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RISK ANALYSIS THROUGH DECARBONIZATION OF ENERGY SYSTEMS TOWARDS NET ZERO EMISSIONS (NZE) IN DONGGI MATINDOK GAS FIELD

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ABSTRACT

Global warming that has an impact on climate change is mostly influenced by an increase in carbon dioxide (CO2) gas in the air. Decarbonization programs in building green industrial ecosystems play an important role in achieving Net Zero Emissions (NZE) by 2060. The Objective of the study is to investigate risk control in the Decarbonization program consisting of Carbon Reduction and Carbon Capture Utilization and Storage (CCUS). The focus of the study area in this research is the Donggi Matindok gas field in Central Sulawesi. The research method is to conduct a risk analysis of the decarbonization program implemented so that it can mitigate the risk of operation failure and safety. The results of the evaluation obtained that the carbon reduction program that has been carried out consists of gas processing innovations, energy efficiency, flaring reduction has a low risk with a reduction of 22% per year from the total CO2 produced. The application of the energy management system or ISO 50001 supports in maintaining energy performance so that energy efficiency can be achieved so that the carbon reduction program can be developed every period. Then for the implementation of the CCUS program has a medium to high risk with significant CO2 reduction potential, which later in this research will review the risk mitigation that needs to be prepared for project completion. CCUS programs that will be carried out are CCU Microalgae and CCS well Injection programs. Well targeted risk mitigation can help ensure that government efforts to support decarbonization programs are effective and successful in the long term.

KEYWORDS *Decarbonization, Global warming, Carbon Reduction*

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INTRODUCTION

Although the climate has been changing for millennia, since the industrial revolution in the 19th century these changes have increased exponentially. It is widely accepted, although some skepticism also exists, that these changes are largely anthropocentric, due to our ever-increasing consumption and dependence on fossil energy sources.

The problem that occurs from the impact of emissions to the environment is that climate change has a direct impact with an increase in global temperature, or global warming. The main cause of global warming is the increase in the concentration of greenhouse gases (GHGs) in the atmosphere, such as methane (CH4), nitrous oxide (N2O), and carbon dioxide (CO2). In particular, the increased concentration levels (from 280 ppm in 1850 to 350ppm in 2005) of CO2 are blamed for the increased greenhouse effect (Bachu, 2008: 255). One of the main goals in countering the effects of climate change in the long term is for Indonesia to strive for Net Zero Emission by stabilizing the level of CO2 in the atmosphere at 550ppm, to limit long-term warming to 2-3 degrees Celsius (Stern, 2007: 16), and avoid destructive disasters that could have environmental consequences.

Although many alternative energy sources are currently being developed to reduce dependence on fossil fuels, the fact remains that "the need for economic growth makes it impossible for the world to rely on available fossil fuels" (Lackner, 2010; in Hester and Har-rison, 2009: 8). Fossil fuels, which currently provide 85% of the world's energy needs, will continue to be the world's primary source of energy supply well into the 21st century. So, as Gibbins and Chalmers point out, it is necessary to develop and implement technologies that enable the continued use of fossil fuels, while at the same time leading to a significant reduction in CO2 emissions into the atmosphere (in Hester and Harrison, 2009: 8). 2009: 42).

Pertamina EP Donggi Matindok Field is committed to continue operating by reducing the amount of Carbon towards NZE. In 2023, PEP Donggi Matindok Field implemented several carbon emission reduction initiative programs. Among others:

1. Improve the efficiency of using Own Used Fuel Gas with the LOTION (Load Priority Selection) Method in the power generation system. which uses calculations and is scientifically based on a combination of AHP (analytical hierarchy process), Pairwise Comparisons Methods and Scoring Methods, which succeeds in reducing emissions by 33,830 tons of CO2eq per year.

2. Optimization of the use of own used fuel gas in the Hot Oil Fire Heater at CPP Matindok with the AFR motto so that it can reduce the use of own used which is equivalent to a reduction in exhaust emissions of 10,516 tonsCO2eq per year, and the same optimization is underway for CPP Donggi with the same potential reduction.

3. Utilization of flaring gas from LP acid Flare to become additional own used fuel gas or equivalent to reducing flare flue gas emissions by 8,558 tons-CO2eq per year.

4. Implementation of the Carbon Utilization Unit (CCU) pilot project by utilizing Co2 exhaust emissions into green biomass (Algae) using environmentally friendly technology with the potential to reduce TOX exhaust emissions by 96 TonCO2 per year on a pilot scale this year.

The problem formulated in this paper covers several important aspects related to decarbonization at Pertamina. First, how regulatory, technical, and environmental factors affect the success of decarbonization, as well as the absence of an appropriate risk management system that can create a safe working climate and improve operational stability. Second, the identification of technical factors that affect the success of decarbonization. Third, the need to assess the safety process for successful decarbonization. Fourth, evaluate how much this project helps achieve Net Zero Emission (NZE) in the midst of high oil and gas production targets by the government. This study aims to analyze the factors affecting the success of decarbonization, examine relevant technical factors, conduct an assessment of the safe-ty process and risk analysis, and evaluate the project's contribution to achieving NZE. The benefits of this research are to find correlations between the potential and barriers to decarbonization in Indonesia, particularly in Donggi Matindok Field, and to provide a clearer implementation plan. The research is limited to the Donggi Matindok Gas Field area in Central Sulawesi, using environmental document measurement data and decarbonization research results, and involving related projects such as Carbon Reduction, CCS Well Injection, and CCU Micro Algae. The research was conducted from 2023-2024 and focused on risk mitigation of the decarbonization program.

Some of the previous studies related to decarbonization in this thesis cover various aspects and methodologies. Md Ainul Kabir et al. (2023) highlighted CCUS supply chain risks from different sectors through Prisma analysis, emphasizing the importance of risk management strategies to prevent negative environmental impacts. Fang Wanga et al. (2022) quantitatively evaluated the safety risks of CCUS systems, showing the potential risks of each module and the importance of process safety management. Yuta Fajar Muhammad identified financial, management, and political factors as dominant risks in energy efficiency projects using Fault Tree Analysis. Satish Chandra Pandey (2022) emphasized the important role of government through policy in the adaptation of CCUS technology in India based on a literature review. Fiqya Fairuz Zaemi and Rian Cahya Rohmana (2021) identified challenges in the development of CCUS in Indonesia, such as regulation, cost, infrastructure, and environment. Andre-as Schaarup Sørensen (2021) explored CCUS business models in Denmark through a literature review, interviews, and questionnaires. Hasan Muslemani (2020) examined innovative business models for CCUS technology in the steel sector through qualitative methods. Behdeen Oraee-Mirzamani (2013) used a tree diagram to assess the risk of CO2 storage. Jaleh Samadi (2012) developed a systemic risk management approach for CCUS projects from construction to completed operations, addressing technical and political lock-in.

The provisional hypothesis of this research is as follows: 1. The results of risk analysis of CCUS implementation towards the goal of NZE or Net Zero Emission at Donggi Matindok Field using the FMEA method obtained a clear correlation between government regulations and the investment climate for the project to be carried out. 2. The results of the risk analysis carried out include pure risk analysis, speculative as well as safety process risks that will be faced during the implementation process have a controlling impact in the form of a clearer CCUS program so that the oil and gas production target in 2030 determined by the government can be realized. 3. There is an overview of the appropriate risk management system for the implementation of CCUS to ensure operational stability at Pertamina.

RESEARCH METHOD

The method in this research is used to answer the formulation of research problems and achieve research objectives, with detailed, brief, and clear stages. This research methodology is the foundation for the research to run systematically, structured, and directed. The researcher explained the research process carried out, starting with field studies to collect actual data related to the existing conditions of the project organization, including target data, project results, operation processes, as well as the results of questionnaires and interviews. The research object includes management projects such as Carbon Reduction and CCUS (Carbon Capture Utilization Storage). Data were collected in Donggi Matindok field, Central Sulawesi, through primary data from interviews and questionnaires, as well as secondary data from literature of other management projects in upstream oil and gas activities. The research instrument considered basic risks such as financial, policy, environmental, technical/operational, knowledge, safety and reputation. Assessment of HSSE risk management at all levels of company management emphasizes leadership, engagement, commitment and culture to develop and improve the effectiveness of risk management processes. A risk assessment scale based on Pertamina's corporate guidelines is used in this analysis, including probability/likelihood and hazard effect (severity) matrices.

RESULT AND DISCUSSION

The application of the methodology to two case studies is described and discussed in four sections. The case studies were selected based on the success rate of the projects. In the first section, the context of each case study described is introduced. The main risks and challenges associated with each project are also reviewed and then the risk control structure of each project is presented. The aim is to learn how (potential) losses can be avoided by ensuring risk limits are in place. The second part is devoted to the comparison of the projects in terms of context. The risks associated with the case studies are reviewed and compared in the third section.

4.1 Case Study

The purpose of this section is to analyze the context and risk control structure of different projects namely CCS Project (CO2 Injection) and CCU Project (Algae Plantation) in Donggi Matindok Field, PT Pertamina EP. The discussion is conducted to find rules and elements that lead to the advancement of the CCUS project to support NZE and commercial scale.

Based on its operational area, Pertamina Upstream Subholding is divided into 5 Regions, one of which is Regional 4 managed by PT Pertamina EP Cepu. PT Pertamina EP Cepu is engaged in the exploration and production of oil and gas in Eastern Indonesia covering Zone 11, Zone 12, Zone 13, and Zone 14. Donggi Matindok Field is one of the working areas included in Zone 13. Donggi Matindok Field

(DMF) is a gas field located in Central Sulawesi Province and has two CPPs (Central Processing Plant), namely Donggi CPP located in West Toili District and Matindok CPP in Batui District, Banggai Regency.

Figure 1 Journey to Donggi Matindok Field in Central Sulawesi

This gas field has an operating area of 15,111 km2 and PT Pertamina EP is the operator. In 2023, the average production of Donggi Matindok Field gas is 95.0025 MMscfd and condensate is 805.770 bcpd. While the average gas sales is 85.00 MMscfd. The produced gas will be delivered through a trunk line to consumers including Donggi - Senoro Liquid Natural Gas (DSLNG) according to the nominations that have been mutually agreed upon. Pertamina EP Donggi Matindok Field forms a good synergy for the process of gas exploitation and sales in Central Sulawesi.

4.1.1 Carbon Reduction Program

Carbon reduction activities carried out in the field include:

- Reducing non-routine flaring through reliability improvements: Reliability improvement has been identified to reduce non-routine combustion, which accounts for 70% of overall combustion emissions due to low reliability. To address this issue, one operator focused on improving the quality of its operations through measures such as predictive maintenance and equipment upgrades, which not only decreased pollution but also increased production. Best-in-class operators use area-based and multi-skilled maintenance to improve reliability, while predictive analytics can help reduce equipment outages such as those involving compressors.
- Upgrade additional gas processing and infrastructure

Upgrading additional gas processing and infrastructure can help reduce routine over-burning due to limited infrastructure capacity. To address this challenge, there is a need for additional gas processing facilities, as well as gathering and transportation infrastructure. GTG load savings at the Donggi Matindok field will indirectly reduce CPP process plant shut downs and hence less wasted gas.

4.1.2 CCS Well Injection Program

Carbon Capture and Storage (CCS) in Donggi Matindok Field is one of the global warming mitigation technologies by reducing CO2 emissions into the atmosphere. This technology is a series of process implementations that are related to each other, starting from the separation and capture of CO2 from the source of flue gas emissions (flue gas), transportation of captured CO2 to a storage area (transportation), and storage to a safe place (storage). CO2 capture is commonly used in hydrogen production processes both on a laboratory and commercial scale. Meanwhile, transportation is carried out using pipes or tankers such as gas transporters in general (LPG, LNG), while storage is carried out into the rock layer below the earth's surface which can trap gas so that it does not escape into the atmosphere, or can also be injected into wells in the Donggi Matindok field at a certain depth (Figure 2).

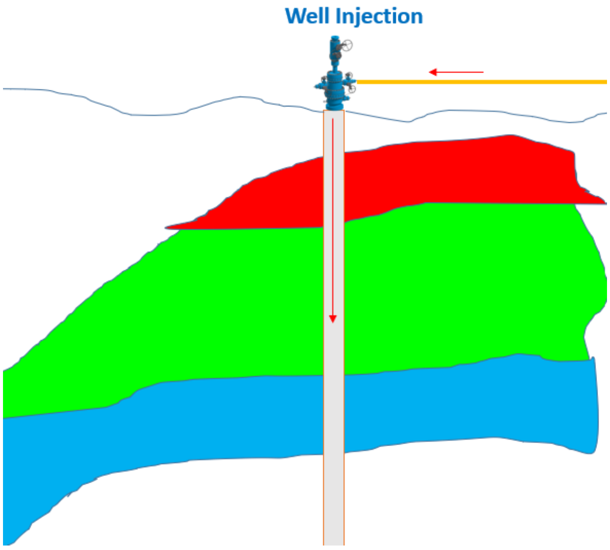

Illustration of a CO2 Injection Gas Well

4.1.3 CCU Program (Microalgae Plantation)

With rising atmospheric temperatures, the increase in carbon dioxide in the atmosphere exacerbates the hazards associated with climate change. Algae-based carbon dioxide mitigation is one of the potential methods to reduce greenhouse gas emissions and may be easily replaced by currently available technologies. Algae-based carbon dioxide mitigation is one of the potential methods to reduce greenhouse gas emissions and may be easily substituted by currently available technologies. Microalgae contribute significantly (about 50%) to photosynthesis on earth by producing most of the oxygen in the atmosphere and absorbing carbon dioxide as shown in the process in Figure 3.

The photosynthetic efficiency of microalgae usually ranges from 11 to 20 percent, higher than that of terrestrial plants (1-2 percent). Microalgae are better able to fix CO2 than C4 plants. When some algae species undergo exponential growth, their biomass may quadruple in just three and a half hours. In addition, due to their benefits in increasing carbon dioxide tolerance, these microorganisms are a good choice for organisms (exhaust gas), low light intensity requirements, environmental sustainability, and co-production of important products. The Algae Harvesting process that has been running in Donggi Matindok Field is shown in Figure 4, where the Algae produced is used for cattle feed.

Different microalgae strains have different levels of carbon dioxide affinity and tolerance. Different carbon dioxide conditions are capable of supporting microalgae. In order to survive in situations with low carbon dioxide concentrations, microalgae at carboxylation sites have developed a process similar to the concentration mechanism. Microalgal cells are immobilized by increased carbon dioxide concentrations, which prevents photosynthesis and algal development.

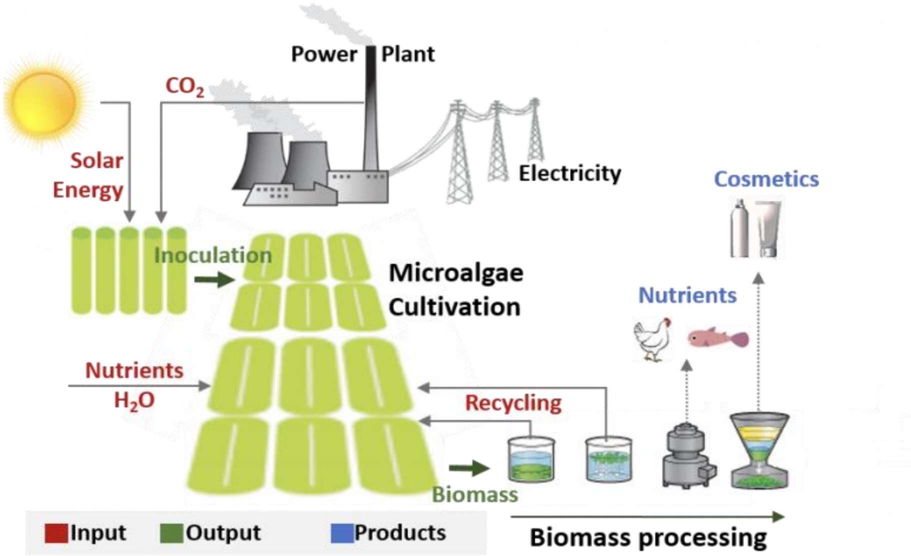

Figure 3 Microalgae Process[29]

Figure 4 Harvesting Algae at Donggi Plant

4.2 Comparison of Study Contexts

As previously discussed in the previous chapters, risks are emergent properties of the system and therefore, should be analyzed considering the context in which they are generated. In addition, the safety control structure of CCUS projects is specific and contextualized depending on several factors. Therefore, it is important to compare the case studies in terms of context.

Nonetheless, a comparison of both case studies (introduced in section 4.1) is equally provided in this section of the report. The aim is to propose an improved control structure for the CCUS project according to the currently available data. Lessons learned from further project development will provide useful information to improve and finalize this analysis.

Table 1 Comparison of Study Contexts

No.	Parameters	Carbon Reduction	CCS Well Injection	CCU Algae
1	Status	In Operation	Study	Pilot
2	Activity	Surface	Subsurface & Surface	Surface
3	% CO2 Rate Reduction	20%	90%	40%
4	Main Objective	Carbon Reduction	Taking CO2 from outside industrial processes to be injected in the field and stored.	Capture CO2 for Algae that is utilized for livestock
5	Field Area	Donggi Matindok	Donggi Matindok	Donggi Matindok

1.3 Risk Comparison of Each Program

In the previous explanation, the list of risks that will be analyzed is conveyed, the following is a comparison of the risks obtained from each program to be examined in table 1. Potential risk parameters are obtained from literature and interviews with oil and gas experts in related project fields.

Table 2 Comparison of Risks Associated with Case Studies

No.	Category	Potential Risk	Carbon Reduction	CCS	CCU
1	Financial	Financial crisis impacts financial support CCS projects		X	X
2		Lack of financial resources	X	X	X
3		High project cost	X	X	
4		Own losses		X	X
5		Economics not achieved	X		
6	Regulation	Legal uncertainty		X	X
7		Policy/priority changes	X	X	X
8		Unavailability of monetary mechanism for CO2		X	X
9		Lack of political support		X	X

10		Unavailability of regulations regarding different types of storage		X	X
11	Environ-ment	CO2 leakage from the compression unit		X	X
13		Leakage through artificial pathways such as abandoned wells		X	X
14		CO2 leakage from storage to the surface		X	X
15		Soil contamination		X	X
16		CO2 plume exceeds safety zone		X	X
17		project waste is not well handled	X		
18	Technical Operation	Project permit not obtained		X	X
19		Technology scale-up		X	X
20		Corrosion		X	X
21		Using the existing wells and facilities (especially pipelines)		X	X
22		CO2 out of specification		X	X
23		Construction field conditions		X	X
24		Geographical infrastructure		X	X
25		Energy consumption		X	X

Table 3 Comparison of Risks Associated with Case Studies (continued)

No.	Category	Potential Risk	Carbon Reduction	CCS	CCU
26	Technical Operation	Maintenance and control procedures (in-cluding ESD system)		X	X
27		Phase change & material problems		X	X
28		Lower Capture efficiency due to the up-stream plant flexible operation		X	X
29		Pipeline construction		X	X
30		Injectivity reduction over time		X	X
31		Uncertainties regarding the storage perfor-mance (capacity/injectivity/containment)	X	X	X
32		Model and data issues		X	
33		Uncertainties related to storage monitoring		X	

34		CO2-resistant compressor		X	
35		Need Drilling and workover in new well or existing well		X	
36		existing facilities are not reliable		X	
37		Potential loss production equipment failure	X		
38		Potential shut down during construction	X		
39		Increase shut down potential (GTG heat gas utilization)	X		
41	Knowledge	Lack of knowledge/qualified resources for operating the unit	X	X	X
42		Organization (lack of people)	X		
43	Safety	Safety related accident	X	X	X
44		Boiling Liquid Expanding Vapor Explosion		X	X
45		Well/Facility integrity	X	X	X
46		CO2 migration		X	X
47	Reputation	Public Opposition		X	X
48		Uncertainties in stakeholder requirements/perceptions - Communication problems	X	X	X
49		Public availability of sensitive information		X	X
50		Proximity to other industrial plants		X	X

1.4 Risk Analysis and Matrix

Risk analysis is carried out from the results of expert oil and gas respondents at Pertamina EP Company who are part of the project being worked on. The following are the results of each carbon reduction program, CCS Well Injection and CCU MicroAlgae in tale 4.4.1, 4.4.2 and 4.4.3

Table 4. Risk Assessment of Carbon Reduction Program

No.	**Base Case**	**Potential Risk**	**Likelyhood**	**Severity**	**Risk Level**
1	Financial	Economics not achieved	4	1	4
2		Lack of financial resources	2	1	2
3		High cost of project	3	1	3
4	Regulation	Change in policies/priorities	3	1	3
5	Environment	project waste is not well handled	3	2	6
6	Technical Operation	Potential equipment failure loss of production	5	3	15
7		Potential shut down during construction	4	3	12

8		Uncertainties regarding the facility modification performance	3	2	6
9		Project permits not obtained (moc)	3	2	6
10		Increase shut down potential (GTG heat gas utilization)	4	3	12
11	Knowledge	Lack of knowledge/qualified resources for operating the unit	4	2	8
12		Organization, additional people	3	1	3
13	Safety	Safety related accident	3	2	6
14		Facility integrity	3	2	6
15	Reputation	Uncertainties in stakeholder requirements/perceptions - Communication problems	2	1	2

Table 5 Risk Assessment of CCS Well Injection Program

No.	**Base Case**	**Potential Risk**	**Likelyhood**	**Severity**	**Risk Level**
1	Financial	Financial crisis impacts financial support CCS projects	3	3	9
2		Lack of financial resources	3	3	9
3		High project cost	4	3	12
4		Own losses	2	3	6
5	Regulation	Legal uncertainties	4	3	12
6		Change in policies/priorities	4	3	12
7		Unavailability of a monetary mechanism for CO2	4	3	12
8		Lack of political support	4	3	12
9		Unavailability of regulations regarding different types of storage	2	3	6
10	Environment	CO2 leakage from compression unit	3	4	12
11		Leakage through manmade pathways such as abandoned wells	3	4	12
12		CO2 leakage from storage to the surface	3	4	12
13		Soil contamination	1	1	1
14		CO2 plumes exceed the safe zone	4	4	16

15	Technical Operation	Project permits not obtained	2	3	6
16		Technology scale-up	2	3	6
17		Corrosion	4	4	16
18		Using the existing wells and facilities (especially pipelines)	3	3	9
19		CO2 out of specification	4	3	12
20		Construction field conditions	3	3	9
21		Geographical infrastructure	3	3	9
22		Energy consumption	4	1	4
23		Maintenance and control procedures (including ESD system)	3	3	9
24		Phase change & material problems	3	3	9

Table 6 Risk Assessment of CCU MicroAlgae Program

No.	Base Case	Potential Risk	Likelyhood	Severity	Risk Level
1	Financial	Financial crisis impacts financial support CCS projects	2	1	2
2		Lack of financial resources	2	1	2
3		Own losses	3	1	3
4	Regulation	Legal uncertainties	2	2	4
5		Change in policies/priorities	2	2	4
6		Unavailability of a monetary mechanism for CO2	1	2	2
7		Lack of political support	1	1	1
8		Unavailability of regulations regarding different types of storage (offshore/onshore)	1	2	2
9	Environment	CO2 leakage from compression unit	3	3	9
10		outflow leakage to the environment	2	3	6
11		Leakage through manmade pathways such as abandoned wells	2	3	6
12		CO2 plumes exceed the safe zone	2	2	4
13		Soil contamination	2	3	6
14	Technical Operation	Project permits not obtained	2	1	2
15		Technology scale-up	2	2	4
16		Corrosion	2	2	4
17		Using the existing facilities (especially pipelines)	2	3	6

18		CO2 plumes exceed the safe zone	2	2	4
19		Construction field conditions	2	3	6
20		Geographical infrastructure	3	3	9
21		Energy consumption	2	3	6
22		Maintenance and control procedures (including ESD system)	2	4	8
23		Phase change & material problems	2	3	6
24		Lower Capture efficiency due to the upstream plant flexible operation	1	2	2
25		Uncertainties regarding the storage performance (capacity)	1	2	2
26		Model and data issues	1	2	2
27		Uncertainties related to storage monitoring	1	2	2
28		Abnormal Operation, parameters not matched	2	4	8
29	Knowledge	Lack of knowledge/qualified resources for operating the unit	2	4	8
30	Safety	Safety related accident	1	3	3
31		Boiling Liquid Expanding Vapor Explosion	1	2	2
32		pipeline integrity	1	4	4
33		CO2 migration	1	1	1
34	Reputation	Public Opposition	1	3	3
35		Uncertainties in stakeholder requirements/perceptions - Communication problems	1	3	3
36		Public availability of sensitive information	1	3	3
37		Proximity to other industrial plants	1	3	3

Based on the risk assessment of each program, risk mapping is obtained to make it easier to see the priority of completing the mitigations that will be taken by the person in charge of the program. For each program is in table 7 below.

Table 7. Risk Maps of Carbon Reduction Risk Assessment

Risk Impact Level	Probability (Likelihood)

		Rare 1	Unlikely 2	Moderate 3	Likely 4	Almost Certain 5
Consequence	Catastrophic 5	5	10	15 A6	20	25
	Major 4	4	8	12 A7	16	20
	Moderate 3	3	6	9	12 A10	15
	Minor 2	2	4	6	8	10
	Insignificant 1	1	2	3	4	5

CCS Well Injection

Risk Impact Level		Probability (Likelihood)				
		Rare 1	Unlikely 2	Moderate 3	Likely 4	Almost Certain 5
Consequence	Catastrophic 5	5	10	15	20	25
	Major 4	4	8	12 B5,6,7,8,35,36,40	16 B14,B17	20
	Moderate 3	3	6	9	12 B10,11,12,19,22,23	15
	Minor 2	2	4	6	8	10
	Insignificant 1	1	2	3	4	5

CCU MicroAlgae

Risk Impact Level	Probability (Likelihood)				
	Rare 1	Unlikely 2	Moderate 3	Likely 4	Almost Certain 5

Conse-quence	Catastrophic 5	5	10	15	20	25
	Major 4	4	8 C22, 28, 29	12	16	20
	Moderate 3	3	6	9 C9, C20	12	15
	Minor 2	2	4	6	8	10
	Insignificant 1	1	2	3	4	5

1.5 Risk Mitigation Discussion

Based on the risk mapping that has been made, the next chapter will discuss risk mitigation on several parameters that have a large impact or high impact.

The following in table 4.5 is a list of the biggest impacts of the carbon reduction project and the CCS Well Injection program which then requires risk mitigation so that the program can run well.

Table 8. High Risk Mitigation

No.	Program	Risk	Impact	Category	Related Parties	Risk Control
1	Carbon Reduction	Equipment failure	- Production loss - Other equipment damage - Production process system disruption	High	Internal	1. Scheduled Maintenance 2. Employee Training 3. Periodic Monitoring 4. Equipment Backup: Have backup equipment ready to use in the event of a major equipment failure.
2	CCS Well Injection	Corrosion	- High Maintenance and Repair Costs - Infrastructure Damage and leaks	High	Internal External	Selection of Corrosion-Resistant Materials
3	CCS Well Injection	Well integrity	Investment Losses and leaks	High	Internal External	Proper Design and Construction

1.5.1 Equipment Failure Risk Mitigation

Pertamina EP Donggi Matindok Field uses part of the natural gas it produces as an energy source and is called own used fuel gas. The use of own used fuel gas is intended for the operation of Gas Turbine Generator (GTG), Hot Oil Fire Heater (HOFH), Incinerator/Tox, Dehydration Unit (DHU), and Produced Water Stripper areas. After implementing the ISO 50001:2018-based Energy Management System, the company determined that the GTG, TOX, and Oil Heater units are significant energy use (SEU). The carbon reduction effort is to reduce the use of GTG using the LOTION innovation program, Top Priority Selection. The success of energy efficiency from the implementation of LOTION has an impact on reducing emissions generated from the GTG operational process. By referring to the Guidelines for the Implementation of GHG Inventory, the calculation of emission reduction is obtained according to the amount of energy efficiency. Graph 4.5.1 shows the reduction in GTG exhaust emissions from 2020 to 2022.

The reduction in GTG emissions from 2020 to 2022 is 24,277.73 tons CO2eq or 19.47% of the total GWP impact baseline.

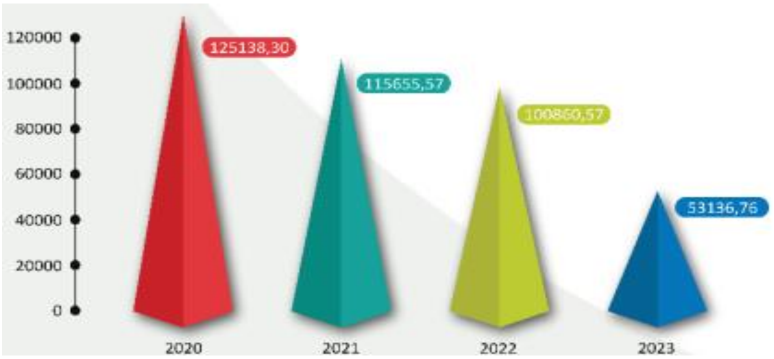

Figure 5 Reduction of CO emission generation^2 eq (in tons)

The risk of equipment failure from this innovation change can cause production loss so that mitigation is prepared so that losses can be prevented. With the application of the LOTION Load Sheeding System in the Donggi CPP and Matindok CPP generation, the LOTION Load shedding system becomes level 1 critical equipment because when there is a failure in the LOTION load shedding system, the plant will shutdown black out, so that the monitoring check list of the main load shedding equipment must be carried out according to the form and schedule. In addition, procedures are also made including the Pre Start Safety Review Document, which is simply a formal verification to ensure that aspects that are important / critical to maintaining the integrity of equipment and operations are ready for use before energy and hazardous materials are flowed into the process equipment. Aspects verified include ensuring that equipment is in accordance with specifications, process safety aspects of the facility, the workforce has the necessary competencies and the operations management system, operating license, PSM system is implemented including ensuring that PHA (HAZOP, HAZID, etc.) has been conducted and recommendations implemented.

1.5.2 Corrosion Risk Mitigation

Natural gas in Donggi Matindok field contains impurities, namely H2S and CO2, to separate them and clean them into sweet gas so that they can be commercialized, an adsorption process using alkanolamine chemical solutions (such as MEA, DEA, MDEA, etc.) is carried out. During this kind of CO2 capture process, impurities, such as O2, SOx, and NOx, can promote the degradation of alkanolamines in the CO2 scrubbing process, leading to the formation of heat stable salts (HSS) that will remain in the amine solution.

High C02 levels mean that the wet process environment tends to be acidic, resulting in high corrosion rates on the unprotected carbon of the steel. Water-soluble C02 gas is known to cause corrosion of steel pipelines used in oil and gas production fields. Most internal corrosion of oil pipelines is caused by C02. The corrosion of C02 in oil pipelines is affected by several factors such as C02 partial pressure, temperature and pH. The impact of corrosion (Figure 25) will lead to loss of product due to leakage of containers, tanks, or piping, as well as loss of efficiency because CCS projects incur high costs. In addition to economic losses, metal corrosion can also cause contamination that is detrimental to health.

Figure 6 Corrosion in Gas Process Facilities

According to the literature review, CO2 is compressed into a supercritical phase and transported via pipeline to injection wells or storage facilities. This process is considered more economical than other means such as trucks, trains, and ships. The coexistence of water and acid gas impurities (SO2, NOx, H2S in pipelines) causes corrosion problems in pipelines due to the effect of condensation or adsorption of water on the steel surface and subsequent dissolution of corrosive species.The solubility limit of CO2 in supercritical media, the uniform corrosion rate of steel pipelines in an impure supercritical CO2 environment is always on the order of a few mm/year, depending on the specific conditions. CO2 corrosion is a complex electrochemical process affected by various factors such as moisture content, pH, flow rate, temperature, pressure, Cl concentration, and oil phase environment. Table 11 shows the influencing factors and their impact.

Table 9 Influencing factors and effects of corrosion

Factor	Impact

Water Content	The corrosion rate of carbon steel materials tends to accelerate when the water content in CO2 increases.
Ph	The higher the pH, the lower the hydrogen ion content and corrosion rate of carbon steel will also be reduced.
Flow rate	The high flow rate accelerates the rate at which the corrosive medium reaches the metal pipe surface, creating stresses that can disrupt the initially stable solid corrosion product layer, thus causing the corrosion velocity to increase.
Temperature	A high temperature environment can increase the electrochemical reaction rate and accelerate the corrosion of CO2.
Pressure	Within a certain pressure range, the corrosive ability of carbonated water is formed by CO2 and the formation of water gradually increases with increasing pressure.
Cl-	Cloride content has minimal impact on uniform corrosion but mainly affects localized corrosion, such as pitting corrosion.
Oil phase content	Oil can change the structure and chemical composition of the corrosion product film plays a role in inhibiting corrosion

Mitigation measures taken to control steel corrosion problems in CCUS systems, the use of inhibitors can be an economical and effective method, in addition to the application of corrosion-resistant alloys, coatings, and cathodic protection. However, when various acid gases are present, it seems difficult to find an inhibitor that can reduce the corrosion rate of steel under the attack of strong and weak acids, including sulfuric acid (H2SO4), nitric acid (HNO3), H2SO3, carbonic acid (H2CO3), and H2S. Recently, it was reported that piperazine can neutralize acid gas impurities and inhibit CS corrosion in supercritical CO2-saturated water phase containing SO2, nitrogen dioxide (NO2), and O2 impurities.15 Piperazine and its derivatives are potential inhibitors of steel corrosion in CCUS environment. Meanwhile, controlling the water content in the CO2 stream can be an alternative corrosion control strategy.

1.5.3 Well integrity risk mitigation

Well integrity standards generally use API, ISO, NACE and NORSOK D-10, where well integrity is a multidisciplinary approach. The following is an injection well profile which generally consists of wellhead, christmasthree, casing, tubing, packer and cement equipment. Wellhead and Cristmasthree that are on the surface have low risk while the biggest risk that will occur during the injection process is the equipment that is downhole or under the well where the condition is not clearly visible. Starting from cement, casing, tubing and packer. To mitigate the risk of leakage is to conduct proper well design and construction.

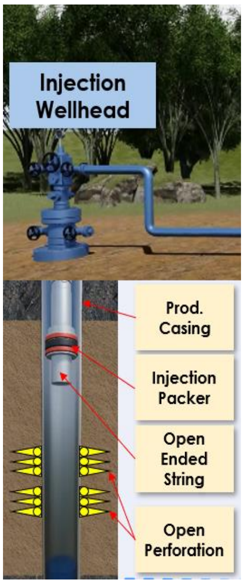

Figure 7. Injection Well Profile

For casing, tubing and packer equipment, mitigation is carried out by evaluating the selection of materials that are suitable for the fluid, temperature and pressure that will pass through the equipment. Stainless steel alloys are well known for their corrosion resistance, ductility and high strength. The corrosion resistance qualities of stainless steels are directly related to their chromium and nickel content the more of these elements correlates with an increase in their resistance. For tubular equipment, the mitigation tubing can use Glass Reinforced Epoxy (GRE) lined carbon steel: internally plastic-coated carbon steel, Corrosion Resistant Alloys (CRA). As for the packer material, namely the rubber part which functions to isolate the casing annulus area so as not to leak into the wellhead annulas, Internally coated hardened Rubber material can be used.

The insulation between the well and the formation is cement, which when completing the well cement slurry with a certain amount of pressure from the surface flowed into the casing up to the annulus and sealed the outer wall of the casing with the formation. The function of cement here is to prevent inter-formation flow or unwanted formation fluid flow that will enter the well and also to isolate the productive zone that will be produced by formation fluid and also to prevent corrosion of the casing caused by corrosive materials.

To mitigate poor cement quality, after the cement is pumped, measure the CBL (Cement Bonding Log) using wireline, so that the value of cement quality can be obtained and it can be decided whether it is necessary to repair the bonding or not. Effective cement bonding repair can be done using a stinger unit so that the cement can fill sufficiently in the empty casing anuular area, generally good cement bonding ranges below 5 mV from the CBL results. The following is an example of CBL measurement results in an area of the casing that needs repair.

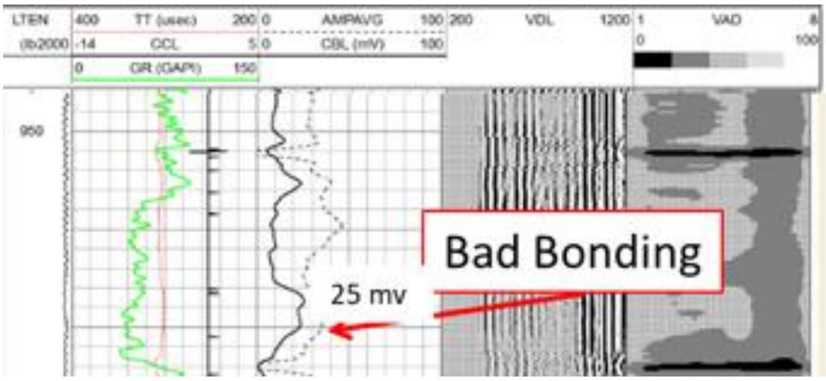

Figure 8: Example of Cement Quality Measurement

The hardness of cement slurry is also affected by:
- Reservoir mineralization
- Passed brines
- High temperature

From the literature review, the new cement slurry selected should be resistant to carbon dioxide compared to conventional cement (i.e. Portland cement). Some types of cement that can be used for CO2 injection wells are Pozzolanic Portland cements, Micro-fine cements and Latex cements.

CONCLUSION

From the results of the study, the following conclusions were obtained first, from 3 decarbonization programs, risk mapping was obtained where ccs well injection had the most high risk (2 high risks) after the carbon reduction program (1 high risk) and the lowest was the CCU Algae program which had the majority of low risks from 50 parameters set. Second, from the results of the discussion, the risk of equipment failure from the carbon reduction program can be mitigated by making pre-safety documents and preparing a workforce system that is in accordance with the procedure of the changes made. Third, the risk contained in the CCS Well Injection program from corrosion and well integrity is by reevaluating the design and selecting the right material so that it can prevent the impact of leaks that occur. Fourth, the program that has been running, namely carbon reduction, shows a significant decrease per year in the emissions generated in the Donggi Matindok field so that the implementation of decarbonization from the CCU Algae and CCS Well Injection pilot programs is expected to help meet the net zero emission target in the future in 2030.

Then as for further suggestions from this research, namely first, theoretically for future researchers with the same theme as this research, the variables can be reduced to focus on one variable such as the effect of government policies on accelerating decarbonization programs on a national scale in energy sector companies in Indonesia. Then secondly, practically risk control is strongly influenced by program implementers, in this case users and contractors in the field so that training and education are needed so that a good risk management culture can be implemented and monitored so that work can run according to plan and safety targets. The Failure Mode and Effect Analysis (FMEA) and Fault Three Analysis (FTA) methods serve to further detail the risks and understand the potential failure modes and causes and effects of failure on the system or end user for a particular product or process can be used for the project in this paper.

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