Original Article

e-ISSN: 2775-5037
p-ISSN: 2614-3917

Riwayat

Original Article

Life Cycle Assessment (LCA) Study on Crude Oil and Natural Gas Production Process for Environmental Impact Analysis and Decarbonization Support in East Java

Shidqi Adhi Prasetyo✉
Institut Teknologi Sepuluh Nopember
shidqiprasetyo@gmail.com✉

Abstract:

The energy industry sector is a significant contributor to greenhouse gas emissions in Indonesia. Increasing global attention to climate change requires decarbonization activities to strengthen the competitiveness of the Indonesian energy industry in the global market and contribute to achieving national emission reduction targets. The selection of efforts in decarbonization requires a strong database, so that improvement efforts can be carried out in a targeted and efficient manner. The LCA method is used to identify and analyze the magnitude of environmental impacts and hotspots in one of the crude oil and natural gas producing companies in East Java to be further used as an effort in decarbonization activities. The environmental impacts produced in this study are midpoints with the ReCiPe 2016 (H) method for the cradle-to-gate scope. The LCA study produced several midpoint impacts such as global warming, stratospheric ozone depletion, ozone formation-human health, fine particulate matter formation, ozone formation, terrestrial ecosystems, terrestrial acidification, freshwater eutrophication, and marine eutrophication. The dominant midpoint impact results are global warming of 78,113,412 kg CO_2 eq, ozone formation-human health of 195,868 kg NOx eq, and ozone formation-terrestrial ecosystems of 195,873 kg NOx eq. The process unit with the largest impact contribution is the GTC-102 CPP.

Keywords: Life Cycle Assessment, environmental impact, hotspot, crude oil, natural gas, decarbonization.

https://jurnal.usk.ac.id/riwayat

Received: April 23, 2025 – Revised: May 14, 2025- Accepted: June 16, 2025 - Published online: July 12, 2025

Introduction

Today, crude oil and natural gas are still one of the main sources of energy in the world. Long-term exploration and production activities have resulted in a decline in crude oil and natural gas production, which has resulted in economic decline and affected the geopolitical conditions of various countries. Based on these conditions, it can be said that crude oil and natural gas are one of the most important natural resources, as well as one of the factors of human civilization [1].

Crude oil and natural gas production is a series of complex processes involving various upstream and downstream industrial sector activities. Upstream activities include exploration and production activities with activities such as well drilling and liquid separation processing of natural gas, crude oil and produced water. Downstream activities include activities in the refinery industry sector for processing natural gas into LNG (liquefied natural gas), CNG (compressed natural gas), or LPG (liquefied petroleum gas). The process of delivering natural gas to consumers is also part of the downstream gas production activities [2].

One of the oil and gas companies in the Madura and Gresik Straits has successfully produced oil and gas since 1993. The oil and gas company's operating fields include the Onshore Receiving Facility (ORF), Poleng Processing Platform (PPP), Floating Storage and Offoading Abherka (FSO Abherka) and Central Processing Platform (CPP) operating fields. In 2023, one of the oil and gas companies in the Madura and Gresik Straits had a production volume of 351,524 Tonne Oil Equivalent (TOE) of crude oil and 11,277 Million Standard Cubic Feet (MMSCF) of natural gas.

The LCA method canusedin evaluating and finding possible environmental improvements due to the impact of activities. The application of LCA consists of four stages, namely goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and data interpretation.[6]. This research method uses a midpoint approach with the ReCiPe 2016 (H) method in the cradle to gate scope. Environmental impacts arising from the LCA study are evaluated, identified, and analyzed to determine what impacts arise and the analysis of process units as the main contributors to environmental impacts or hotspots. Decarbonization efforts are also carried out based on hotspot analysis.

Methods

This research has a cradle to gate scope in the LCA study. The scope of cradle to gate is a life cycle analysis based on raw materials to the gate or production process before the use of the product by consumers [3]. Analysis of the potential for achieving the company's decarbonization target based on the results of the LCA study was also carried out. The stages in this study are:

Goal and Scope

*Goal*or the purpose of the LCA study is determined in detail regarding the purpose of applying LCA to a study. Scope or system boundaries are a series of determinations of all process units to be studied [4].

Life Cycle Inventory

The life cycle inventory stage is an analysis of all inventory data from input to output of all process units related to the production system. The LCI stage produces a quantitative description of the flow of material, energy, and pollutants within system boundaries.[5]. The data sources used are divided into 4 (four), namely electronic databases, literature data, unreported data, and measurement or calculation data.[6]. The data validation and verification process is carried out by experienced personnel by comparing the data in the notes/logbook with conditions in the field.[7].

Life Cycle Impact Assessment

Life Cycle Impact Assessment(LCIA) is a stage in LCA that is intended to understand and evaluate the magnitude and importance of the potential environmental impacts of a product system throughout its life cycle [8]. The LCIA stage aims to make the results of the LCI analysis easier to understand and manage in relation to human health, resource availability and the environment [6]. Based on SNI ISO 14044 (2017), several elements in the LCIA stage are divided into 3 (three) stages, namely classification, characterization, and normalization.

Classification step, elementary flow from LCI is assigned to impact category (e.g. CO2 emission into air causes global warming impact) [11]. Some elementary flow can have many impacts in 2 (two) modes, namely in parallel or an elementary flow has several simultaneous impacts, such as SO2 which causes acidification and is toxic to humans when inhaled and in series, namely an elementary flow has a detrimental effect and causes another impact, such as SO2 which causes acidification which then causes mobilization of heavy metals in the soil which are toxic to humans and ecosystems.

Characterization factors that can*used*based on the impact pathway, namely the midpoint and endpoint approaches. The midpoint approach focuses more on a single environmental problem that describes the cause and effect of environmental impacts that appear based on LCI results. The endpoint approach produces environmental impacts with a higher and greater level of categorization, such as human health, ecosystem quality, and natural resources[10].

Normalization is calculating the magnitude of the results of category indicators relative to reference information.[9]. Generally, the LCIA method already provides a normalization factor that can be calculated from the characterization score.[11]. Normalization is carried out to facilitate analysis in comparing the magnitude of impacts between impact categories.[12].

Interpretation

Interpretationis a combination of goal and scope, LCI, and LCIA, which aims to draw final conclusions. The Interpretation stage aims to identify the life cycle stage which under certain conditions can reduce environmental impact.[13].

Data Requirements

This researchuseprimary data obtained from direct monitoring in the company. The data used in the time span of the period of 1 (one) year. Primary data for this study can be seen in Table 1.

Table 1.Data Types and Retrieval

o.	Data Types	Data Collection Method	Dat a Duration
.	Natural gas crude oil production process flow	Primary Data	-
.	Details of the components of each process unit	Primary Data	-
.	Data on the quantity of raw materials and products from each process unit	Primary Data	1 year
.	Data on the amount of fuel and/or electrical energy used by each	Primary Data	1 year

	process unit		
.	Data on the amount of emissions, water usage, wastewater, produced in each process unit	Primary Data	1 year
.	Data and information that supports data quality assessment	Primary Data	1 year
.	Data on the amount of crude oil and natural gas products produced	Primary Data	1 year
.	Environmental programs that have been carried out	Primary Data	-

Results

Goal and Scope

*Goal*from this research isconduct the largest environmental impact analysis for all inputs and outputs from each crude oil and natural gas production process unit. Scope orThe scope of the LCA study in this study is cradle to gate. The cradle scope begins with the process of lifting crude oil and natural gas from production wells and ends with the process of separating 3 (three) phase liquids in the separator unit. The gate scope begins with the process of separating 3 (three) phase liquids in the separator unit and ends with the residual gas combustion unit in the flare unit and the collection of condensate in the condensate tank unit.The scope of the LCA study can be seen in Figure 1.

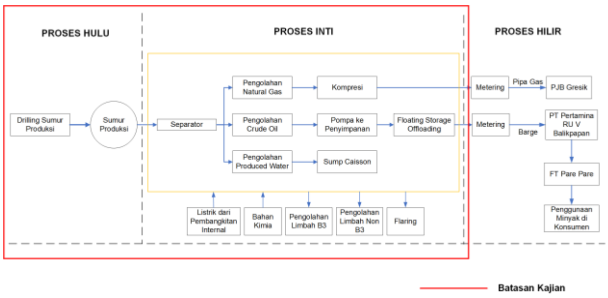

Figure 1.Crude Oil and Natural Gas Production Process

Source: Research results, (2025)

Life Cycle Inventory

*Life Cycle*Inventory contains input and output data for each unit of crude oil and natural gas production process. The data obtained is then normalized by inventory with the main product. Inventory normalization is the result of dividing the input and output data for each unit of the process by the final product of crude oil and natural gas in BTU units. The following is the inventory data used in the LCA study.

Table 2.Cradle to Gate Input-Output Data for Crude Oil and Natural Gas Production

No	***Inventory*Data**	**Amount**	**Unit**
		Input	
1	*Fresh water*	6.28E-05	kg/BTU
2	*Crude oil*	4.35E-08	bbl/BTU
3	*Natural gas*	8.79E-10	mmscf/BTU

4	*Diesel*	6.89E-08	L/BTU
5	*Fuel gas*	1.08E-10	mmscf/BTU
6	*Gas flare*	2.27E-12	mmscf/BTU
7	Demulsifier (SX-4801 RD)	1.13E-09	gallon/BTU
8	PPD (SFM-4805)	2.19E-09	gallon/BTU
9	*Corrosion inhibitor*(SRN- 6160 (3 phase))	4.84E-10	gallon/BTU
10	*Sludging Compound*(IX - 203)	3.36E-10	gallon/BTU
11	*Water clarifier* (SZB-4690)	4.18E-10	gallon/BTU
12	*Scale Inhibitors* (ST-4835)	3.09E-11	gallon/BTU
13	H2S Scavenger (SGT-6230)	1.37E-09	gallon/BTU
14	*Wax remover*	1.52E-10	gallon/BTU
15	*Antifoulant*	9.11E-12	gallon/BTU
16	*Glycol*	1.07E-10	gallon/BTU
17	*Activated carbon*	4.23E-11	kg/BTU
	Output		
18	*Crude oil*	2.12E-01	BTU/BTU
19	*Natural gas*	7.88E-01	BTU/BTU
20	*Condensate*	1.29E-08	bbl/BTU
21	*Water Production*	4.55E-05	kg/BTU
22	CO2	4.33E-06	kg/BTU
23	CH4	3.73E-10	kg/BTU
24	N2O	4.94E-10	kg/BTU
25	SOx	3.08E-10	kg/BTU
26	NOx	1.46E-08	kg/BTU
27	PM	5.14E-10	kg/BTU
28	nmVOC	3.96E-12	kg/BTU
29	TOC	7.72E-12	kg/BTU
30	H2S	1.29E-19	kg/BTU
31	NH3	1.78E-17	kg/BTU
32	TDS	4.30E-15	kg/BTU
33	COD	8.56E-16	kg/BTU
34	Phenol	4.20E-19	kg/BTU
35	*Oil and Grease*	2.26E-17	kg/BTU

Source: Research results, (2025)

Life Cycle Impact Assessment

a. Classification

Impact classification is carried out based on inventory inventory with the ReCiPe 2016 (H) method. Inventory classification can be seen in Figure 2. The results of the Classification stage in the LCIA Analysis can be seen that the use of diesel and gas fuel in the production process unit can produce GHG emissions such as CO_2, CH_4 and N_2O so that they have an impact on several categories of environmental pollution such as; global warming potential, ozone depletion, eutrophication and photochemical oxidation. In addition to the use of fossil fuels in the production process unit, GHG emissions are also generated from the process of lifting crude oil and natural gas from production wells directly.

In conventional emissions such as SOx, NOx and PM produced from the combustion of fossil fuels in production process units and the process of lifting crude oil and natural gas from production wells directly, it can also have an impact on several categories of environmental pollution such as; acidic rain, eutrophication, photochemical oxidation, and toxicity.

In addition to environmental impacts based on GHG and Conventional emissions,

Shidqi Adhi Prasetyo. (2025). https://doi.org/10.24815/jr.v8i3.47632

at the LCIA Classification stage it can be seen that the crude oil and natural gas production process can have a direct impact on the availability of natural resources or in the classification of the impact of abiotic depletion of fossil fuels. Supporting processes in companies such as wastewater treatment units also have emissions to surface water bodies with several parameters such as TDS, H2S, NH3, COD and Phenol so that they have an impact on environmental pollution with the categories of eutrophication, toxicity, biotic depletion and water footprint.

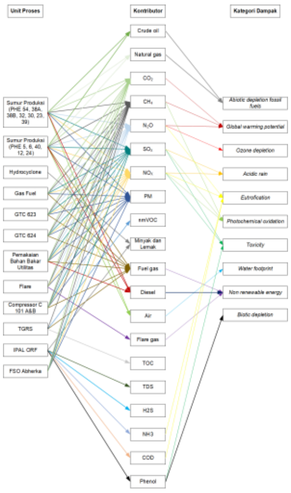

Figure 2.Classification of Production Process Impacts From Inventory

Source: Research results, (2025).

b. Characterization

Characterization methodsimpactusing ReCiPe 2016 (H). The ReCiPe 2016 method divides indicators into two levelsthat is18 midpoint indicators. Characterization of production processescrude oil and natural gascan be seen in Table 3.

Table 3. Impact CharacterizationCrude Oil and Natural Gas Production Process

Cradle		
Impact Category	**Amount of Production Proces Emissions**	**Unit**
Midpoint		
Global warming	594,616.49	kg CO2 eq
Ozone formation, Terrestrial ecosystems	0.05	kg NOx eq
Ozone formation, Human health	17,674.08	kg NOx eq
Terrestrial acidification	2,281.20	kg PM2.5zA eq
Fine particulate matter formation	17,674.08	kg PM2.5 eq
Stratospheric ozone depletion	7,524.91	kg CFC11 eq
Gate		
Impact Category	**Amount of Production Proces Emissions**	**Unit**

Midpoint		
Global warming	60,994,797.00	kg CO2 eq
Stratospheric ozone depletion	63.14	kg CFC11 eq
Ozone formation, Human health	152,104.08	kg NOx eq
Fine particulate matter formation	17,435.80	kg PM2.5 eq
Ozone formation, Terrestrial ecosystems	152,109.14	kg NOx eq
Terrestrial acidification	57,186.43	kg SO2 eq
Freshwater eutrophication	0.07229	kg P eq
Marine eutrophication	0.00049	kg N eq

Source: Research results, (2025)

Based on Table 3, it can be seen from the company's crude oil and natural gas production in the Gresik area, East Java in 2023, it produced 8 (eight) categories of midpoint impacts. Some of these impacts are global warming potential from emissions of 60,994,797 kg CO2 eq, stratospheric ozone depletion from emissions of 63.14 kg CFC 11 eq, ozone formation - human health from emissions of 152,104 kg NOx eq, fine particulate matter formation from emissions of 17,435 kg PM 2.5 eq, ozone formation - terrestrial ecosystems from emissions of 152,109 kg NOx eq, terrestrial acidification from emissions of 57,186 kg SO2 eq, fresh water acidification from emissions to water bodies of 0.0723 kg P eq, and marine eutrophication from emissions to water bodies of 0.000488 kg N eq. The visualization of the impact characterization on all gate process units can be seen in Figure 3. In the impact characterization graph, each type of impact is displayed in the form of a bar graph with a percentage unit. This can make it easier for researchers to quickly identify the dominant unit in each type of impact. For example, manual reading of the dominant unit in the impact characteristics is as follows; Researchers determine one of the impacts in the gate scope, namely stratospheric ozone depletion. It can be seen from Table 3 that the total magnitude of the impact of stratospheric ozone depletion in the gate scope is 63.14 kg CFC 11 eq, then identification is carried out for process units with dominant similar impact contributions. Based on research data, it is also known that the process unit with the dominant similar impact contribution is Flare CPP with an impact magnitude of 40.2 kg CFC 11 eq. Furthermore, the ratio calculation is carried out between the total impact and the magnitude of the dominant unit impact and the final result is known to be 63.62%.

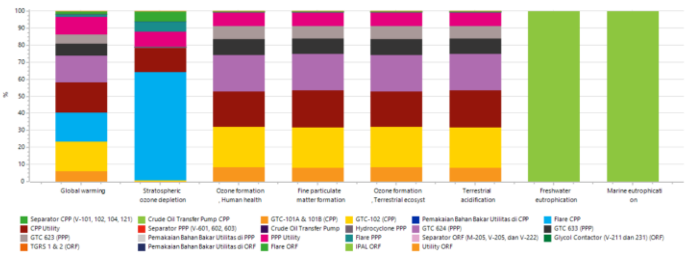

Figure 3.Characterization of the Company's Crude Oil and Natural Gas Production Process Midpoint (gate) in Gresik, East Java in 2023

Source: Research results, (2025)

c. Normalization

The normalization score is the result of dividing the characterization impact by the normalization factor (without units). The normalization factor used is sourced from the

ReCiPe 2016 method (H). The normalization of the crude oil and natural gas production process of the company in Gresik, East Java can be seen in Table 4.

Table 4. Normalization of Crude Oil and Natural Gas Production Impacts

Cradle	
Impact Category	**Impact Normalization Results**
Midpoint	
Global warming	74.33
Ozone formation, Terrestrial ecosystems	0.88
Ozone formation, Human health	858.96
Terrestrial acidification	89.19
Fine particulate matter formation	995.05
Stratospheric ozone depletion	183.61
Gate	
Impact Category	**Impact Normalization Results**
Midpoint	
Global warming	7,624.35
Stratospheric ozone depletion	1,054.44
Ozone formation, Human health	7,392.26
Fine particulate matter formation	681.74
Ozone formation, Terrestrial ecosystems	8,563.74
Terrestrial acidification	1,395.35
Freshwater eutrophication	0.11132
Marine eutrophication	0.00011

Source: Research results, (2025)

Based onin Table 4. midpoint impact categories with the highest to lowest normalization scores in the gate scope are; ozone formation - terrestrial ecosystems of 8,563, global warming of 7,624, ozone formation - human health of 7,392, terrestrial acidification of 1,395, stratospheric ozone depletion of 1,054, fine particulate - matter formation of 681, freshwater eutrophication of 0.11 and marine eutrophication of 0.000106. The normalization of impacts per process unit can be seen in Figure 4.

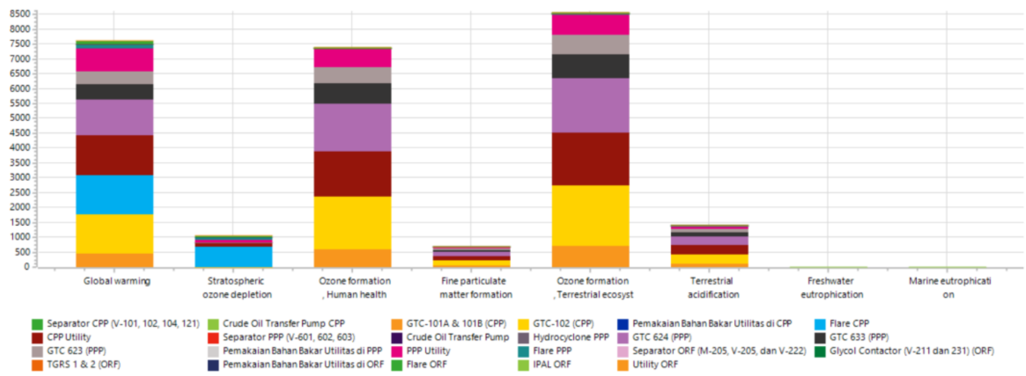

Figure 4.Normalization of the Impact of the Company's Crude Oil and Natural Gas Production Process (gate) in Gresik, East Java in 2023.

Source: Research results, (2025)

Interpretation

Based onTable 3, the results of the characterization of the company's crude oil and natural gas production in Gresik, East Java, produced 8 (eight) midpoint impact categories. Based on Figure 3, the main contributors to the categoriesThe environmental impacts of global warming and stratospheric ozone depletion are mostly generated by the CPP Utility and CPP Flare units, contributing 17.67% and 63.62% respectively. Both magnitudes of impacts are generated from the combustion of fuel gas, diesel and flare gas..Recommendations for improving other units to reduce the impact of global warming and stratospheric ozone depletion can be carried out on 5 (five) units, namely GTC 102 CPP, Utilities CPP, Flare CPP and GTC 524.

Other environmental impacts such as ozone formation-human health, fine particulate matter formation, ozone formation-terrestrial ecosystems and terrestrial acidification are mostly generated from the GTC 102 CPP unit with impacts of 23.98%, 23.66%, 23.98% and 23.64% respectively. This is due to the use of gas fuel in the pressure-boosting process at the GTC 102 CPP unit.. Recommendations for improvementOther units for this impact reduction are CPP Utilities and GTC 624 PPP.

The impact categories of freshwater eutrophication and marine eutrophication are all generated from the ORF IPAL unit. This is because the ORF IPAL unit releases emissions into water bodies such as TDS, H_2S, NH_3, COD, Phenol and Oil and Fat..Environmental improvement recommendations can be made directly to the ORF wastewater treatment plant unit.

Environmental Improvement Program Recommendations

The environmental impact reduction recommendation scenario in the form of an environmental program is implemented in priority units (hotspots) in the crude oil and natural gas production process according to the previous analysis, namely GTC-624 PPP. The environmental improvement program recommendations in the GTC-624 PPP unit are Online Cleaning System Gas Compressor CTAR Method, Lowering Pressure GTC-624, Vibration Reduction and Management Analysis. The three programs are then analyzed related to their ability to reduce emissions and reduce impacts on the crude oil and natural gas production process. The percentage of the potential of the three environmental improvement programs in reducing environmental impacts can be seen in Table 5.

Based on Table 5, it can be seen that the Vibration Reduction and Management Analysis program has the potential to significantly reduce emissions and environmental impacts. This can be the basis for implementing the selection of environmental improvement programs. Calculations in the potential contribution to meeting the company's decarbonization targets are also analyzed for the most optimal program and the accumulation of the entire program.

Table 5. Potential Emission Reduction and Impact of Each Recommended Program, Environmental Improvement

Online Cleaning System Gas Compressor CTAR Method					
Impact Category	**Existing**	**Program Implementation**	**Decrease**	**Percentage**	**Unit**
Midpoint					

Global warming	9,620,000.00	9,607,019.90	12,980.10	0.13%	kg CO_2 eq
Stratospheric ozone depletion	0.22700	0.22099	0.01	2.65%	kg CFC11 eq
		Lowering Pressure GTC-624			
Impact Category	**Existing**	**Program Implementation**	**Decrease**	**Percentage**	**Unit**
Midpoint					
Global warming	9,620,000.00	9,612,277.40	7,722.60	0.08%	kg CO_2 eq
Stratospheric ozone depletion	0.22700	0.22429	0.0027	1.19%	kg CFC11 eq
		Vibration Reduction and Management Analysis			
Impact Category	**Existing**	**Program Implementation**	**Decrease**	**Percentage**	**Unit**
Midpoint					
Global warming	9,620,000.00	9,601,645.20	18,354.80	0.19%	kg CO_2 eq
Stratospheric ozone depletion	0.22700	0.21758	0.0094	4.15%	kg CFC11 eq

Potential for Achieving Corporate Decarbonization Targets

It is known that the company's decarbonization target in 2025 is 85,328 tons of CO_2 eq. The potential for decarbonization is generated from several activities such as combustion, flaring, venting & process, internal combustion/fugitives and calculation of scope 2 (two) emissions based on electricity usage from PLN. The company's decarbonization target can be seen in Table 6.

Table 6.Emission Reduction Targets in Corporate Decarbonization

Activity Source	2022	2023	2024	2025	Unit
Burning	99.018	81,897	71,833	70,706	Ton CO_2 Eq
Routine Flaring	32,264	22,952	1.152	641	Ton CO_2 Eq
Non Routine Flaring	0	0	0	0	Ton CO_2 Eq
Safety Flaring	0	0	12,774	12,639	Ton CO_2 Eq
Venting & Process	270	289	184	214	Ton CO_2 Eq
Fugitives	192	288	288	317	Ton CO_2 Eq
PLN Electricity Scope 2 Emissions	545	554	729	811	Ton CO_2 Eq
Total	**132,289**	**105,980**	**86,960**	**85,328**	**Ton CO_2 Eq**

Based on Table 6, the company's decarbonization target in 2025 is 85,328 Ton CO2 eq. It can be seen that the three environmental improvement program scenarios are all located in combustion activities, so that the decarbonization target of PT X in 2025 is focused on the scope of combustion activities, which is 70,706 Ton CO2 eq. Furthermore, an analysis was carried out regarding the percentage of the company's potential reduction in Ton CO2 eq in 2025 for one program scenario with the highest potential reduction in Ton CO2 eq emissions and the accumulation of the three programs in reducing Ton CO2 eq emissions. The results of the percentage of potential reduction in Ton CO2 eq emissions can be seen in Table 7.

Based on Table 7, it can be seen that the percentage contribution of the program with the highest potential for reducing CO2 eq emissions is the program*Vibration Reduction and Management Analysis*can contribute 18.54% in achieving a reduction in emissions of Tons of CO2 eq in all combustion activities at PT X in 2025. If the entire environmental program scenario is implemented, the percentage of contribution to reducing emissions of Tons of CO2 eq in all combustion activities at PT X in 2025 is 34.79%.

Table 7.Percentage of Environmental Improvement Program Scenarios to Contribution to Achieving Decarbonization Targets in Company Combustion Activities in 2025

Program Name	CO2 Emission Reduction eq (Ton)	CO2 Emission Reduction Target eq from Combustion Activities (Ton)	Contribution Percentage
Vibration Reduction and Management Analysis	13,105.99	70,706	18.54%
Online Cleaning System Gas Compressor CTAR Method	8,164.62		11.55%
Lowering Pressure GTC-624	3,330.09		4.71%
Total	**24,600.70**		**34.79%**

Conclusion

PotentialThe impacts arising from the LCA study of the crude oil and natural gas production process using the ReCiPe 2016 (H) method are 8 (eight) midpoint impacts.The production process of 1 BTU of crude oil and natural gas of the company in Gresik, East Java has an environmental impact of global warming of 6.76386E-06 kg/BTU, stratospheric ozone depletion of 6.72363E-13 kg/BTU, ozone formation-human health of 1.83676E-08 kg/BTU, fine particulate matter formation of 2.13844E-09 kg/BTU, ozone formation, terrestrial ecosystems of 1.83676E-08 kg/BTU, terrestrial acidification of 7.02386E-09 kg/BTU, freshwater eutrophication of 6.2142E-15 kg/BTU, and marine eutrophication of 4.19437E-17 kg/BTU.

The percentage of contribution of the environmental improvement program scenario with the highest environmental impact reduction capability, namely the Vibration Reduction and Management Analysis program, to the company's decarbonization target in the scope of combustion activities in 2025 is 18.54%. The percentage of contribution of the overall environmental improvement program scenario to the company's decarbonization target in combustion activities in 2025 is 34.79%.

References

Angela, V. F. (2023). Strategi Pengembangan Ekowisata dalam Mendukung Konservasi Alam Danau Tahai. *JIM: Jurnal Ilmiah Mahasiswa Pendidikan Sejarah*, *8*(3), 984–993.

Azis, A., Nurasiah, N., Zulfan, Z., Kusnafizal, T., Fahmi, R., & Abdar, Y. (2023). Analysis of Aceh's Economic Recovery After the Tsunami Disaster and Prolonged Conflict Year, 2005. *Riwayat: Educational Journal of History and Humanities*, *6*(1), 249–261. https://doi.org/10.24815/jr.v6i1.31455.

Koesoemadinata, R. P. 1980. Geologi Minyak dan Gas Bumi, Jilid 1 dan 2. Institut Teknologi Bandung: Bandung.

Hasiany, S., Noor, E., dan Yani., M. 2015. Penerapan Produksi Bersih untuk Penanganan Air Terproduksi Di Industri Minyak Dan Gas. Jurnal Pengelolaan Sumber daya Alam dan Lingkungan. 5 (1): 25-32.

Hartoyo, R., & Sulistyowati, S. (2023). The Role Of The Legal Aid Post Is In Providing Legal Assistance To Disadvantaged People In Order To Obtain Justice In The Courts Of The Holy Land. *JIM: Jurnal Ilmiah Mahasiswa Pendidikan Sejarah*, *8*(3), 1599–1611. https://doi.org/10.24815/jimps.v8i3.25236.

Hermawan, P. F. Marzuki, M. Abduh, and R. Driejana, "PERAN LIFE CYCLE ANALYSIS (LCA) PADA MATERIAL KONSTRUKSI DALAM UPAYA MENURUNKAN DAMPAK EMISI KARBON DIOKSIDA PADA EFEK GAS RUMAH KACA," in Konfrensi Nasional Teknik Sipil 7, Y. Arfiadi and S. As'ad, Eds., Surakarta: Universitas Sebelas Maret (UNS), Oct. 2013, pp. 47–52.

Bayer Charlene, Gamble Michael, Gentry Russell, and Joshi Surabhi, AIA Guide to Building Life Cycle Assessment in Practice Authorship and Acknowledgements A Guide to Life Cycle Assessment of Buildings 2. New York: The American Institute of Architects, 2010.

SNI ISO 14044, Manajemen Lingkungan - Penilaian Daur Hidup – Persyaratan dan Panduan. Jakarta: Badan Standarisasi Nasional, 2017.

Sonnemann Guido, Tsang Michael, and Schuhmacher Marta, Integrated Life-Cycle and Risk Assessment for Industrial Processes and Products Second Edition. Boca Raton: CRC Press, 2019.

EPA QA/G-8, "Guidance on Environmental Data Verification and Data Validation EPA QA/G-8," Washington, DC, 2002. [Online]. Available: www.epa.gov/quality

SNI ISO 14040. (2016). Manajemen Lingkungan – Penilaian Daur Hidup – Prinsip dan Kerangka Kerja. Badan Standarisasi Nasional. Jakarta.

Hauschild, M., Z., Rosenbaum, R., K., & Olsen, S., I., (2018). Life Cycle Assessment. Springer International Publishing AG. https://doi.org/10.1007/978-3-319-56475-3.

K. A. I. Menoufi, Life cycle analysis and life cyle impact assessment methodologies: a state of the art. Maig: Universitat de Lleida, 2011. Accessed: Jan. 09, 2024. [Online]. Available: http://hdl.handle.net/10459.1/45831.

M. Z. Hauschild, R. K. Rosenbaum, and S. I. Olsen, Life Cycle Assessment. Cham, Switzerland: Springer International Publishing AG , 2018. doi: 10.1007/978-3-319-56475-3.

M. Esa, A. Bagaswara, and Y. Hadi, “Analisis dan Rekayasa Proses Produksi untuk Mengendalikan Environmental Impact Menggunakan Metode LCA,” 2017. [Online]. Available: http://ojs.atmajaya.ac.id/index.php/metrisTelp.

T. R. Harjanto and S. Bahri, “Life Cycle Assessment Pilihan Penggunaan Alat Transportasi Bagi Siswa SMA di Cilacap Dalam Kerangka Penerapan Mekanisme Pembangunan Bersih,” in Jurnal Rekayasa Teknologi Industri Hijau RATIH VOL.2 Edisi 1, 2018, pp. 1–13.