioxide emissions from the Ventanilla thermoelectric power plant in Lima, Peru, using the process simulation software ProMax 6.0. The scenarios involve blending hydrogen (0% and 15%) with natural gas (NG) as fuel and implementing CO_2 capture systems using monoethanolamine (MEA), 2-amino-2-methyl-1-propanol (AMP), and amine blends such as MEA/piperazine (PZ), MEA/methyldiethanolamine (MDEA), and MDEA/PZ. The study aimed to achieve CO_2 capture with a purity equal or higher than 99.8% to evaluate its commercialization potential. Additionally, an economic analysis was conducted to assess the profitability of the process, considering carbon taxes from Argentina (\$3.33 per ton CO_2), Chile (\$5 per ton CO_2), and Peru (\$5, \$10, or \$20 per ton CO_2 depending on the total emissions). A sensitivity analysis was also performed, taking into account the maximum and minimum dollar exchange rates observed in Peru over the past five years (4.134 soles and 3.434 soles respectively). And, hydrogen costs were evaluated based on their production pathways, with prices considered for green (\$1.3 per kg H_2), blue (\$2.49 per kg H_2), and gray (\$1.1 per kg H_2). Among the alternative studied scenarios, the MDEA (40%) and PZ (10%) blend with 100% NG as fuel exhibited the best net profit margin of 43.91%, achieving 426.49 MW of net power generation and CO_2 emissions of 101.28 kgCO₂/GJ. Moreover, vent gas with 99.8% CO_2 purity was obtained.

Keywords– Modeling and Simulation, NG Combined Cycle (NGCC), Carbon Capture, Amines, ProMax

I. Introduction

Carbon dioxide emissions from the power industry represent 40% of the total emissions generated by all industries worldwide. In Peru, these emissions have increased by 337% since 1990 [1]. Although NG combined cycle power plants are more efficient than traditional fossil-fueled power plants, they still contribute to carbon dioxide emissions. In this context, previous studies have researched methods to reduce CO_2 emissions in NG combined cycle power plants, being the post-combustion capture with amine scrubbing one of the most studied due to its cost-effectiveness [2].

Ref. [3] determined 10% PZ and 40% MDEA blend as the most cost-effective option for carbon capture when compared to amine blends with MEA. Ref. [4] compared 15% MDEA/15% PZ and 25% MEA/5% PZ amine blends and found similar results, identifying the first one as the most efficient in CO_2 capture. Additionally, other studies highlighted 20% AMP/2-10% PZ blends as a promising alternative for post-combustion carbon capture [5]. Blends of NG and hydrogen as fuel are widely studied for combined cycle power plants, as the combustion of hydrogen with NG lowers significantly the CO_2 content in the flue gas, this while still relying on existing infrastructure for power generation [6].

This study is centered on identifying the optimal scenario for reducing carbon dioxide emissions for the Ventanilla thermoelectric power plant, located in Lima, Peru. Additionally, it aims to capture carbon dioxide with a purity higher than 97%, to assess its potential commercialization. Scenarios involve the use of different amine blends for post-combustion CO_2 capture from the flue gas and blending NG with hydrogen as fuel. The compositions of the amine blends are obtained from [7, 8, 9], while the NG and hydrogen blend compositions are derived from [4]. The process simulations were conducted using ProMax 6.0, and the cost-effectiveness of each scenario is evaluated through a profit margin analysis. Additionally, the environmental impact of each scenario is assessed to determine its feasibility for large-scale implementation, considering both operational and economic factors.

II. Methodology

A. *ProMax 6.0*

ProMax 6.0 is a simulation software developed by Bryan Research & Engineering (BR&E), which is a useful tool for modeling chemical processes, and since its latest update has improvements for natural gas, refinery and CO_2 capture applications [10].

B. *General Simulation Details*

The simulation of the complete process consists of two parts: Combined Cycle and CO_2 Capture Process. In the first part, information from [11] was used to model the Ventanilla Thermoelectric Power Plant and its corresponding streams, with the composition of dry NG from Camisea used as fuel, whose composition is described in Table 1.

TABLE I
Composition of dry NG from Camisea in the combined cycle

Compound	% molar
Methane (CH_4)	88.05
Ethane(C_2H_6)	10.44
Nitrogen (N_2)	1.07
Carbon Dioxide (CO_2)	0.25
Propane (C_3H_8)	0.17
Butane (C_4H_{20})	0.02

Adapted from [11]

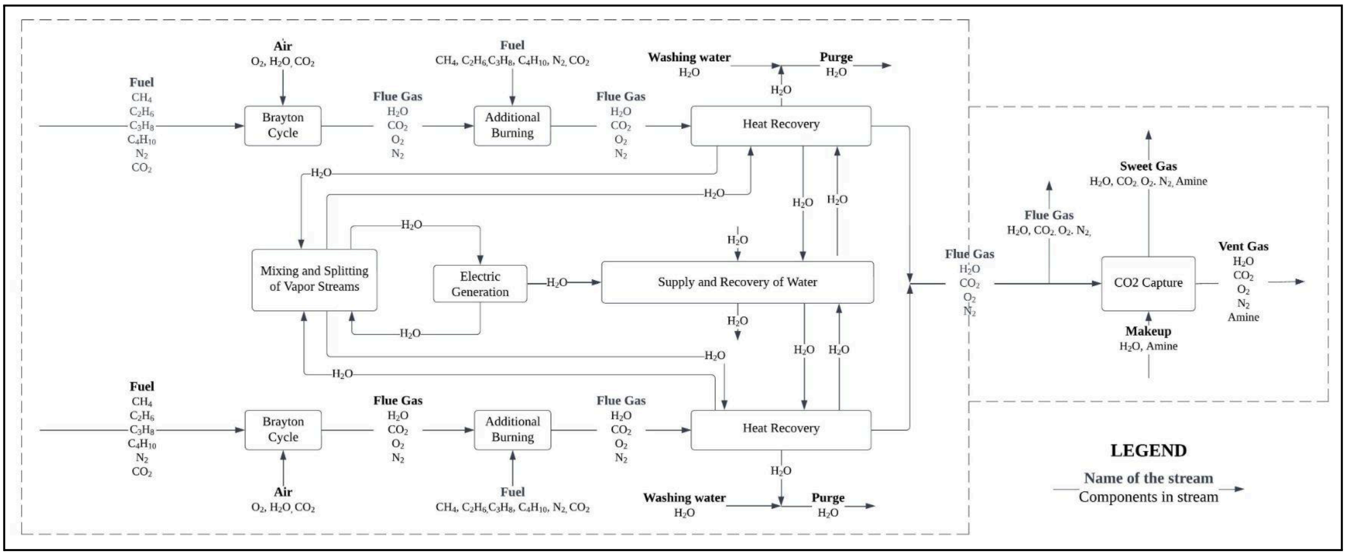

Fig. 1 Flow Diagram of the complete process.

The second part of the process corresponds to CO_2 capture using amines, with a model inspired by the one presented in [12], but modified to operate properly under the conditions of the flue gas from the Combined Cycle, also the aqueous amine flows are determined using the scenarios Tool available in ProMax 6.0.

Fig. 1 shows the flow diagram of the complete process to be modeled in ProMax 6.0.

C. Thermodynamic Models

Due to the differences in the components used in each part of the simulation, two thermodynamic models were selected in alignment with the literature presented by [13]. The Combined Cycle employs the "Peng Robinson - Polar" model, as it is well-suited for systems with a predominance of water and steam. For CO_2 capture with amines, the "Amine Sweetening - Peng Robinson" model was chosen in accordance with previous studies that simulate amine sweetening processes using ProMax, ensuring alignment with established methodologies and accurate representation of the gas-liquid equilibrium in amine systems [14].

D. Combined Cycle

NG and air are initially introduced into a burner, generating combustion gases that are directed to a gas turbine to generate power. The residual oxygen in the combustion gases is utilized in a secondary burner. Then, flue gas is routed to a series of heat exchangers, where its high temperature is used to evaporate water in the Rankine cycle. This process is carried out in duplicate and in parallel, as shown in Fig. 1. The Rankine cycle consists of three turbines operating at high, medium, and low pressure. Finally, a part of the lower-temperature flue gas is directed to the capture process, while the remainder is released into the atmosphere [11].

Additionally, scenarios are evaluated in which the fuel is a mixture of NG and hydrogen, aiming to reduce CO_2 emissions. The hydrogen percentages used in these scenarios are derived from [4] and are detailed in Table 2. Also, the percentages employed do not exceed the embrittlement limit [15]. For all scenarios, the system operates with a fixed inlet volumetric flow rate of 1532.94 m^3/h, ensuring consistency in the comparison.

TABLE 2
COMPOSITION OF FUEL FOR COMBINED CYCLE

Scenario	Hydrogen (% mass)	NG (% mass)
1.1	0	100
1.2	15	85

Adapted from [4]

E. CO_2 capture with amines

The CO_2 capture process begins with the conditioning of 17.52% mass of the combined cycle flue gas to the pressure and temperature required for the operation of the selected amines. This is achieved using a compressor and a heat exchanger, after which the gas enters the absorber. In this equipment, the flue gas is brought into contact with a lean amine stream, which selectively captures CO_2, producing a flue gas stream with reduced CO_2 content that is released into the atmosphere.

The CO_2-rich amine stream extracted from the bottom of the absorber is sent to a flash separator, where the light gaseous fraction, mainly composed of nitrogen, oxygen, and other non-condensable gases is released to the atmosphere. The remaining liquid phase, with low pressure, then passes through a heat exchanger, where it is preheated before entering the stripper. In the stripper, through the addition of heat provided by the reboiler, the CO_2 is desorbed from the amine solution. The desorber top stream is then partially condensed, drawing a vent gas stream rich in CO_2 and a condensate stream that is recycled for reuse in the system.

The regenerated amine solution, now with a low CO_2 content, is cooled through a heat exchanger, pumped and cooled again with an additional cooler before being recirculated back to the absorber. Additionally, a makeup flow is maintained to compensate for losses and ensure process efficiency.

Fig. 2 shows the block diagram of the CO_2 capture process.

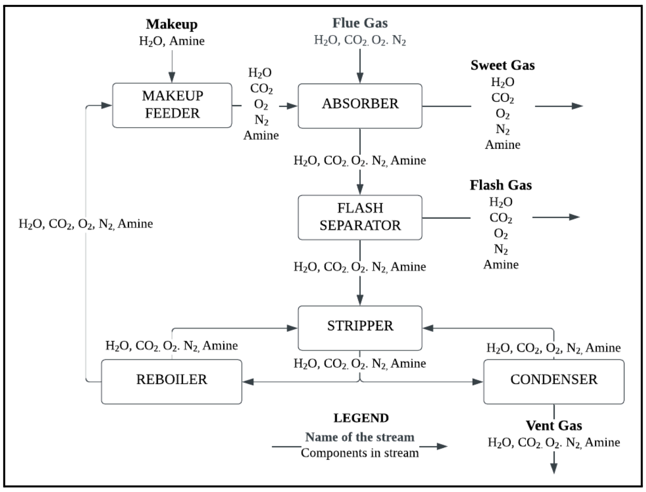

Fig. 2 Block Diagram of the CO_2 capture process.

In this case, scenarios employing different amines for CO_2 capture are evaluated, with their compositions obtained from [7, 9], as shown in Table 3. The parameters of interest for this analysis include CO_2 emissions per gigajoule of electricity produced, net power output, capture percentage, and CO_2 purity in the vent gas stream. The ProMax' scenarios tool is used with the objective of determining the lowest amine flow that results in the highest possible CO_2 capture.

TABLE 3
AMINES FOR CO_2 CAPTURE

Scenario	Amines (% mass)
2.1	MEA (30%)
2.2	MEA (25%) and PZ (10%)
2.3	MEA (22.5%) and MDEA (15%)
2.4	AMP (30%)
2.5	MDEA (40%) and PZ (10%)

Adapted from [7, 9].

E. Operational Profitability Analysis

The operational profitability of the base scenario, without CO_2 reduction alternatives, will be compared to various scenarios involving the use of hydrogen with NG as fuel and the implementation of CO_2 capture. The methodology for this type of analysis is derived from the approach outlined in [16].

For this analysis, the net utility and net sales are calculated, and the net profit margin is determined using Equation 1 as a percentage. Monetary values will be expressed in U.S. dollars, considering an exchange rate of 3.735 soles per US dollar [17].

$$\text{Net Profit Margin} = \frac{Net\ Utility}{Net\ Sales} \times 100\% \quad (1)$$

Net profit is calculated as the difference between sales revenue and total operating costs. These costs include both direct and indirect costs; however, this analysis focuses on the direct costs related to production, which are detailed in Table 4.

TABLE 4
DIRECT COSTS

Direct Costs	Considerations
Raw Material	Market prices will be used
Services	Market prices will be used
Labor	10% of Total Cost
Supervision	15% of Total Cost
Maintenance	0.00212 USD/kWh [18]
Operational Supplies	15% of Maintenance
Laboratory Charges	10% of Labor
Patents and Royalties	2% of Total Cost

The maintenance cost when using hydrogen and natural gas blend is obtained from [19], considering a maintenance factor of +0.375%. For scenarios involving CO_2 capture with amines, an additional maintenance cost is included based on the annual amount of CO_2 captured, considering a rate of 0.00331 USD per ton of CO_2 captured [20].

Currently, there is no carbon tax in Peru; however, plans for its implementation are underway [21]. Therefore, the carbon taxes from Argentina ($3.33 per ton CO_2), Chile ($5 per ton CO_2), and the one proposed by [11] for Peru ($5, $10, or $20 per ton CO_2 depending on the total emissions) are considered. Also, sales revenue includes the sale of captured CO_2, considering a selling price of 0.416 dollars per kilogram of CO_2 [22].

The market prices of the raw material used in the process are detailed in Table 5, with the conversion from soles to dollars already applied.

TABLE 5
COSTS OF RAW MATERIALS AND UTILITIES

Raw Material	Cost
Natural Gas	3.9139 USD/MMBTU [23].
Shaft Water	0.328 USD/m^3 [24, 25].
MEA	1.19 USD/kg [26].
MDEA	0.5 USD/kg [27].
PZ	0.101 USD/kg [28].
AMP	8 USD/kg [29].
Electricity	0.161 USD/kWh [30].
Steam at 50 psig	3 USD/1000 lb [2].
Process Air	0.03 USD/1000 ft^3 [31].
Demineralized Water	2.78 USD/1000 gal [32].
Hydrogen	1.3 USD/kg [33].

After identifying the scenario with the highest net profit margin, a sensitivity analysis will be carried out for both the hydrogen and non hydrogen version, in order to provide a more comprehensive economic evaluation. It considers the impact of the maximum (4.134 soles) and minimum (3.343 soles) exchange rates registered in Peru over the last five years [17], and the use of green ($1.3 per kg H2), blue ($2.49 per kg H2) and gray ($1.1 per kg H2) hydrogen [33, 34].

III. RESULTS

A. Combined Cycle

Fig. 3 illustrates the combined cycle in its base scenario (without hydrogen), modeled and simulated in ProMax 6.0.

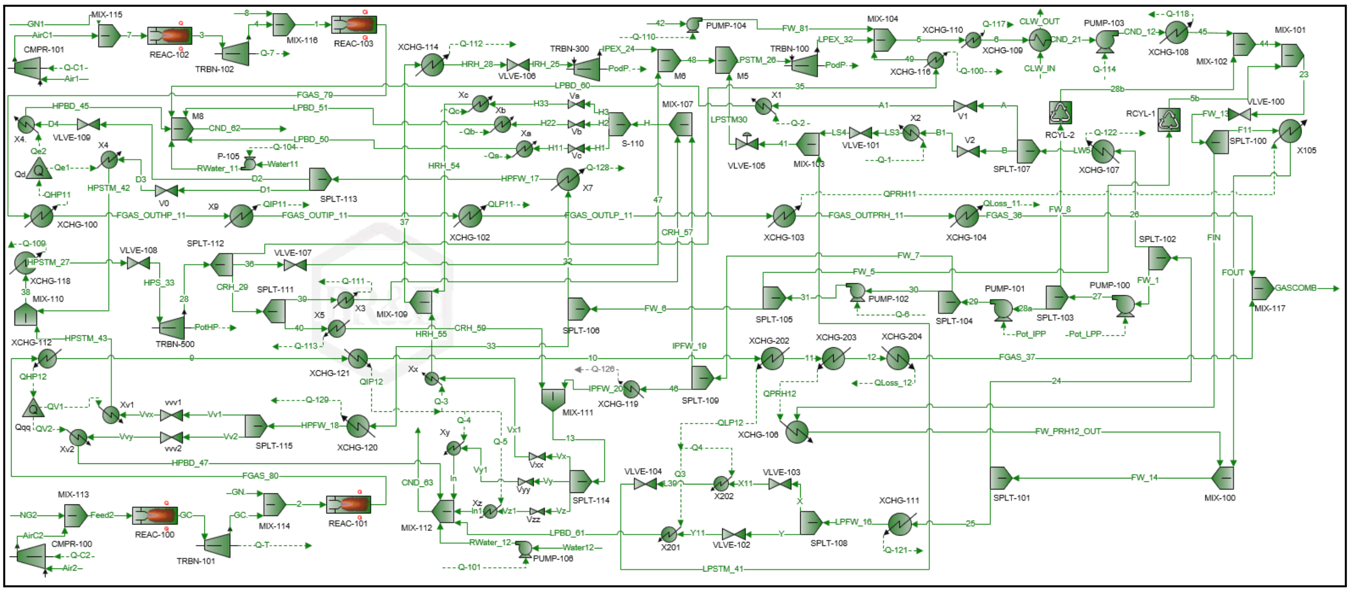

Fig. 3 Combined cycle simulation on ProMax 6.0.

The design is equivalent to that presented in Fig. 1, with the key difference that flowsheet connectors have been added on the right side to direct the specified percentages of flue gas to each CO_2 capture scenario. Table 6 below presents each one of the flows used in each scenario.

TABLE 6
FLOW OF RAW MATERIALS

Scenario	1.1	1.2
Process Air (ft^3/yr)	8.44×10^{11}	4.25×10^{11}
Hydrogen (kg/yr)	0.0	3.84×10^{7}
NG (MMBTU/yr)	1.61×10^{3}	5.58×10^{8}
Shaft Water (m^3/yr)	1.67×10^{8}	1.67×10^{8}
Demineralized Water (gal/yr)	9.70×10^{8}	9.70×10^{8}

Table 7 presents the key parameters to be analyzed, which are essential for evaluating the performance of the thermoelectric power plant and assessing the effectiveness of emission reduction strategies.

TABLE 7
RESULTS FOR DIFFERENT SCENARIOS IN COMBINED CYCLE

Scenario	Net Power (MW)	Emissions (kg CO_2/GJ)
1.1	487.10	107.54
1.2	336.20	86.96

B. *CO_2 capture scenarios*

Fig. 4 illustrates the CO_2 capture system, modeled and simulated in ProMax 6.0, which is consistently applied across all evaluated scenarios. This system allows for the separation of CO_2 from flue gas using different amine-based solvents.

To analyze the effectiveness of each capture scenario, Table 8 presents the amine flows utilized in different cases. These values are essential for assessing the required solvent quantities and their impact on operational profitability analysis.

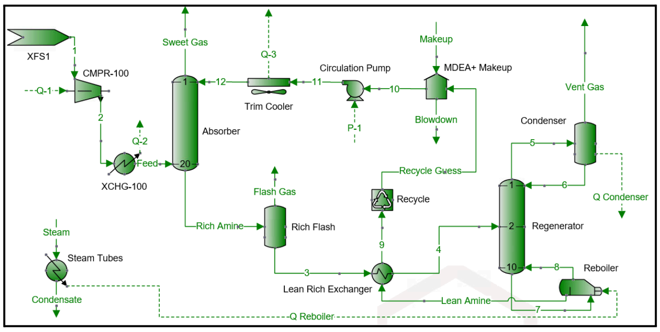

Fig. 4 CO_2 capture simulation on ProMax 6.0.

TABLE 8
RESULTS FOR DIFFERENT SCENARIOS WITH CO_2 CAPTURE

Scenario	MEA (kg/yr)	MDEA (kg/yr)	PZ (kg/yr)	AMP (kg/yr)
2.1	7.57×10^{7}	0.00	0.00	0.00
2.2	6.25×10^{7}	0.00	2.52×10^{7}	0.00
2.3	6.23×10^{7}	4.08×10^{7}	0.00	0.00
2.4	0.00	0.00	0.00	7.09×10^{7}
2.5	0.00	1.47×10^{8}	3.72×10^{7}	0.00

A more detailed analysis of the system's overall performance, including net power, CO_2 emission rates and purity percentage, is presented in Table 9 and Table 10. This table integrates the different evaluated scenarios to provide a comprehensive overview of their implications.

TABLE 9
RESULTS OF SCENARIOS WITH 0% HYDROGEN

Combined Cycle Scenario	1.1				
CO_2 Capture Scenario	2.1	2.2	2.3	2.4	2.5
Net Power (MW)	426.5	426.5	426.5	426.6	426.5
Emissions (kg CO_2/GJ)	101.9	101.8	101.9	106.9	101.3
CO_2 purity (%)	99.8	99.8	99.8	99.8	99.8

TABLE 10
RESULTS OF SCENARIOS WITH 15% HYDROGEN

Combined Cycle Scenario	1.2				
CO_2 Capture Scenario	2.1	2.2	2.3	2.4	2.5
Net Power (MW)	289.5	289.5	289.5	289.5	289.5
Emissions (kg CO_2/GJ)	84.1	84.4	76.8	79.8	83.3
CO_2 purity (%)	99.8	99.8	99.8	99.8	99.8

E. Operational Profitability Analysis

Table 11 illustrates the net profitability margin for every scenario evaluated without hydrogen, employing the same methodology as the one used for the base scenario.

TABLE 11
NET PROFIT MARGIN OF ALL SCENARIOS WITHOUT HYDROGEN

Combined Cycle Scenario	1.1				
CO_2 Capture Scenario	2.1	2.2	2.3	2.4	2.5
Net Profit Margin no carbon taxes (%)	44.62	48.99	43.73	-107.37	51.76
Net Profit Margin for \$3.33 per ton CO_2 (%)	43.30	47.67	42.40	-108.85	50.45
Net Profit Margin for \$5 per ton CO_2 (%)	42.64	47.01	41.74	-109.59	49.80
Net Profit Margin for \$20 per ton CO_2 (%)	36.68	41.07	35.78	-116.23	43.91

Table 12 illustrates the net profitability margin for every scenario evaluated with 15% hydrogen, employing the same methodology as in Table 11.

TABLE 12
NET PROFIT MARGIN OF ALL SCENARIOS WITH 15% HYDROGEN

Combined Cycle Scenario	1.2				
CO_2 Capture Scenario	2.1	2.2	2.3	2.4	2.5
Net Profit Margin no carbon taxes (%)	-5.93	-4.68	1.97	-217.53	10.01
Net Profit Margin for \$3.33 per ton CO_2 (%)	-7.07	-5.83	1.00	-218.57	8.88
Net Profit Margin for \$5 per ton CO_2 (%)	-7.65	-6.41	0.52	-219.09	8.32
Net Profit Margin for \$20 per ton CO_2 (%)	-12.81	-11.61	-3.80	-223.74	3.26

Table 13 and 14 shows the net profit margin for the minimum and maximum exchange rate values. The first one is calculated for the most profitable scenario, 2.5 (MDEA/PZ) without hydrogen (1.1), and for each of the proposed carbon taxes. The second one considers the three hydrogen types by production method and both the minimum and maximum exchange rates.

TABLE 13
NET PROFIT MARGIN OF SCENARIO 2.5 WITH 0% HYDROGEN

Combined Cycle Scenario		1.1
CO2 Capture Scenario		2.5
Net Profit Margin no carbon taxes (%)	Dollar for 4.134 soles	49.64%
	Dollar for 3.434 soles	53.43%
Net Profit Margin for \$3.33 per ton CO2 (%)	Dollar for 4.134 soles	48.23%
	Dollar for 3.434 soles	52.20%
Net Profit Margin for \$5 per ton CO2 (%)	Dollar for 4.134 soles	47.53%
	Dollar for 3.434 soles	51.59%
Net Profit Margin for \$20 per ton CO2 (%)	Dollar for 4.134 soles	41.18%
	Dollar for 3.434 soles	46.07%

TABLE 14
NET PROFIT MARGIN OF SCENARIOS 2.5 WITH 15% HYDROGEN

Combined Cycle Scenario			1.2
CO2 Capture Scenario			2.5
Net Profit Margin no carbon taxes (%)	Green H2 for 1.3 USD/kg	Dollar for 4.134 soles	5.18%
		Dollar for 3.434 soles	13.80%
	Blue H2 for 2.49 USD/kg	Dollar for 4.134 soles	-17.07%
		Dollar for 3.434 soles	-5.42%
	Gray H2 for 1.1 USD/kg	Dollar for 4.134 soles	8.91%
		Dollar for 3.434 soles	17.03%
Net Profit Margin for \$3.33 per ton CO2 (%)	Green H2 for 1.3 USD/kg	Dollar for 4.134 soles	3.96%
		Dollar for 3.434 soles	12.75%
	Blue H2 for 2.49 USD/kg	Dollar for 4.134 soles	-18.28%
		Dollar for 3.434 soles	-6.47%
	Gray H2 for 1.1 USD/kg	Dollar for 4.134 soles	7.70%
		Dollar for 3.434 soles	15.98%
Net Profit Margin for \$5 per ton CO2 (%)	Green H2 for 1.3 USD/kg	Dollar for 4.134 soles	3.35%
		Dollar for 3.434 soles	12.22%
	Blue H2 for 2.49 USD/kg	Dollar for 4.134 soles	-18.89%
		Dollar for 3.434 soles	-7.00%
	Gray H2 for 1.1 USD/kg	Dollar for 4.134 soles	7.09%
		Dollar for 3.434 soles	15.45%
Net Profit Margin for \$20 per ton CO2 (%)	Green H2 for 1.3 USD/kg	Dollar for 4.134 soles	-2.13%
		Dollar for 3.434 soles	7.49%
	Blue H2 for 2.49 USD/kg	Dollar for 4.134 soles	-24.37%
		Dollar for 3.434 soles	-11.73%
	Gray H2 for 1.1 USD/kg	Dollar for 4.134 soles	1.61%
		Dollar for 3.434 soles	10.72%

III. DISCUSSION

A reduction in net power from the baseline scenario is observed when using a fuel blend of 15% hydrogen and 85%

natural gas, decreasing from 487.1 MW to 336.2 MW. This reduction highlights the trade-off between lower carbon emissions and power output. Likewise, CO_2 emissions per GJ of energy produced decrease significantly, from 107.54 kg CO_2/GJ in scenario 1.1 to 86.96 kg CO_2/GJ in scenario 1.2, demonstrating the potential of hydrogen blending to mitigate emissions. However, this comes at the cost of reduced efficiency, which must be carefully considered when evaluating the feasibility of hydrogen integration.

For the base scenario with carbon capture, the net power remains constant at 425.5 MW across all CO_2 capture scenarios (2.1 to 2.5), indicating that the implementation of carbon capture technology reduces the net power output by the same magnitude compared to the baseline. CO_2 emissions show slight variations, ranging between 101.8 and 106.9 kg CO_2/GJ, with scenario 2.4 exhibiting the highest emissions (106.9 kg CO_2/GJ) and scenario 2.2 the lowest (101.8 kg CO_2/GJ). These differences can be attributed to variations in capture efficiency and process conditions. Additionally, the captured CO_2 purity remains consistently high at 99.8% in all cases, ensuring its compliance with market requirements for potential commercialization. This high purity level is crucial for industries looking to utilize captured CO_2 in enhanced oil recovery, chemical synthesis, or other applications.

In the case of natural gas blending with hydrogen, the net power follows the same trend as the baseline scenario, decreasing to 289.5 MW and remaining constant across the different amines used. The scenario with the highest emissions was 2.2 (84.4 kg CO_2/GJ), while the lowest-emission scenario was 2.3 (76.8 kg CO_2/GJ). Additionally, the purity of the recovered CO_2 stream meets market distribution requirements, reaching 99.8%. This indicates that in the presence of hydrogen, MDEA/PZ is not the optimal amine combination; instead, MDEA/MEA proves to be the better choice. Therefore, from an environmental perspective, it represents the most suitable option.

For the baseline scenario without hydrogen blending (1.1), the net profitability without carbon taxes is positive for all capture scenarios except for scenario 2.4, where a significant loss of -107.37% is observed. This behavior indicates that while CO_2 capture can be profitable in some cases, the selection of the solvent and operating conditions play a key role in economic feasibility. In the case of scenario 2.5, the highest profitability is observed (51.76%), suggesting that this capture approach could be the most suitable from an economic perspective within this group.

In contrast, when hydrogen is blended with natural gas (1.2), overall profitability decreases significantly. Without CO_2 capture, profitability values are negative for most cases, suggesting that the reduction in system efficiency significantly impacts the economic viability of the process. Scenario 2.4 shows the largest loss at -217.53%, reinforcing the trend observed in scenario 1.1 regarding the lack of viability of this configuration.

When carbon taxes are introduced, it is observed that as the cost per ton of emitted CO_2 increases, the profitability of scenarios without capture decreases, while capture scenarios tend to be less affected. With a tax of $3.33 per ton of CO_2, capture scenarios maintain positive profitability margins in most cases, although the reduction is noticeable. With a tax of $5 per ton of CO_2, capture scenarios continue to show better profitability margins compared to those without capture, reinforcing the importance of implementing emission mitigation strategies to avoid economic penalties.

CO_2 emissions exceeded 500000 tons in all evaluated scenarios; therefore, a maximum carbon tax of 20 USD per ton of CO_2 emitted is considered. For this case, losses become more pronounced in scenarios without capture; whereas capture scenarios, though affected, manage to maintain certain positive values—especially scenario 2.5 in case 1.1 and scenario 2.5 in case 1.2. This suggests that some capture configurations can become economically more attractive under high-tax schemes.

The use of hydrogen (scenario 1.2) introduces a profitability penalty compared to the exclusive use of natural gas (scenario 1.1). In all capture scenarios, profitability values in case 1.2 are lower, with some configurations even showing losses. This suggests that while hydrogen blending contributes to emission reduction, the loss of system efficiency negatively impacts profitability, making it less economically viable without additional incentives or improvements in process efficiency.

Additional insight was gained through a sensitivity analysis applied to the most profitable capture scenario in both configurations: with and without hydrogen blending. For scenario 2.5 without hydrogen (1.1), the net profit margin remained positive in all cases, with a notable increase when the dollar value decreased. In contrast, for the hydrogen-based configuration (1.2), profitability was strongly influenced by the type of hydrogen and exchange rate. While green and gray hydrogen allowed for positive margins under favorable conditions, blue hydrogen resulted in significant losses in all cases due to its high production cost. This cost is influenced by technological advancements, which are expected to lower costs over time, and the price of natural gas, which has shown an upward trend.

IV. Conclusions

This study evaluated different strategies to reduce CO_2 emissions from the Ventanilla thermoelectric power plant, focusing on fuel blending with hydrogen and CO_2 capture using various amine-based solvents. The analysis considered both environmental impact and economic viability to determine the most effective approach.

The implementation of CO_2 capture using amines proved to be an effective emission reduction strategy. Among the studied blends, the mixture of MDEA (40%) and PZ (10%) exhibited the best overall performance, achieving the highest net profit margin and the lowest CO_2 emissions per GJ of energy produced. The purity of the captured CO_2 also remained consistently high (99.8%), ensuring its suitability for commercialization.

Replacing 15% of natural gas with hydrogen led to a reduction in CO_2 emissions. However, the associated decrease in net power generation must be carefully considered when evaluating the feasibility of this approach. In these scenarios, the highest net profit margin obtained was 8.88%, corresponding to the MDEA (40%) and PZ (10%) amine blend. Despite its environmental benefits, hydrogen blending introduced economic challenges due to efficiency losses.

The economic analysis revealed that the MDEA (40%) and PZ (10%) blend provided the highest profitability for hydrogen and non hydrogen based scenarios, when incorporating carbon taxes from Argentina, Chile, and a proposed tax for Peru. This highlights the importance of considering regional tax policies when selecting carbon reduction strategies, as taxation can significantly influence the economic feasibility of CO_2 capture technologies.

The sensitivity analysis showed the high dependence between the dollar exchange rate in Peru and the type of hydrogen employed. The net profitability increased when the exchange rate was lower, reaching a maximum of 53.43% for the minimum exchange rate and employing gray hydrogen.

Finally, while both hydrogen blending and CO_2 capture contribute to emission reduction, they also result in efficiency losses that impact profitability. Therefore, establishing an optimal balance between environmental benefits and economic viability is crucial for the successful implementation of these strategies in the power generation sector.

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