Impact Assessment of Crude Oil Exploration Using Life Cycle Assessment (LCA)

S Sulistyawati1, A P Iswara2 and R Boedisantoso1

1Department Environmental Engineering, Faculty of Civil, Environmental and Geo Engineering. Institut Teknologi Sepuluh Nopember Surabaya 60111, Indonesia
2Department Environmental Engineering, Universitas Pembangunan Nasional Veteran Jawa Timur, Indonesia

Abstract. Oil and gas are strategic, non-renewable natural resources and are vital commodities. It is explained that upstream business activities are business activities that are core or rely on exploration and exploitation. While downstream business activities are business activities whose core are in processing, transportation, storage and/or commercial business activities. At present, 68% of the world's energy needs are derived from fossil fuels. Fossil fuels that are often used include coal, petroleum and natural gas. The results of the 2007 Intergovernmental Panel on Climate Change (IPCC) study showed that the concentration of CO$_2$ gas in the pre-industrial period amounted to 278 ppm, while in 2005 it was 379 ppm. The consequences of this change are rising global temperatures by 0.74°C, and there has also been a sea-level rise of 0.17 m, then there has also been a 7% reduction in snow cover in the northern hemisphere and rivers experience slower freeze. The contribution of greenhouse gas emissions from the oil and gas sector is expected to increase from 122 metric tons (Mt) of CO$_2$ in 2005 to 137 metric tons (Mt) of CO$_2$ in 2030. Emissions produced by crude oil exploration in 2015 amounted to 48,947.35 tonnes of CO$_2$e and increased in 2016 amounting to 232,950.30 CO$_2$e. Therefore, an LCA study is needed as a solution to reduce the emissions of greenhouse gas CO$_2$, CH$_4$, N$_2$O, NOx and SOx at a company in East Java. The purpose of this study is to determine the environmental impacts generated by crude oil exploration. The emission data of CO$_2$, CH$_4$, N$_2$O, NOx and SOx, mass balance, the amount of raw materials, fuels used and emissions produced in each of the main process units and supporting units, as well as data on the amount of products produced from petroleum production activities in one company in East Java, are used to determine the impact on the environment that would arise through the stages of LCA analysis using the Eco Indicator 99 method in the SimaPro 8.5.2 software. The results obtained from this study revealed that the process which has the highest impact value on the environment is the process of producing oil in the PV-9900 separator unit, with an impact value of 12620 MPt and the value of each category of damage was 4.76 x 10$^{11}$ MJ surplus for the “resources” category, 0.00118 DALY for the “human health” category and 0.0847 PDF.m$^2$.year for “ecosystem quality” category.

Keywords: Eco Indicator 99, LCA, Crude Oil, SimaPro 8.5.2.
1. Introduction

Oil and gas business activities are a combination of upstream activities and downstream activities which consist of exploration, exploitation, processing, transportation, storage, and trade. Exploration is an activity that aims to obtain information about geological conditions to find and obtain estimates of oil and gas reserves in a specified area. Exploitation is a series of activities aimed at producing oil and gas from a designated area, which consists of drilling and settlement of wells, construction of means of transportation, storage, and processing for the separation and refining of oil and gas [1]. Petroleum is a complex mixture of hundreds of hydrocarbon chains, which is composed of hydrocarbons as much as 50-98% by weight, and the rest consists of organic substances including sulfur, oxygen and nitrogen and inorganic compounds such as vanadium, nickel, and sodium which is a metal compound. In general, the composition of petroleum is as follows: carbon (C) 84-87%, hydrogen (H) 11-14%, sulfur (S) 0-3%, nitrogen (N) 0-1%, oxygen (O) 0-2% and metal compounds (vanadium, nickel and sodium) 0.001-0.05% by weight of metal [2].

At present, the world energy demand is mainly fulfilled by fossil fuels. Fossil fuels that are often used include coal, petroleum and natural gas [3]. The results of the 2007 IPCC study showed that CO2 concentration in the pre-industrial period was 278 ppm, while in 2005 it was 379 ppm. The consequences of this change are global temperatures rising by 0.74 °C, and there has also been a sea-level rise of 0.17 m, then there has also been a 7% reduction in snow cover in the northern hemisphere and rivers experience slower freeze. Global warming is one indication of the occurrence of climate change [4]. Global warming is a global phenomenon triggered by human activities, especially those related to the use of fossil fuels and land-use change activities. These activities produce gases which are increasing in number in the atmosphere, especially carbon dioxide gas (CO2) [5].

Life Cycle Assessment (LCA) is a mechanism for analyzing and calculating the total environmental impact of a product in each stage of its life cycle. Starting from the preparation of raw materials, the production process, sales and transportation and disposal of products [6]. LCA can analyze and compare several processes or systems that contribute to environmental damage. The use of LCA is expected to help quantify and evaluate the environmental performance of a product or process and help determine the basis for making environmental improvements. The data needed in conducting LCA consists of each environmental impact, by-products, energy consumption and materials used at each stage of the process.

The standard of an LCA is carried out in four phases, namely:

1. Goal and Scope Definition
   Goal and Scope Definition / Goal and Scoping is an important phase in carrying out LCA. Goal and Scoping are needed to carry out an inventory of activities that are estimated to have a significant impact on certain processes or products on the environment [7].

2. Inventory Analysis
   Inventory Analysis is part of LCA that contains input inventory in the form of energy or raw materials and emissions and waste output. In this process, quantitative data collection is carried out to determine the level or type of energy and material inputs in an industrial system and results released into the environment [7].

3. Impact Assessment
   Impact Assessment is used to analyze the impact of a process on the environment and human health that has been quantitatively analyzed in inventory analysis. In the classification process, inventory data associated with potential effects on ecology and human health are placed in special categories [7].

4. Interpretation
   At this stage, the interpretation of results, evaluation, and analysis of efforts that can be done for improvement are performed [8].

In SimaPro software, there are two types of impact assessment approach methods, namely the midpoint method and the endpoint method. The midpoint method is a method of evaluating the effects of certain substances in the environment, resulting in changes in the natural aspects of the
environment. Meanwhile, the endpoint method is a method that describes the effects of environmental damage due to a particular substance on environmental aspects [9].

The method used to analyze impacts in this study is Eco Indicator 99. The Eco Indicator 99 (EI 99) method is considered to be more comprehensive in evaluating environmental impacts [10]. The EI 99 method is an evaluation method that classifies substances according to their effects on environmental impacts and can show the relative contribution of each calculated process [11]. The EI 99 method is categorized as an endpoint method or method based on the final approach that assesses the overall impact up to the damage that might be caused. There are 11 categories of impacts assessed, namely climate change, ozone layer depletion, acidification/eutrophication, carcinogens, respiratory organics, respiratory inorganics, ionizing radiation, ecotoxicity, land use, mineral depletion, and fossil fuel depletion[12]. This method categorizes environmental impacts in three categories of damage, namely the impact on human health (human health), the impact on ecosystem damage (ecosystem quality) and the impact on the use of natural resources [13].

2. Methodology

Data analyses will be carried out on raw materials, fuel, as well as products and emissions produced in the petroleum extraction and production activities. The data used are the production design data of the petroleum exploration industry for one year. In conducting an impact analysis using the LCA method, SimaPro 8.5.2 software is used. The steps taken are as follows:

1. Collection of data, in the form of secondary data consisting of concentrations of CO2, CH4, N2O, NOx and SOx in process units, mass balance, number of raw materials, amount of fuel used and number of products produced during one year period.
2. Recapitulation of data.
3. Entry of data into SimaPro 8.5.2 software.
4. Selection of environmental impact methods, namely the EI 99 method.
5. Stages of characterization, normalization, and weighting.
6. Selection of the impacts to be analyzed, namely climate change, ozone depletion layer, respiratory inorganic effects, respiratory organic effects, fossil fuels, and land use.

3. Result and Discussion

3.1 The Calculation of Emissions Load

Based on the Process Flow Diagram (PFD), petroleum production activities in the company CPA have units that become sources of stationary emissions, namely 2 separator units, 1 unit of column stripper, 1 unit of degassing boot, 1 unit of flares and 5 units of generator [14]. These units are supporting units for the petroleum production process carried out by the studied petroleum exploration industry at the CPA. In this study, the source of stationary emissions to be analyzed for emission loads are the separators, flares, and generators. This is because separator units are categorized as an equipment type that is a source of fugitive emissions from onshore oil production activities [15]. Then for emission unit analysis, emission load is carried out, due to continuous or non-continuous combustion of gases produced by oil and gas operations. As well as the generator unit, the emission load analysis is carried out due to the occurrence of internal combustion, which produces heat as a direct driver of the Electrical Submersible Pump (ESP) unit in the petroleum extraction process. The results of the emission load calculation for the separator units, flares, and generators in the studied Petroleum exploration industry can be seen briefly in Table 3.1.
Table 3.1. The Calculation of Emission Load

| Emissions Parameter | Separator | Flare   | Generator | Total     |
|---------------------|-----------|---------|-----------|-----------|
| (ton/year)          | 9,600.24  | 128.74  | 0.0400    | 10.51966  |
| CO₂                 | 0,432     | -       | -         | 129.21    |
| CH₄                 | -         | 0.298   | 0.06300   | 0.361     |
| N₂O                 | -         | 5.52    | 2.30      | 7.82      |
| NOx                 | -         | -       | -         | -         |
| SO₂                 | -         | 0.047   | 0.0116    | 0.0116    |
| nmHC                | 0.116     | -       | -         | -         |
| **Total**           | **10.677.33** |       |           |           |

From the emission load calculation data in Table 3.1, it can be seen that the biggest emission load of CO₂, CH₄, N₂O and NOx is produced by the unit flares. Meanwhile, the biggest burden of SOₓ emissions is generated by generators and the largest emission load of nmHC (non-methane Volatile Organic Compound) is produced by the separator unit. So the total burden of emissions produced by the studied petroleum exploration industry throughout 2017 is 10.677.33 tonnes/year.

3.2 Life Cycle Analysis Using SimaPro 8.5.2

Life Cycle Assessment (LCA) is an objective process to assess the environmental impact of a product, process, or activity. The assessment is carried out by identifying energy sources, the use of raw materials and disposal in the environment. Additionally, the method can evaluate and apply the possibility of environmental improvement [13]. To do the LCA analysis, SimaPro 8.5.2 software was used, which at the stage of processing the data, the software had been adjusted to the stages of LCA analysis. The LCA analysis stages are goal and scope selection, inventory life cycle, life cycle impact assessment, and data interpretation.

3.2.1 Goal and Scope Selection

The purpose of this stage is to identify the environmental impacts that occur in the process of taking and producing petroleum, which consists of ESP, separator units, column stripper units and boot gas units and processes in supporting units (flares) contained in petroleum production activities at CPA, the studied petroleum exploration industry.

The method used to analyze impacts in this study is Eco Indicator 99. The Eco Indicator 99 method is considered more comprehensive in evaluating environmental impacts [10]. In this method, the environmental impacts analyzed include ozone depletion, climate change, land use, organic respiratory effects, inorganic respiratory effects, and fossil fuel depletion. The environmental impact categories chosen do not only have an impact on air quality, but they might also generate other environmental damage and this will also be assessed by the assessment method used. Moreover, the EI 99 method approach, especially the endpoint method, includes an analysis of what damage might be carried out, which is divided into three main categories, namely human health, ecosystem quality and resources [9].

3.2.2 Life Cycle Inventory (LCI)

To assess the impact of the analyzed process, data input is needed at this stage which includes material equilibrium between the raw material used and the product produced, the energy used, and the emissions produced. The data used are the production design data in one year, which was obtained from the petroleum exploration company studied. The final stage of the LCI process is the incorporation of raw material inputs, production processes and emissions issued to form a life cycle. From the life cycle, the process which will have the greatest impact on the environment can then be
seen[10]. The unit used in the LCI stage is Pt (point), in which 1 Pt is representative for one-thousandth of the annual environmental load of one European average population [16].

- **Life Cycle Inventory Production Well**

At the studied petroleum exploration company, there are five production wells equipped with ESP, with each ESP being skw 15, sk 12 a, sk 25, sk 32 and sk 34. Please note that this petroleum production well does not produce petroleum all the time, and there are pauses when the wells do not produce oil and at that time the ESPs are not turned on. Therefore, the use cycle of an ESP follows a petroleum production well. The electricity used by ESP comes from a generator, where one ESP uses one generator. Hence, there are a total of five generator sets in the CPA studied petroleum exploration industry. The mass balance of each pump is presented in Figure 1 to Figure 5.

- **Life Cycle Inventory of Crude Oil Production Process**

Petroleum produced from production wells flows towards the separator units V-100 and PV-9900, then the oil from the separation from the separator unit is channeled to the column stripper (PV-9500). Furthermore, petroleum flows into the oil gas boot unit (TK-900) and excess gas from the results of the oil separation is then transferred to LP Flare. The following figure displays the mass balance of each processing unit (Figure 6 to Figure 10).
Figure 6. Mass Balance of Separator V-100

Figure 7. Mass Balance of Separator PV-9900

Figure 8. Mass Balance of Stripper PV-9500

Figure 9. Mass Balance of Oil Gas Boot TK-900
3.2.3 Life Cycle Impact Assessment

After the inventory data stage, it three stages were found to have the greatest contribution of impact, namely characterization, normalization, and weighting. In the impact assessment phase in this study, the method used in SimaPro 8.5.2 was the Eco Indicator 99 method. The Eco Indicator 99 (EI 99) method is the most important and recommended method based on ISO 14040-43 [17]. This method is based on a final approach that assesses the overall impact including damage that might be caused. The following is the result of the impact analysis of the process of taking and producing petroleum in the studied petroleum exploration industry, using the software SimaPro 8.5.2 and EI 99 method.

1. Characterization

The characterization phase of the EI 99 impact assessment method used in the SimaPro software explains that the valuation of characterization and normalization is done using natural resource extraction and emissions data. These values are based on the environmental interventions produced from European production in 1990-1994 [9]. After the impact category has been determined based on the relative contribution of each input and output of a product system to the environmental burden, the impact category is converted into an indicator that represents the potential impact on the environment. The characterization stage is done by multiplying the inventory results in the classification phase with the characterization factors of each substance in each impact category. The calculation in the characterization stage can be seen in the following equation.

\[
\text{Category Indicator} = \sum_x \text{Characterisation Factor} \times \text{Emission Inventory}
\]
Based on Figure 11, it can be seen that the petroleum extraction process causes the greatest impact in the fossil fuels category, compared to other impact categories, because petroleum is a type of fossil fuels, and the main process of petroleum extraction uses petroleum as raw material. Therefore, the extraction of petroleum has resulted in a reduced availability of petroleum which has an impact on the decline of natural resources. The next main impact categories are organic and inorganic respiratory effects, climate change and ozone depletion caused by emissions released by the generator unit as the main energy supply in carrying out ESP. The generator unit uses diesel fuel and in the process, there is internal combustion, thus emitting CO₂, CH₄, N₂O, NOx and SOx emissions. The emission of exhaust gases results in the disruption of human health and results in global warming. In contrast, the process did not produce any impact on land use at this stage, because the number of production wells analyzed was only a small part of the number of wells found in the studied petroleum exploration industry, namely 5 production wells using ESP of 113 wells.

![Figure 12. Diagram of the Characterization Stage in Petroleum Production Process Source: SimaPro 8.5.2](image)

Based on Figure 12, it can be seen that the effects on fossil fuels and land use are caused by the gas output in the V-100 and PV-9900 separator units, excess gas in the LP Flare unit and oil in the stripper PV-9500 unit. However, the impact on fossil fuels is greater in value than the impact on land use, and one of the reasons this is so is because petroleum is used as the main raw material and can cause a reduction in the supply of petroleum in nature, also due to the large use of energy in the oil production process. Regarding the impact on land use, the output of these units affects the quality of ecosystems around the production process area, which can result in the disappearance of species/ecosystems in the area. Compared to the disappearance of species/ecosystems, the use of energy in producing petroleum is of greater value to environmental loads. Therefore, the impact of fossil fuels is greater than the impact of land use even though it is caused by the output of the same units. The effects on organic and inorganic respiratory effects, as well as the impact on climate change and ozone layer depletion, are caused by emissions released by the LP Flare unit. These can disrupt human health and global warming, which is caused by exhaust emissions from LP Flare units in the form of CO₂, CH₄, N₂O, NOx and SOx emissions due to the combustion of residual gas in the petroleum production process.

2. Normalization

Normalization is an optional step following ISO 14040 standards. However, normalization adds to the benefits of placing marked impact indicator results in a broader context. This is explained in a way that allows impact indicators to be compared to each other, so the number of each indicator is divided by normalization factors [9]. The normalization calculation can be seen in the following equation.

\[ Nk = \frac{Sk}{Rk} \] (2)
Where:
K : Impact category
N : Indicator of normalization
S : Indicator from the characterization stage
R : Normalization factor

Normalization factors are chosen to represent the real or potential magnitude of the impact category that is appropriate for the geographical area and within a certain period.

**Figure 13.** Diagram of the Normalization Stage in The Petroleum Extraction Process

**Figure 14.** Diagram of the Normalization Stage in Petroleum Production Process

Source: SimaPro 8.5.2 (Source: SimaPro 8.5.2)

Based on Figures 13 and 14, it can be seen that in the petroleum production process, the normalization stage shows that the decline in the natural resource category is greater than the other categories. Referring to the explanation of normalization above, that the value of the resource category at this stage is due to the calculation of the normalization stage using the indicator value from the characterization stage, which at the characterization stage the impact of fossil fuels is greater than the other impacts, therefore the category of resources is greater than the other categories. The small value of the categories of human health and ecosystem quality from the previous stage of damage assessment, other than because the indicator value in the characterization stage of each impact is small, is also caused by the potential magnitude of the impact that is adjusted to the geographical area in a
certain period. Thus, the human health category that was in the third position in the damage assessment stage, moved up to the second position in the normalization stage, this is because the human health category has greater potential from the ecosystem quality category which is caused by various exhaust emissions into the air, resulting in health problems and probably causing death.

3. Weighting

The weighting stage is the same as the normalization stage, which is based on ISO 14040 and also an optional stage. Normalization and weighting are important stages where several solutions need to be compared clearly. Weighting is the process of changing the results of normalized indicators from different impact categories into other values using numerical factors (weighting factors) based on subjective judgments. The weighting stage consists of multiplying the weighting factor by the normalization results for each impact category [9]. Calculation of the weighting stage can be seen in the following equation.

\[ EI = \sum V_k \times N_k \]  

Where:
- \( EI \): Indicator of overall environmental impact
- \( V_k \): Weight factor for impact category \( k \)
- \( N_k \): Indicator normalized

The weighting factor of each impact category represents the relative importance of each category’s impact on the environment. The difference between normalization and weighting steps are as follows: normalization provides a basis for comparing various types of damage categories (all categories of damage with the same unit), while weighting gives weight or relative value to the impact of different categories based on the importance or relevance caused.

![Diagram of Weighting Stage in the Petroleum Extraction Process](source: SimaPro 8.5.2)
Based on Figures 15 and 16 it is known that in the oil production process the biggest impact is in the resource category. This means that the decline in natural resources has considerable importance on the environmental burden incurred compared to other categories of damage.

3.2.4 Interpretation of LCA Analysis

The results of the Life Cycle Impact Assessment (LCA) stage in the petroleum extraction and production processes can be seen in Table 2 below.

**Table 2. The Results of The LCA**

| Process                      | Units with The Greatest Impact Value | Total Value of Impact (MPt) |
|------------------------------|--------------------------------------|----------------------------|
| Petroleum Extraction Process | ESP skw 25                           | 0.899                      |
| Petroleum Production Process | Separator PV-9900 (gas)              | 12.620                     |

Based on Table 2, it can be concluded that the process that has a very large impact on the environment is the process in the PV-9900 (gas) separator unit with an impact value of 12,620 MPt or 12.62 GPt. The result of the analysis using the SimaPro 8.5.2 software for the value of the category of human health decline due to the PV-9900 (gas) separator unit is 0.00118 DALY. This means that if the life of a person who should be able to reach the age of 80 years can be reduced as much as 0.00118 years or experience a disability at the final 0.00118 years of his life. For the category of the ecosystem, quality damage is 0.0847 PDF.m2.year, which means that there is an extinction of 0.0847 plant or animal species per square meter in the area in one year. Whereas for the category of reduction in natural resources is $4.76 \times 1011$ MJ surplus within one year, in which this number denotes an excess of energy that must be used at this time which could have been saved for future interests.

4. Conclusion

The conclusions that can be drawn from this study, namely the greatest impact on the petroleum production process at CPA petroleum exploration company is the impact on the category of decreasing natural resources (resources) and decreasing human health (human health). The process that has the
greatest impact on the environment is the process in the PV-9900 separator unit with an impact value of 12620 MPt and the value of each category of damage of 4.76 x 1011 MJ surplus for the resources category, 0.00118 DALY for the human health category and 0.0847 PDF.m2.year for ecosystem quality category.

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