International Journal on Advanced Science Engineering Information Technology

Vol.13 (2023) No. 5
ISSN: 2088-5334

Analysis of Energy Efficiency by Using Gas Venting the Start-Up Process of PT Pupuk Iskandar Muda

Muhammad Hijrin [a,*], Siti Shara [a], Agustria [a], Ahmad Ghufran [a], Giffari Almuzani [a], Didik Nurhadi [a], Suryadi Idris [a], Fachrian [a], Aidil Azhar [a]

[a] *PT Pupuk Iskandar Muda, Krueng Geukueh, Aceh Utara, Aceh, 24354, Indonesia*

*Corresponding author: *muhammadhijrin05@gmail.com*

***Abstract*— PT Pupuk Iskandar Muda, as a manufacturing industry that produces fertilizers and ammonia, requires much energy at the start of the plant. Hence, optimizing energy consumption and increasing energy efficiency is necessary to reduce greenhouse gas (GHG) emissions. Start-up, as one of the vital activities carried out in the industry, significantly affects high energy consumption, especially when the start-up frequency is high, resulting in significant exhaust gases. This study analyzes energy efficiency in plant start-up activities using a gas venting outlet, finally desulfurized as a Low-Temperature Shift Converter heating medium. Determination of targets for problems related to energy efficiency using the Quality, Cost, Delivery, Healthy, Safety, and Environment (QCDHSE) method. At the same time, the Nominal Group Technique (NGT) method is used to identify problems in energy efficiency in the ammonia plant. Using gas venting reduces the factory's start-up time to three hours, which reduces the ammonia plant's start-up energy consumption from 48,832 MMBtu to 45,565 MMBtu, resulting in an energy efficiency of 277 MMBtu/hour. With 6.7% and 20% improvements in energy efficiency and reduced fuel consumption. PT Pupuk Iskandar Muda has saved IDR 343,035,000 in ammonia plant start-up costs. Energy efficiency is a measure taken to avert catastrophic climate change. Increasing energy efficiency is consistent with reducing carbon emissions, which can decrease environmental air pollution.**

***Keywords*— Energy efficiency; emission reduction; gas venting; ammonia plant; start-up.**

Manuscript received 1 May 2023; revised 14 Jun. 2023; accepted 15 Sep. 2023. Date of publication 31 Oct. 2023

I. INTRODUCTION

Nowadays, optimizing energy consumption, increasing energy efficiency, and reducing greenhouse gas emissions are critical for sustainable operations and lowering the operating costs of industrial facilities. Every industrial facility depends on more than one form of utility for its operation, including power plants, steam systems, instrument and plant air, nitrogen systems, hot oil systems, and others. As one of the activities carried out in the industry, the start-up is used in the manufacturing industry to turn on/start plant equipment to produce products. High start-up time can affect the high energy consumption of plant start-up, resulting in high exhaust gas production. In 2019, the industrial sector contributed 31,8 percent or about a third of the world's energy consumption [1]–[3].

PT Pupuk Iskandar Muda, as a petrochemical manufacturing industry that produces fertilizers and ammonia, requires a lot of energy when the plant wants to start up. Start-up is usually done when the plant is completed construction (new plant) or after being shut down (off) due to problems or other things. The start-up frequency becomes very high when the plant often has natural gas supply problems. The impact of the problems can result in relatively long start-up times for ammonia, decreased energy efficiency, increased plant operating costs, and increased pollution at start-up. The start-up duration of PT Pupuk Iskandar Muda usually takes 41 hours according to the Standard Operating Procedure (SOP), which requires 48,832 MMBtu of energy. Start-up requires a substantial cost because, at the time of start-up, natural gas is released into the atmosphere in large quantities through venting facilities. Natural gas costs represent more than 80 percent of the total cost of producing ammonia, reaching 90 percent in some cases [4], [5]

The fertilizer industry has considerable energy consumption; therefore, measuring and optimizing the amount of energy it uses is essential to determine the potential for improving energy efficiency and identifying the most effective methods [6]–[8]. This study analyzes energy efficiency in plant start-up activities by utilizing a gas venting outlet, finally desulfurized as a Low-Temperature Shift Converter heating medium. Using gas venting can reduce the start-up duration so that the energy required at start-up decreases and increases the efficiency of the ammonia plant. Thus, PT Pupuk Iskandar Muda can reduce the start-up time of the ammonia plant and improve energy efficiency, thereby reducing plant operating costs. In order to increase operational effectiveness, lessen greenhouse gas emissions, and boost energy efficiency, the biggest oil and gas companies in the world, including Shell, ExxonMobil, and Chevron, are also reducing the amount of gas vented. Efficiency is one of the pillars of decarbonization. The Indonesian government aims to achieve the Net Zero Emission target by 2060 or sooner.

Member nations concurred in the 2015 Paris Agreement to limit global warming to 2 °C above pre-industrial levels [9]–[11]. This requires an 80 to 95 percent reduction in greenhouse gas (GHG) emissions from 1990 levels by 2050. As industry accounts for approximately 29.2% of CO_2 emissions [12], [13], this target cannot be achieved without industrial decarbonization activities [14]–[16]. The implementation of energy conservation in Indonesia has the potential for enormous energy savings in the future derived from efficiency improvements.

II. Materials and Method

This study uses actual data from the company PT. Iskandar Muda fertilizer. PT. Pupuk Iskandar Muda is a manufacturing industry with two units of urea and ammonia fertilizer plants, namely PIM-1 and PIM-2. PIM-1 plant has an ammonia production capacity of 330,000 tons and urea of 570,000 tons per year. Meanwhile, the PIM-2 plant has a production capacity of 396,000 tons of ammonia and 570,000 tons of urea annually.

The data used is information on the operation and production processes, especially the start-up of the ammonia plant. This study uses the Quality, Cost, Delivery, Healthy, Safety, and Environment (QCDHSE) method to set targets for problems related to energy efficiency [17], [18]. The Nominal Group Technique (NGT) method is used to identify problems in energy efficiency in ammonia plants [19], [20]. In addition, the discussion of this study also collects data from the research results carried out by previous researchers, books, journals, or other documents that contain topics related to this research. Based on the analysis results using the QCDHSE method, the target of the problem in the start-up process of the ammonia plant is set as in Table 1.

TABLE I
Targets determination QCDHSE method

Aspects	Problems	Targets
Quality	High energy consumption at start-up	To increase the energy efficiency of start-up
Cost	The cost of natural gas raw materials is high	Saving natural gas consumption
Delivery	The time to start up urea plant is delayed	Urea plant start-up faster
Healthy	Noise at start-up	The duration of the noise at start-up is reduced
Safety	The potential for unsafe action and conditions is high	Reduce the potential for unsafe actions and high conditions
Environment	CO_2 exposure to the atmosphere during the start-up process	Reduce the exposure time of CO_2 gas to the atmosphere during the start-up process

III. Results and Discussion

Based on the data on the stratification of the ammonia plant problem, there are many problems if the plant is doing a start-up process. The one with the most effective cost measurement is the amount of gas vented at the start-up. The cost of venting gas is lost when the start-up process spends about thousands of dollars. The high frequency of start-ups affects the high energy consumption for start-ups (monthly and yearly energy accumulation). The limitation and continuity of gas supply often cause an unscheduled shutdown. That will also create another cost because of the unscheduled shutdown, for example, a plant equipment failure that may increase its maintenance cost.

A. Improvement of the Start-Up Process

From several problems of ammonia plant start-up, the results obtained are the sequence of the most important problems (Table 2).

TABLE II
Ranking of problems using the NGT method

Factors	Root Causes (n)	Priority Value					
		Result 1	Result 2	Result 3	Result 4	Total	Percentage (%)
Human	The operator lacks a comparative study	2	1	2	1	6	10
Method	Insufficient nitrogen	1	3	1	2	7	11,67
Equipment	Equipment lifetime decreased	4	2	3	3	12	20
Materials	There is no comprehensive review of the Standard Operating Procedure for start-up on changes in gas composition	5	4	5	5	19	31,67
	Source natural gas problem (PTGN)	3	5	4	4	16	26,67
Total		15	15	15	15	60	100

There are four factors in the results of problem identification, where the equipment and material factors significantly affect the high gas consumption at start-up. The root cause is the decline in equipment performance, the absence of a comprehensive SOP for the utilization of venting gas, and the problem of natural gas sources. Based on the problem ranking table using the NGT method, the three causes have a high priority value above 20 percent.

With the existing problems, gas venting improves energy efficiency at start-up ammonia plants. Ammonia is an essential intermediate for the production of nitrogen fertilizers and complex fertilizers. Energy accounts for about 90 percent of the variable costs of ammonia production [21]. Ammonia accounts for 80 percent of the energy consumption of urea and other fertilizers [22]. Energy conservation has always been a focus area in the fertilizer sector [23]. Efficiency in energy use plays an essential role in supporting national energy security. Energy consumption will be proportional to the resulting CO_2 emissions so that efficient energy use can reduce the resulting CO_2 emissions. Additionally, energy efficiency drives numerous economic, environmental, and health benefits related to local air quality [24], [25].

About 80 percent of the energy needed to produce urea and complex fertilizers is used to produce ammonia. Thus, ammonia plants have always focused on energy conservation measures [23].

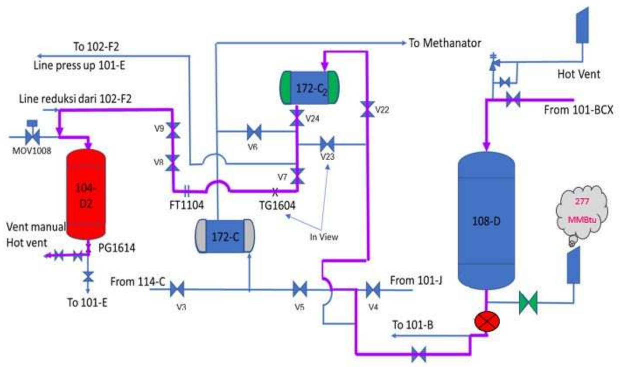

Fig. 1 Schematic before using Gas venting outlet Final Desulfurizer (61-108 D) as a medium for heating Low-Temperature Shift Converter (61-104 D2).

During average start-up, each catalyzed vessel requires heating up by flowing hot gas media into the vessel at 200 to 250ºC and discharging into the atmosphere (Fig. 1). The process is heating the final desulfurized catalyst, and gas venting starts stage 1.

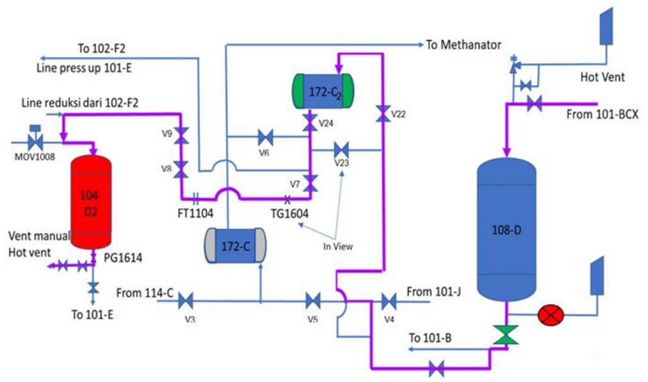

Fig. 2 Schematic after utilization of Gas venting outlet Final Desulfurizer (61-108 D) as a medium for heating Low-Temperature Shift Converter (61-104 D2).

Gas venting is used as a heating catalyst in the low-temperature shift converter. In contrast, before the use of gas venting, the heating up low-temperature shift converter process is carried out after gas venting. As a result, the LTS temperature is reached when heating up by utilizing the gas venting outlet, finally desulfurized. The appropriate input composition (CO and H2O) and suitable operating parameters, i.e., pressure and residence time, are the variables affecting the LTS converter.

Hot gas venting is heating energy produced by burning fuel or chemical reactions discharged into the environment. Exhaust gas from engine combustion can be used as a new energy source. The utilization of exhaust gas is an effort to reduce fuel consumption to increase efficiency and economic value. The strategy on how to utilize the heat energy of the flue gas depends on the temperature of the flue gas and its pressure. Fuel use can be more efficient if the hot flue gas can be recovered [26].

After reviewing and making SOP for the utilization of the 108-D gas venting outlet at start-up for heating the 104-D2 catalyst (Low-Temperature Shift Converter), the catalyst bed temperature can be achieved optimally and following the 104-D2 functional design caused by the mass flow from the 108-D venting outlet is sufficient for the 104-D2 catalyst carrier bed gas. With the catalyst bed temperature of 104-D2, the start-up time is reduced by 3 hours, whereas previously, the start-up duration took 41 hours (Fig. 3). This impacts energy efficiency at a start-up of 277 MMBtu/hour, equivalent to IDR 87,237,384.

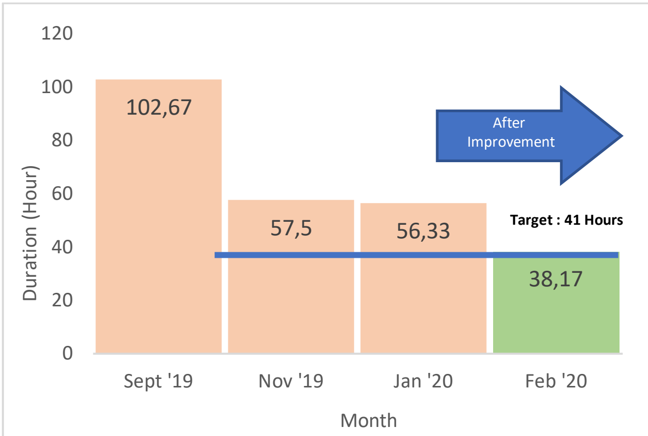

Fig. 3 Start-Up Duration Before and After Improvement.

The calculation of gas savings is based on the average number of stresses per compressor per year, the quantity of gas required per start, and the number of avoided or unsuccessful engine starts. Units with frequent unsuccessful starts and downtime are inconvenient and expensive, necessitating many maintenance hours [27].

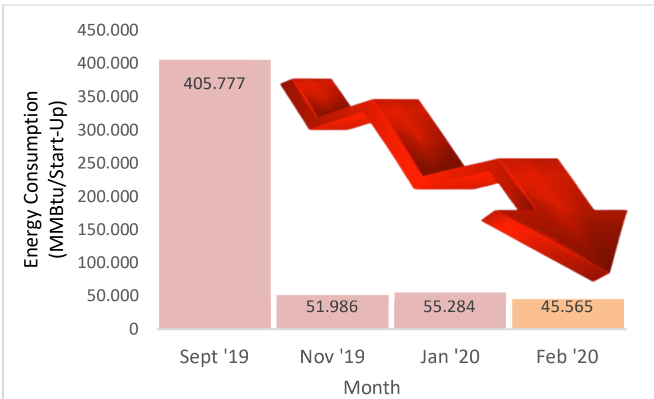

Fig. 4 Start-Up Energy Consumption after Improvement.

The energy use efficiency of a factory can be seen from the amount of energy used to produce one unit of production. The fertilizer industry is included in the category of energy-intensive manufacturing industry, namely the high energy user industry group [28]. After making improvements, the start-up energy for the ammonia plant decreased from 48,832 MMBtu to 45,565 MMBtu (Fig. 4), so energy efficiency increased by 6,7 percent. These energy efficiency improvements can reduce carbon emissions competitively. Reducing fuel consumption by 15 to 20 percent can be economical in the long run [14]. The purpose of energy conservation is to preserve natural resources in the form of energy sources through policies on technology selection and efficient and rational use of energy. Energy savings can be achieved by using energy efficiently, with the same benefits obtained by using less energy.

Production processes with a higher intensity of energy use, such as the fertilizer industry, are sectors whose production prices are strongly influenced by the price of energy used (i.e., natural gas) [29], [30]. So, to prevent higher production costs, PT Pupuk Iskandar Muda made improvements that led to more efficient use of energy and resulted in lower emissions. Energy savings can lead to reduced costs and increased efficiency and profitability. For example, with an increase in the energy efficiency of 6,7 percent, the savings in start-up costs for the ammonia plant are equivalent to IDR 343,035,000 (Fig. 5). Energy resource management is one of the most crucial issues. Energy needs will also increase along with the improvement and growth of national economic conditions after the COVID-19 pandemic. This challenge must be solved by industry, which is the leading actor in the country's economic cycle and one of the largest energy consumers.

Fig. 5 Start-Up Cost of Ammonia Plant after Improvement.

The positive impact of using gas venting can make the start-up of the urea plant faster, reduce work time at start-up, reduce the risk of unsafe actions and conditions, and reduce the cost of production. The duration of start-up usually takes longer before the plant gets an improvement, so it consumes high energy (natural gas). Reducing energy consumption can improve the quality of the environment, which can be measured by the level of emissions or pollutants around industry decreasing. Indonesia has the technical potential to greatly reduce energy-related CO emissions to levels significantly contributing to global efforts to prevent a 2°C temperature increase by 2050 [31]. Policies to reduce air pollutants and greenhouse gas emissions produce co-benefits for the global climate [32], [33]. Reducing greenhouse gas emissions in place can affect global climate change because the global climate system affects the atmosphere and local changes[34].

TABLE III
ACHIEVEMENTS THROUGH QCDHSE

Aspect	Problems	Targets	Achievement
Quality	High energy consumption at start-up of ammonia plant	To increase the energy efficiency of start-up	After making improvements, energy start-up for the ammonia plant decreased from 48.832 MMBtu to 45.565 MMBtu, so energy efficiency increased by 6,7 percent.
Cost	The cost of natural gas raw materials is high	Saving natural gas consumption	With an increase in the energy efficiency of 6,7 percent, the savings in start-up costs for the ammonia plant is equivalent to IDR 343.035.000.
Delivery	The time to start-up urea plant is delayed	Urea plant start-up faster	The start-up duration of the ammonia plant is reduced by 3 hours.
Healthy	Noise at start-up	The duration of the noise at start-up is reduced	Reduced noise duration at the start-up of the ammonia plant.
Safety	The potential for unsafe actions & conditions is high	Reduce the potential for unsafe actions & high conditions	Reduced potential for work accidents due to shorter start-up duration for ammonia plants.
Environment	CO_2 exposure to the atmosphere during the start-up process	Reduce the exposure time of CO_2 gas to the atmosphere during the start-up process	CO_2 gas pollution in the atmosphere can be minimized.

Reducing the start-up duration of the ammonia plant to 3 hours has reduced the energy used during the start-up period. As a result, exposure to CO_2 gas in the atmosphere during the start-up process is decreasing to minimize pollution of carbon emissions to the environment. Energy savings can reduce greenhouse gas emissions and is one of the efforts to mitigate climate change. Efficient energy use is critical to a future with universal access to energy-efficient industries [35], [36]. The Government of Indonesia recognizes climate change as a significant economic development and planning issue. The Government of Indonesia also recognizes that early action to mitigate and adapt will be strategically and economically beneficial for Indonesia. Considering the Indonesian government's planned mitigation options, it is anticipated that the industry will be able to more effectively prepare for the potential socio-economic implications of emission mitigation policies and consider future policy improvements.

B. Supporting Factors and Constraining the Application of Gas Venting

1) Supporting factors

- Environmental Regulations

Compliance with environmental regulations is a crucial factor in the success of gas venting applications. Before being released into the atmosphere, these regulations may mandate reducing or treating certain toxic gases. The incorporation of exhaust gas conversion equipment reduces the environmental impact of gas venting by converting hazardous gases into less hazardous or more beneficial forms.

- Pollutant Abatement

Gas venting with apparatus for exhaust gas conversion can contribute to efforts to reduce pollution. The emissions emitted into the environment can be considerably reduced by converting or treating harmful gases, resulting in improved air quality and a healthier environment.

- Recovery of Resources

Some processes for converting exhaust gases enable the recovery of valuable resources from the expelled gases. Certain gases, for instance, can be converted into useful residues or captured for recycling. This aspect of resource recovery benefits the economy and promotes sustainability.

- Operating Profitability

Incorporating exhaust gas conversion apparatus into the process of gas venting can improve operational efficacy. It enables the recovery of additional value from the exhausted gases and reduces waste. By optimizing the conversion process, operational expenses can be reduced, and overall process efficiency enhanced.

2) Constraints

- Technical Difficulties

Technological constraints may limit the application of apparatus for converting exhaust gases. Developing and implementing efficient and cost-effective gas conversion technologies can be difficult. Designing and optimizing effective conversion systems requires research, development, and engineering knowledge.

- Financial Factors

The addition of exhaust gas conversion equipment incurs expenses associated with the equipment's acquisition, installation, operation, and maintenance. These costs must be assessed carefully to ensure they are economically viable and justifiable concerning the environmental and operational benefits obtained.

- Compatibility of Process

The conversion apparatus for exhaust gases must be compatible with the specific gases being vented. Gases require various conversion technologies and catalysts, so the equipment must be customized to the gas stream's characteristics. There may be compatibility issues when handling complex gas mixtures or contaminants.

- Integration Process

Integrating the apparatus for exhaust gas conversion into the existing gas venting process can present logistical challenges. It may necessitate changes to the overall process design, such as installing additional equipment, reconfiguring conduits, and modifying process parameters.

IV. Conclusion

Using gas venting reduces the start-up duration of the factory to 3 hours, which impacts the start-up energy for the ammonia plant from 48,832 MMBtu to 45,565 MMBtu, so that energy efficiency at start-up is 277 MMBtu/hour. PT Pupuk Iskandar Muda has been saving energy and reducing carbon emissions competitively. Efficient energy use can lead to reduced costs and increased efficiency and profits. With an increase in energy efficiency of 6.7 percent, PT Pupuk Iskandar Muda has saved an ammonia plant start-up cost equivalent to IDR 343,035,000. Reducing fuel consumption by 15 to 20 percent can be economical in the long run. Energy efficiency is an effort to prevent extreme climate change. Increasing energy efficiency is in line with reducing carbon emissions, which can reduce air pollution in the environment.

Acknowledgment

We are grateful to PT Pupuk Iskandar Muda that funding this research.

References

[1] EIA, "EIA Annual Energy Review," *URL: https://www.eia.gov/totalenergy/data/annual/ (Accessed: 2021-06-20)*, 2020.

[2] L. Zhou, J. Li, F. Li, Q. Meng, J. Li, and X. Xu, "Energy consumption model and energy efficiency of machine tools: A comprehensive literature review," *Journal of Cleaner Production*, vol. 112. 2016. doi: 10.1016/j.jclepro.2015.05.093.

[3] M. Gao, K. He, L. Li, Q. Wang, and C. Liu, "A review on energy consumption, energy efficiency and energy saving of metal forming processes from different hierarchies," *Processes*, vol. 7, no. 6. 2019. doi: 10.3390/pr7060357.

[4] D. Velázquez, F. Rossi, and J. Rodríguez, "Improving energy efficiency in an ammonia plant," 2013.

[5] M. Di Salvo and M. Wei, "Synthesis of natural gas from thermochemical and power-to-gas pathways for industrial sector decarbonization in California," *Energy*, vol. 182, 2019, doi: 10.1016/j.energy.2019.04.212.

[6] E. A. Biryuzova and A. S. Glukhanov, "Studying the Features of Method Choice of Heat Networks Laying Which Affect Their Energy Efficiency," *Proceedings of the Southwest State University*, vol. 24, no. 4, 2021, doi: 10.21869/2223-1560-2020-24-4-29-41.

[7] M. Abdi Oskouei and K. Awuah-Offei, "A method for data-driven evaluation of operator impact on energy efficiency of digging machines," *Energy Effic*, vol. 9, no. 1, 2016, doi: 10.1007/s12053-015-9353-3.

[8] B. Hariyanto, "Energy Efficiency: The Manufacturing Sector in Indonesia," *JEJAK*, vol. 14, no. 2, 2021, doi: 10.15294/jejak.v14i2.28850.

[9] J. Delbeke, A. Runge-Metzger, Y. Slingenberg, and J. Werksman, "The paris agreement," in *Towards a Climate-Neutral Europe: Curbing the Trend*, 2019. doi: 10.4324/9789276082569-2.

[10] A. Zaklan, J. Wachsmuth, and V. Duscha, "The EU ETS to 2030 and beyond: adjusting the cap in light of the 1.5°C target and current energy policies," *Climate Policy*, vol. 21, no. 6, 2021, doi: 10.1080/14693062.2021.1878999.

[11] G. Luderer *et al.*, "Residual fossil CO_2 emissions in 1.5-2 °C pathways," *Nat Clim Chang*, vol. 8, no. 7, 2018, doi: 10.1038/s41558-018-0198-6.

[12] A. A. G. Bruzzone, D. Anghinolfi, M. Paolucci, and F. Tonelli, "Energy-aware scheduling for improving manufacturing process sustainability: A mathematical model for flexible flow shops," *CIRP Ann Manuf Technol*, vol. 61, no. 1, 2012, doi: 10.1016/j.cirp.2012.03.084.

[13] EPA, "EPA Inventory of U.S. greenhouse gas emissions and sinks: 1990-2017," *URL: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2017*, 2019.
[14] A. de Pee, D. Pinner, O. Roelofsen, K. Somers, E. Speelman, and M. Witteveen, "Decarbonization of industrial sectors: the next frontier," *McKinsey & Company*, no. June, 2018.
[15] T. Rajabloo, W. De Ceuninck, L. Van Wortswinkel, M. Rezakazemi, and T. Aminabhavi, "Environmental management of industrial decarbonization with focus on chemical sectors: A review," *Journal of Environmental Management*, vol. 302. 2022. doi: 10.1016/j.jenvman.2021.114055.
[16] E. Kawai, A. Ozawa, and B. D. Leibowicz, "Role of carbon capture and utilization (CCU) for decarbonization of industrial sector: A case study of Japan," *Appl Energy*, vol. 328, 2022, doi: 10.1016/j.apenergy.2022.120183.
[17] R. Ding, J. Xu, and Y. Sui, "An Integrated Management System for Quality, Health and Safety, and Environment: A Case Study," *Journal of Electrical and Electronic Engineering*, vol. 9, no. 5, 2021, doi: 10.11648/j.jeee.20210905.14.
[18] J. Santos, V. W. Y. Tam, and A. C. Jorge Evangelista, "Implementation and Analyses of Quality, Health, Safety, and Environment (QHSE) Management in Retrofit Works.," *International Journal of Construction Project Management*, vol. 9, no. 1, 2017.
[19] K. Manera, C. S. Hanson, T. Gutman, and A. Tong, "Consensus methods: Nominal group technique," in *Handbook of Research Methods in Health Social Sciences*, 2019. doi: 10.1007/978-981-10-5251-4_100.
[20] N. Harvey and C. A. Holmes, "Nominal group technique: An effective method for obtaining group consensus," *Int J Nurs Pract*, vol. 18, no. 2, 2012, doi: 10.1111/j.1440-172X.2012.02017.x.
[21] Y. Bicer and I. Dincer, "Life cycle assessment of ammonia utilization in city transportation and power generation," *J Clean Prod*, vol. 170, 2018, doi: 10.1016/j.jclepro.2017.09.243.
[22] N. Zecca and G. Manzolini, "Definition of the base and reference cases for KPIs assessment Deliverable report D5.3."
[23] M. Goswami and S. Nand, "Recent Efforts in Energy Conservation in Ammonia and Urea Plants," *Indian Journal of Fertilisers* , vol. 17, no. 7, pp. 628–634, 2021.
[24] X. Yang, X. Xi, W. Lin, and S. Guo, "Effect of China's energy conservation efforts on reducing health damage," *Energy Procedia*, vol. 158, pp. 3768–3773, 2019, doi: 10.1016/j.egypro.2019.01.878.
[25] Y. L. Chen, Y. H. Shih, C. H. Tseng, S. Y. Kang, and H. C. Wang, "Economic and health benefits of the co-reduction of air pollutants and greenhouse gases," *Mitig Adapt Strateg Glob Chang*, vol. 18, no. 8, pp. 1125–1139, 2013, doi: 10.1007/s11027-012-9413-3.
[26] I. Mustain, "Analisis Pemanfaatan Gas Buang Pada Mesin Generator Set Melalui Sistem Organic Rankine Cycle,"*Jurnal Sains Dan Teknologi Maritim*, vol. 21, no. 2, 2021, doi: 10.33556/jstm.v21i2.271.
[27] Epa and GasSTAR, "Partner Reported Opportunities (PROs) PRO Fact Sheet No. 102 for Reducing Methane Emissions."
[28] S. H. Pranolo, S. U. Muzayanha, C. S. Yudha, L. M. Hasanah, and E. N. Shohih, "Kajian Konsumsi Energi Spesifik Sektor Industri Kimia Di Indonesia Sebagai Acuan Efisiensi Energi."
[29] K. Rademaekers *et al.*, "Study on Energy Prices, Costs and Subsidies and their Impact on Industry and Households," 2018.
[30] F. Pietro Colelli, J. Emmerling, G. Marangoni, M. N. Mistry, and E. De Cian, "Increased energy use for adaptation significantly impacts mitigation pathways," *Nat Commun*, vol. 13, no. 1, p. 4964, 2022, doi: 10.1038/s41467-022-32471-1.
[31] M. Malahayati and T. Masui, Potential impact of introducing emission mitigation policies in Indonesia: how much will Indonesia have to spend?, vol. 26, no. 8. Springer Netherlands, 2021. doi: 10.1007/s11027-021-09973-2.
[32] C. H. Tseng, L. L. Chen, and Y. H. Shih, "Quantifying the environment and health co-benefits of low-emission vehicles in Taiwan," *Journal of Integrative Environmental Sciences*, vol. 12, no. 1, pp. 39–48, 2015, doi: 10.1080/1943815X.2014.980747.
[33] D. A. Permadi, A. Sofyan, and N. T. Kim Oanh, "Assessment of emissions of greenhouse gases and air pollutants in Indonesia and impacts of national policy for elimination of kerosene use in cooking," *Atmos Environ*, vol. 154, 2017, doi: 10.1016/j.atmosenv.2017.01.041.
[34] S. Dissanayake, R. Mahadevan, and J. Asafu-Adjaye, "Evaluating the efficiency of carbon emissions policies in a large emitting developing country," *Energy Policy*, vol. 136, no. November 2019, p. 111080, 2020, doi: 10.1016/j.enpol.2019.111080.
[35] J. G. D. B. Leite *et al.*, "Sugarcane: a way out of energy poverty," *Biofuels, Bioproducts and Biorefining*, vol. 10, no. 4, 2016, doi: 10.1002/bbb.1648.
[36] G. Kalt, P. Thunshirn, F. Krausmann, and H. Haberl, "Material requirements of global electricity sector pathways to 2050 and associated greenhouse gas emissions," *J Clean Prod*, vol. 358, 2022, doi: 10.1016/j.jclepro.2022.132014.