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Application of Life Cycle Assessment for Improving the Energy and Waste Management Strategy: A Case Study of Fertilizer Plant in Indonesia

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Indonesia is one of the countries worldwide that consume significant fertilizer for agricultural activities. A total of 6.27 Mt of urea fertilizer per annum was consumed. Therefore, some fertilizer plants operate in Indonesia and one of the plants is managed by PT Pupuk Kujang. The plant is located at Cikampek West Java and has two production lanes where each lane has a production capacity of 570,000 t urea annually. This study is aimed to identify the potential impact and environmental hotspots of a fertilizer plant. The Life Cycle Assessment (LCA) method was applied and using Centrum Voor Milieuwetenschappen Impact Assessment (CML-IA) analysis for life cycle impact assessment (LCIA). Three main categories were analysed, namely climate change, acidification, and eutrophication. The functional unit was the potential environmental impacts generated by 50 kg of urea fertilizer production. The productions (ammonia, and urea) and distribution process were considered as the system boundary. Seven production processes occurred in the urea plant including synthesizing, purification, concentration, prilling, recovery, process condensate, and bagging process. The results showed that the 50 kg of urea fertilizer emitted 4.73 kg CO_2-eq, 0.03 kg SO_2-eq, and 0.015 kg PO_4-eq and the environmental hotspots were caused by the consumption of electricity from state-owned company (31.5 %), polypropylene content in the fertilizer packaging (0.74 %), and transportation (1.48 %). These environmental hotspots provided an opportunity for the renewable energy introduction and the application of a packaging reuse program to reduce those potential environmental impacts. These strategies improved the environmental performance of PT Pupuk Kujang as a urea fertilizer producer.

1. Introduction

Fertilizer is one of the critical plant nutrients that commonly applied by the farmer to increase yield production. There are three primary nutrients, namely Nitrogen (N), Phosphorus (P), and Potassium (P), that required for crop growth and development. These three nutrients have their usage purposes. The usage of Nitrogen helps plant growth, vigour, colour, and yield while Phosphorus nutrient contributes to plant development including the ripening of seed and fruit (Firmansyah et al., 2017). In addition, the Potassium will improve the crop resistance level to the external factors including disease and drought.

There are two common types of fertilizer worldwide, namely organic fertilizer and mineral fertilizer. Organic fertilizer is produced from organic materials such as food waste, animal, and crop residue. On the other hand, the mineral fertilizer (usually known as inorganic fertilizer) raw materials include natural gas, and air. The comparison of these two fertilizer types is presented in Table 1.

Mineral fertilizer consumption worldwide tends to increase yearly as presented in Figure 1 where the average total percentage increase of three main fertilizers during 2010-2018 is approximately 15 %. The highest consumption is Nitrogen (N) fertilizer that reaches 107 Mt and followed by phosphorous (P) fertilizer with a total consumption of approximately 47 Mt.

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Table 1: Comparison between organic and inorganic fertilizer (Yara, 2018)

Characteristics	Organic Fertilizer	Mineral Fertilizer
Sources	animal manure, food waste, plant waste	natural gas, air, mines
Nutrient combination and Application	high nutrient content, low consumption per area	low nutrient content, high consumption per area
Production	small and medium scale	industrial scale
Quality	high deviation	product standardization

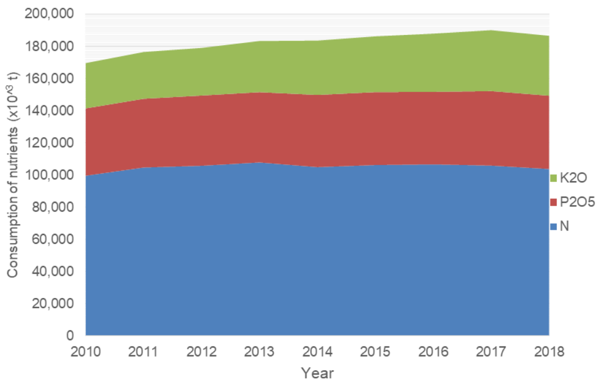

Figure 1: Fertilizer consumption worldwide (IFA, 2019)

These two fertilizers (N and P) are mainly distributed in two Asian regions, namely East Asia and South Asia, as presented in Figure 2. According to the FAO (2019) that the classification of East Asia regions covers some countries including Brunei Darussalam, Cambodia, China, Indonesia, Japan, Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, Philippines, Republic of Korea, Singapore, Thailand, Timor-Leste, and Vietnam. The East Asia countries consume 31 % of Nitrogen and 33 % of Phosphorous fertilizer approximately as presented on Figure 2. As part of the East Asia region, Indonesia consumed about 6.27 Mt of Nitrogen fertilizers as Urea in 2018 where the consumption rate increases 5 % compared with the previous year (Kemenperin, 2019).

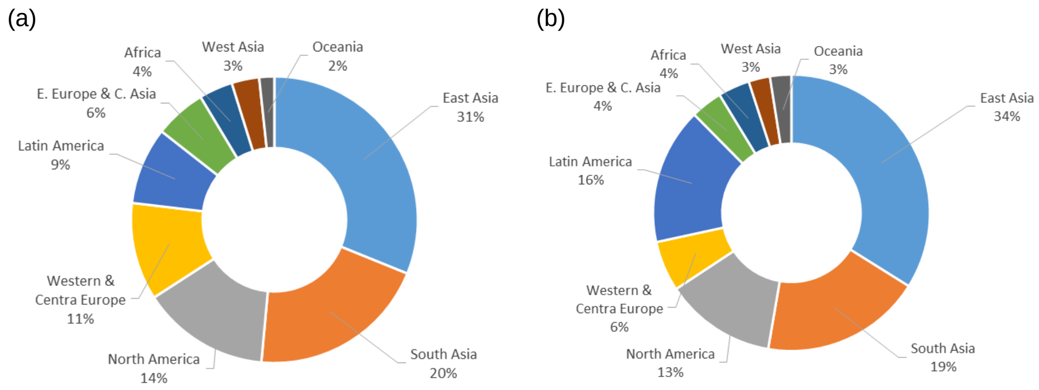

Figure 2: The percent consumption of (a) Nitrogen, and (b) Phosphorous (adapted from IFA, 2019)

The bulk production and consumption of fertilizer contribute to environmental degradation (Kytta et al., 2020). The impact contributions are commonly generated from production processes, distribution, and application stage. Some of the environmental impacts that might occur from production, distribution, and application stage include global warming (Chen et al., 2018), water pollution, and soil acidification (Quiros et al., 2015). Another environmental issue associated with the fertilizer industry is the energy consumption and waste generated. Total energy consumption for fertilizer production annually is estimated at 1.2 % of the world's total energy (IFA, 2014). In addition, DEN (2019) and EIA (2016) record that the fertilizer industry is among the top three main industrial sectors for energy consumers in Indonesia and China. Therefore, the fertilizer industry is also known as an energy-intensive industry. Some studies also recorded that used-fertilizer bags is one of the municipal plastic wastes that commonly found in landfill (Hidayah and Syafrudin, 2018). These two facts conclude why energy and waste management are essential two elements that should be considered in improving the environmental performance of a fertilizer plant.

One of the strategies that can be taken to increase industrial environmental performance is by implementing effective environmental management. The environmental performance could be improved by managing the environmental hotspots occurred. Currently, environmental management has various tools that would assist in locating the environmental hotspots including Life Cycle Assessment (LCA). In addition, LCA is also a useful tool to identify the potential environmental impact of a production process such as geothermal (Adiansyah, et al., 2021), fertilizer (Adiansyah et al., 2019), mine tailing management (Adiansyah et al., 2017). Hasler et al. (2015) conducted a study to compare five environmental impacts (climate change, acidification, eutrophication, fossil fuel depletion, and resources depletion) of various fertilizer types. The study revealed that the highest contributor for climate change, acidification, and fossil fuel impact category was fertilizer process production. Other studies on fertilizer application were also found such as fertilizer application on coffee (Vera-Acevedo et al., 2016), maize and soybean (Romeiko, 2019), cauliflower and tomato (Quiros et al., 2015). The author found that only one study associated with fertilizer production in Indonesia (Adiansyah et al., 2019). Current literature, however, has not covered the scenarios for reducing the environmental hotspots due to fertilizer production. Therefore, this study attempts to fill the gap and discover the novelty on environmental impacts of fertilizer production and distribution in Indonesia.

This paper aims to assess the potential environmental impact and environmental hotspots of fertilizer production at PT Pupuk Kujang, West Java, Indonesia.

2. Methods

PT Pupuk Kujang has two fertilizer plants as known as Pupuk Kujang 1A and Pupuk Kujang 1B. This LCA study is focused on Pupuk Kujang Plant 1B that has 570,000 production capacity of urea annually. The LCA method refers to ISO 14040:2006 that divided into four main stages, namely goal and scope, inventory analysis, life cycle impact analysis, and interpretation (ISO, 2006). Energy consumption and waste management of fertilizer used-packaging were chosen as two main parameters in this study. The potential environmental impact was analysed using SimaPro with the CML-IA characterization factor.

Scenario analysis presented in section 3.3 was applied by introducing some strategies to reduce the identified environmental hotspots. Two main possible scenarios were partly substituting fossil fuel energy with renewable energy, and introducing the reuse program of urea fertilizer packaging. The solar PV was proposed for substitute the fossil fuel energy in bagging plant facility that currently consumes 538,000 kWh/y electricity. Two reduction scenarios are applied, namely 10 % renewable energy, and 100 % renewable energy. In addition, the contribution of fertilizer packaging reuse scenario to the reduction of environmental impacts was simply calculated from the percent contribution impact of propylene material.

2.1 Functional unit and system boundary

The goal of this study was analysing the environmental impact of urea production in Pupuk Kujang Plant 1B. In addition, the functional unit used was associated with the potential environmental impact of 50 kg urea production. There were three critical potential environmental impact categories associated with fertilizer plant that analysed: climate change, acidification, and eutrophication (Hasler et al., 2015).

The scope of this study was described by its system boundary. The system boundary that defined as cradle to gate system boundary was divided into three main stages, as presented in Figure 3. The upstream process covered the raw material supply including natural gas, chemical, and water. Two main production processes involved in the core stage were ammonia and urea production. The final product of 50 kg urea was transported to the urea storage facility, and this stage was classified as a downstream process.

2.2 Life cycle inventory

The life cycle inventory is aimed to collect all materials and energy consumption for generating urea fertilizer as per its functional unit. The materials required include natural gas, water, chemical, and diesel. PT Pupuk Kujang Indonesia provides the operational data for ammonia plant, urea plant, and distribution process. Total consumption of natural gas (raw material) that injected to the Ammonia Plant was approximately 7,589,577 MBTU/y for producing 307,422 t of hot Ammonia and 7,985 t of cold Ammonia as presented in Table 2. The Ammonia plant supplies hot ammonia to the urea plant for generating 528,350 t of urea. The distribution of urea fertilizer to the seller (fertilizer distributor) using a truck with total capacity of 8 t.

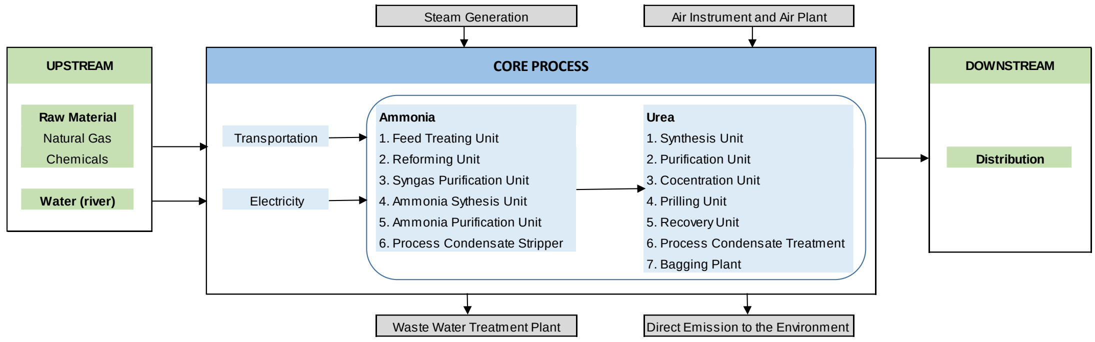

Figure 3: System boundary

Table 2: Life cycle inventory

Process	Product/Output	Amount/year	Unit
Ammonia Plant	Product – Hot Ammonia	307,422	t
	Product – Cold Ammonia	7,985	t
Feed treating unit	Output – Treated Natural Gas	210,427,873	Nm^3
Reforming unit	Output – Synthesis Gas	1,108,943,022	Nm^3
Syngas purification unit	Output – Treated Synthesis Gas	984,096,347	Nm^3
Ammonia synthesis unit	Output – Ammonia (concentration 13 %)	312,942	m^3
Ammonia purification unit	Output – Ammonia (concentration 99.8 %)	315,407	t
Process condensate stripper	Output – Condensate	388,396	t
Urea Plant	Product – Urea	528,350	t
Synthesis unit	Output – Urea Solution (concentration 49 %)	1,109,454	t
Purification unit	Output – Urea Solution (concentration 64 %)	798,955	t
Concentration unit	Output – Urea Solution (concentration 99.8 %)	536,112	t
Prilling unit	Output – Prilled Urea	533,829	t
Recovery unit	Output – Carbamate Solution	415,354	t
Process condensate treatment	Output – Off Gas	71,288	t
	Output – Treated Condensate to Prilling	3,240	t
	Output – Treated Condensate to Utility	7,315	t
Bagging Plant	Output – Urea 50 Kg package	528,350	t
Distribution	Product – Transporting Urea	63,917	t

Source: PT Pupuk Kujang (2019)

3. Results and Discussion

3.1 Impact assessment

Data inventory presented in Table 2 was analysed by using SimaPro (version 8.5.2) and focused on three mid-point impact categories: climate change, acidification, and eutrophication. In general, the Life Cycle Assessment Impact (LCIA) indicated that the process production of urea contributed about 70 % of the total environmental impact, as presented in Table 3. The result also showed that the contributions of 50 kg urea fertilizer process production to the global warming, acidification, and eutrophication generated were 4.73 kg CO_2-eq, 0.03 kg SO_2-eq, and 0.015 kg PO_4-eq as presented in Table 3.
The consumption of materials, energy and water in urea fertilizer production was higher compared to the distribution process resulted in a higher environmental impact. For example, the process production required molybdenum as a catalyst to convert the Sulphur compound into hydrogen sulphide, as presented in Eq(1).

$$R\text{-}SH + H_2 \rightarrow R\text{-}H + H_2S \qquad (1)$$

On the other side, no chemical input was required by the distribution stage, electricity and diesel fuel were the only two main inputs consumed. Total electricity annually consumed by two fertilizer storages (35,475 m^2) was approximately 194.034 KWh. The environmental impacts detailed of those three mid-point impact categories are discussed in sub-section 3.1.1 – 3.1.3.

Table 3: Life cycle impact assessment

Impact category	Unit	Stages				Total impact – system boundary
		Urea Product	Percentage	Distribution	Percentage	
Global warming	kg CO_2-eq	4.73	71.12	1.92	28.88	6.65
Acidification	kg SO_2-eq	0.0302	76.14	0.0095	23.86	0.0397
Eutrophication	kg PO_4-eq	0.0153	70.16	0.0065	29.84	0.0218

3.1.1 Global Warming Potential (GWP)

The greenhouse gases (GHG) emissions play an essential role in fertilizer production. Ammonia production as the main input for the urea fertilizer plant requires fossil fuels in the form of electricity. Therefore, global warming is one of the most critical parameters in this study. Network analysis with cut-off 0.5 % showed that Global Warming Potential (GWP-100) was mainly contributed by the production process where 31.5 % was recorded as the electricity usage. In addition, the utilization of propylene material as the packaging of urea fertilizer was also sharing an environmental impact of 0.74 %. This sharing indicated that the effective utilization of fertilizer packaging i.e., reuse should be considered and would help the reduction of GHG emissions emitted by PT Pupuk Kujang. The Indonesian state-owned company supplies PT Pupuk Kujang electricity demand and coal-fired power plant is the main energy source in the current Indonesian energy mix where the renewable energy contributes only 14 % of the total 64.5 GW of power plant installed capacity (DEN, 2019). In other words, energy consumption and energy mix are two primary parameters that could affect the global warming indicator.

3.1.2 Acidification

Sulphur (S) and Nitrogen (N) are two compounds that affect the acidification and one of the potential emission sources of these compounds is the power plant. In Indonesia, the energy mix is dominated by two fossil fuel power plants, namely the coal-fired power plant, and diesel power plant. Another source of Sulphur and Nitrogen compound in the form of SO_x (Sulphur Oxide) and NO_X (Nitrogen Oxide) gas is generated by process production of urea fertilizer. This process production requires natural gas and emits Sulphur Oxide and Nitrogen Oxide. LCIA showed that the contributions of natural gas and electricity usage were 71 % and 22.3 % for the acidification impact category. The high contribution of natural gas usage associated with the acidification impact category due to the high consumption of natural gas for supporting the Ammonia Plant operation. The consumption of natural gas during the Ammonia production process was approximately 7,589,577 MBTU/y.

3.1.3 Eutrophication

The most common causes of eutrophication are coming from two nutrients, namely nitrogen and phosphorous. The primary source of nitrogen pollutants is fertilizer utilization for agriculture purposes and some activities including power plant will generate phosphorous pollutant. LCIA showed that the fertilizer production process contributed 95.1 % of the total eutrophication impact category. One of the crucial inputs that play to the creation of eutrophication was electricity consumption supplied by the Indonesia state-owned company (45.4 %). The total of PO_4-eq generated by two main processes were 0.0153 kg for urea production and 0.0065 kg for distribution process.

3.2 Improvement scenario

The Business as Usual (BAU) scenario as discussed in Section 3.1.1 - 3.1.3, revealed that energy consumption and packaging material contributed to the environmental impact category (climate change, acidification, and eutrophication) and categorized as the environmental hotspot. Therefore, these two environmental hotspots should be managed properly to increase PT Pupuk Kujang environmental performance. The energy and waste management strategy should be applied to reduce the environmental impact category value. Introducing solar PV in one of the Fertilizer Plant facilities (bagging plant) was chosen as a scenario where total electricity consumed by bagging plant facility was approximately 538,000 kWh/y. Two reduction scenarios were applied, namely 10 % renewable energy, and 100 % renewable energy. The LCIA of improvement scenarios indicated that the utilization of renewable energy reduced the impact category value where the highest reduction occurred on the global warming that ranges from 2.6 t CO_2-eq to 3.6 t CO_2-eq per annum and the lowest reduction was eutrophication impact category. The implementation of fertilizer packaging reuse programs should be applied intensively for increasing the lifetime usage of fertilizer packaging. As discussed in sub Section 3.1.1 that propylene (fertilizer packaging material) contributed about 0.74 % of total environmental impact. On the other word, the reuse of fertilizer packaging would contribute to the reduction of global warming impact category less than one percent. In addition, this program would reduce the production of fertilizer packaging and the number of packaging that disposed into landfills.

4. Conclusions

One of the main environmental impact sources in the operation of PT Pupuk Kujang was contributed by electricity consumption from fossil fuel power plant and the implementation of renewable energy as well as reuse of fertilizer packaging program could obviously reduce the following three main environmental impacts, namely climate change, acidification, and eutrophication. The highest emission reduction would be climate change impact category with 6.7 % reduction by substituting the fossil fuel electricity source with PV solar. In addition, the reuse of fertilizer packaging program would contribute approximately 0.74 % of the total emissions. However, in order to obtain a comprehensive result, an economic feasibility analysis should be performed as an additional study.

In general, some continuous improvements that can be applied for improving the current environmental performance in PT Pupuk Kujang are conducting an energy audit, and waste management program.

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