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Environmental impact investigation of natural gas refinery process based on LCA CML-IA baseline method

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Abstract: Gas refinery is an important process in point of energy production and economics. The importance of gas refinery and high amounts of inputs and emissions in the processes emphasize the studying the environmental burdens. The environmental impacts of the natural gas refinery process were evaluated in a gate-to-gate life cycle assessment study based on CML-IA baseline model. Eleven environmental indicators of 1-tonne output gas were calculated and then normalized in SimaPro Software. The values of intermediate indicators of abiotic depletion, fossil abiotic depletion, global warming, ozone layer depletion, human ecotoxicity, freshwater ecotoxicity, marine water ecotoxicity, terrestrial ecotoxicity, photochemical oxidation, acidification potential, and eutrophication were 2.25×10-6 kg Sb eq, 140700.40 MJ, 6846.57 kg CO2 eq, 4.30 kg CFC-11 eq ×10-8, 28.34 1,4-DB eq, 0. 13 Kg 1,4-DB eq, 0752.85 kg 1,4-DB eq, 7.91 kg 1,4-DB eq, 0.40 kg C2H4 eq, 10.27 kg SO2 eq, and 2.68 kg PO4 eq, respectively. The greatest indicator was fossil abiotic depletion with a value of 4.47×10-9 and global warming (1.36×10-9). Acidification potential (3.65×10-10), eutrophication (2.03×10-10), and terrestrial ecotoxicity (1.63×10-10) indicators were ranked after those and the ozone layer depletion indicator had the lowest value. The refinery process, electricity, electronics devices, amine, sodium sulfite, steel, and copper inputs were the main factors affected by most of the studied environmental indicators. The life cycle assessment as a reliable method can be applied in gas refinery sector to address, evaluate, and then decrease the environmental burdens.

keywords: Natural gas; Refinery; Pollution; Environmental impact assessment; Life cycle; CLM baseline.

1. Introduction

One of the main sustainability aspects of each activity is the environment. It includes air, water, and soil and all creatures in those. Hence, decreasing the environmental impacts of all activities is an important concern throughout the world. The first step in this regard is determining the environmental impacts, specifying the critical impacts, and distinguishing the main burden contributors for managing and programming environmental preservation tasks.

Life cycle assessment (LCA) has been used as a standard method to investigate the environmental loads of producing and servicing activities (Kheiralipour, 2020). The calculated environmental impacts by the life cycle assessment method are efficient criteria to compare different active systems with each other

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and identify the weaknesses and hotspots of the systems (Ghadirianfar, 2013; Bojacá et al., 2014). The method has been vastly used to study the environmental effects in agriculture (Payandeh et al., 2017; Kheiralipour et al., 2017; Hesampour et al., 2018), agricultural processes (Pourmehdi and Kheiralipour, 2020; Gholamrezayi et al., 2021; Jalilian et al., 2021), industry (Wang et al., 2020; Zang et al., 2020), and petroleum and oil refinery (Bengtsson et al., 2011; Hwang et al., 2019; Jungbluth et al., 2018; Vineyard and Ingwersen, 2017; Young et al., 2019; Liu et al., 2020).

One of the main energy sources is fissile natural gas that is consumed for heating in commercial and residential portions, producing steam and heat in industry, and generating electricity in power plant companies (Anonymous, 1998). Gas is one of the main sectors due to gas increasing demand, high dependency of other sectors on the gas product, and high environmental impacts, (Shrivastava and Unnikrishnan, 2019). The increasing consumption trend of natural gas compared to is due to the fact that gas is cleaner than coal. Besides zero solid wastes, natural gas has lower nitrogen and sulfur contents and consequently lower SOx and NOx emissions (Spath and Mann, 2000). Due to energy consumption and pollution emitted by gas refinery companies, the environment is one of the main aspects of this sector (Sevenster and Croezen, 2006).

Life cycle assessment was applied to study in production or processing of different gas kinds such as liquefied natural gas (Barnett 2010; Tagliaferri et al., 2017), shale gas (Tagliaferri et al., 2015), and biogas (Zaresani et al. 2017). The conducted studies in natural gas processing just included studying of some such as greenhouse gas emissions (GHG) (Korre et al. 2012; Sapkota et al., 2018) or energy and GHG (Bahmannia, 2008). So, the novelty of the present study is studying all environmental indicators based on CML-AI baseline model. Hence, the novel goal of the present study was to estimate and evaluate the 11 environmental impact indicators of gas refinery process by life cycle method based on CML-IA baseline model.

2. Materials and methods

2.1. Data collection

In life cycle assessment studies, some data must be gathered about inputs, outputs, and emissions of the producing or servicing systems, processes, or activities. These data are necessary to calculate the environmental impacts of the systems.

The present study was conducted based on the data gathered from the Bidboland Gas Refining Company (BGRC) in 2019. The BGRC is the first gas refinery company in the Middle East which was been established in Bidboland, Khuzestan Province, Iran. This refinery has been established to purify natural gases from Aghajari Oil Fields (Kheiralipour et al., 2020).

2.2. Methodology

In the present research, the LCA methodology was applied to study the environmental indicators of the BGRC based on ISO 14040 Standard in four phases including explaining the goal and scope of the study, analyzing the system inventory, assessing the environmental indicators, and interpreting the obtained results (ISO 14040, 2006). These phases have been explained in the following subsections.

2.2.1. Explaining the goal and scope

The systems boundary and functional unit were determined in explaining the goal and scope phase (Guinee, 2002). As the present LCA study was conducted in a gate to a gated project, the system boundary was considered to be started from the input gate to the output gate of the refinery process in the company. The entered material and energy to the company and produced gas were considered as inputs and output, respectively.

In LCA studies, a functional unit is a reference unit for providing a quantitative description of the system (Sonesson, 2010). In the present research, the functional unit was considered to be 1 tonne of output natural gas. Hence, all calculations were done based on 1 tonne of the output. This end allows ease of comparison of the obtained results with those of other research .

2.2.2. Analyzing the system inventory

The main task in the second phase is data collection and analysis to provide an inventory set of the data (Curran, 2017). The material, energy, and emission flow in the gas refinery process were studied in the inventory analyzing phase. The data related to the inputs, output and environmental emissions of the system were gathered in the company. The inputs included feed, fuel, electricity, etc. and the output was produced natural gas, and the emissions were those emitted to air, water, and soil. Then the values of all inputs and emissions were calculated to provide those for 1 tonne of output gas.

2.2.3. Assessing the environmental indicators

The obtained data in analyzing the system inventory phase were used in the third LCA phase. The SimaPro Software was used in assessing the environmental loads to calculate the impact indicators (Kheiralipour, 2020). The Ecoinvent database (Frischknecht and Rebitzer, 2005) in the software was used to calculate the environmental impacts of the inputs in the company. CML-IA baseline impact assessment model (Costa et al., 2018) was selected to calculate the environmental impact categories of the studied system. In this impact assessment model, 11 environmental indicators are selected and those values are calculated. The indicators were normalized in the assessing the environmental indicators phase to provide a comparison of the indicator with each other. This end allows finding the great indicators with the highest values and effects on the environment.

2.2.4. Interpreting the obtained results

Interpreting the obtained results phase of the life cycle assessment methodology is related to the interpretation of the obtained findings in the three previous phases (Kheiralipour, 2020). In the fourth phase, the results were examined to determine the effect of various factors on the environmental indicators. Also constructive solutions and suggestions are provided in this phase (Weiler, 2013) to improve the system performance with better management strategies and optimization of input consumption and conducting the processes to reduce environmental impacts based on the results obtained.

3. Results and discussion

3.1. The values of the environmental indicators

The CML-IA baseline impact assessment model was used to determine 11 environmental indicators of the gas refining process. The results of the model including the intermediate environmental indicators have been listed in Table 1.

Table 1. The environmental indicators of refinery process for producing 1-tonne natural gas.

No.	Indicator	Unit	Value
1	Abiotic depletion	kg Sb eq	2.25×10^{-6}
2	Fossil abiotic depletion	MJ	1.41×10^{5}
3	Global warming,	kg CO2 eq	6.85×10^{3}
4	Ozone layer depletion	kg CFC-11 eq	4.30×10^{-8}
5	Human toxicity	kg 1,4-DB eq	28.30
6	Freshwater ecotoxicity	kg 1,4-DB eq	0.13
7	Marine water ecotoxicity	kg 1,4-DB eq	7.53×10^{3}
8	Terrestrial ecotoxicity	kg 1,4-DB eq	7.91
9	Photochemical oxidation	kg C2H4 eq	0.40
10	Acidification potential	kg SO2 eq	10.27
11	Eutrophication	kg PO4 eq	2.68

The value global warming indicator in the natural gas process in the present study (6.85×10^{3} kg CO2 eq) is comparable with that of the hydrogen gas production process. Petrescua et al. (2014) reported the maximum value of global warming index for 1 kg hydrogen production as 703.13 kg CO2 eq/MW, equivalent to 23000 kg CO2 eq/tonne, which is more than that obtained in the present study. Also, the value of this indicator in the gas process in Canada was higher than that of the corresponding indicator in the presented research. Sapkota et al. (2018) obtained the value of greenhouse gas indicator for the natural gas supply chain life cycle from various production sites in Canada to northern and southwestern Europe between 5.86 to 11.45 g-CO2eq/MJ, which is equivalent to 39,000 to 76333 kg-CO2eq/tonne.

The values of most environmental indicators such as fossil abiotic depletion, global warming, human ecotoxicity, water and soil ecotoxicity, photochemical oxidation, acidification potential, and eutrophication in the present research were higher than those reported by Kheiralipour and Tashanifar (2019) for gas refinery process. This is because the electricity was not generated in the BGRP and was supplied from the national electricity grid.

3.2. The values of the normalized indicators

The normalization results of the environmental indicators in BGRP based on the CML-IA baseline method have been reported in Table 2.

Table 2. The normalized indicators of the gas refinery process.

No.	Indicator	Value
1	Abiotic depletion	2.65×10^{-14}
2	Fossil abiotic depletion	4.47×10^{-9}
3	Global warming	1.36×10^{-9}
4	Ozone layer depletion	4.81×10^{-16}
5	Human toxicity	3.66×10^{-12}
6	Fresh water ecotoxicity	2.46×10^{-13}
7	Marine water ecotoxicity	6.45×10^{-12}
8	Terrestrial ecotoxicity	1.63×10^{-10}
9	Photochemical oxidation	4.67×10^{-11}
10	Acidification potential	3.65×10^{-10}
11	Eutrophication	2.03×10^{-10}

The values of the normalized indicators of the natural gas process ranged from 4.81×10^{-16} to 4.47×9^{-10}. Among the various calculated indicators, the fossil abiotic depletion was ranked as the greatest indicator with a value of 4.47×10^{-9}. After fossil abiotic depletion, the global warming indicator had the highest value at 1.36×10^{-9}. The acidification potential, eutrophication, terrestrial ecotoxicity, photochemical oxidation, marine water ecotoxicity, human toxicity, freshwater ecotoxicity, abiotic depletion, and ozone layer depletion indicators were in the next ranks with values of 3.65×10^{-10}, 2.03×10^{-10}, 1.63×10^{-10}, 4.67×10^{-11}, 6.45×10^{-12}, 3.66×10^{-12}, 2.46×10^{-13}, 2.65×10^{-14}, and 4.81×10^{-16}, respectively. Liu et al. (2020) studied the environmental impacts of the petroleum refining process in China by the life cycle assessment method. As reported by the researchers, the indicators with the highest values in the oil refinery process were ozone layer depletion and human toxicity indicators.

3.3. The effects of factors on the indicators

Fig. 1 shows the effect of the different factors on the calculated environmental indicators of the gas refinery process. In the figure, only nine factors have been shown and due to a high number of factors, all of those have not been shown.

The factors in Fig. 1 included the consumed inputs and processes in the company. The process corresponded to all emissions emitted when consuming inputs in the gas refinery process.

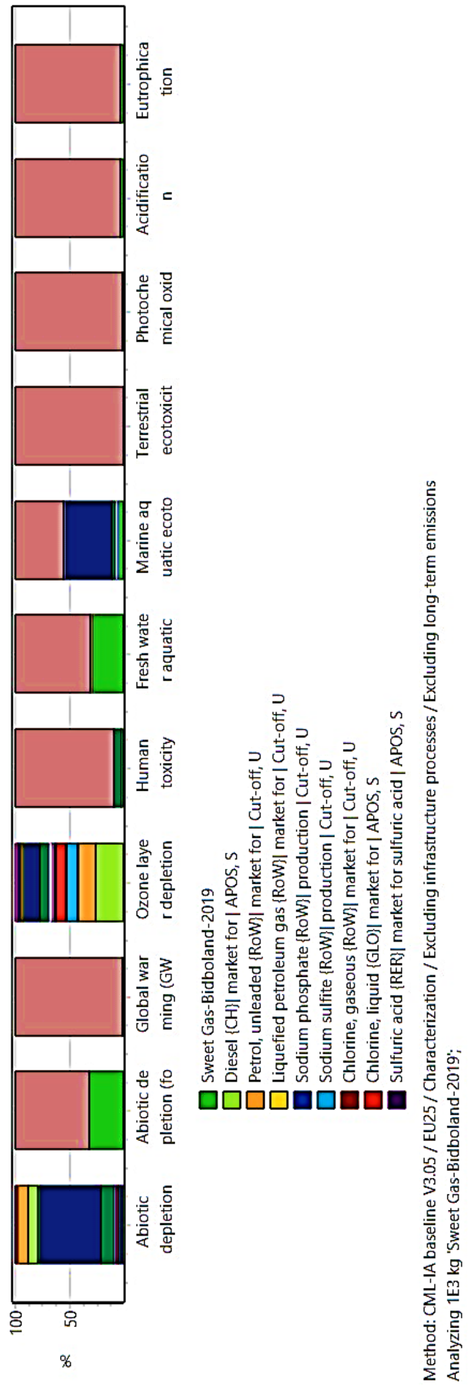

Fig. 1. The effective factors on the environmental indicators of gas refinery process.

Abiotic depletion indicator: The abiotic depletion indicator of the gas refinery process was mainly affected by electronic devices, amine, steel, and copper with values of 1.30×10^{-6}, 2.59×10^{-7}, 2.23×10^{-7}, and 2.16×10^{-7} kg Sb eq, respectively.

Fossil abiotic depletion indicator: The factors which had the greatest impact on the fossil abiotic depletion were electricity, refinery process, amine, electronic devices, diesel, gasoline, sodium sulfite, activated carbon, and steel with amounts of 96390.69, 44304.56, 1.63, 1.30, 0.84, 0.55, 0.17, 0.13, and 0.12 MJ, respectively.

Global warming indicator: Among different factors, electricity, refinery process, and electronic devices had the highest effects on the global warming indicator. The values of the main factors were 6803.45, 42.85, and 0.12 kg CO2 eq, respectively.

Ozone layer depletion indicator: The major contributors to the ozone layer depletion indicator were diesel, gasoline, electronic devices, sodium sulfite, and chlorine gas with values of 1.09×10^{-8}, 6.92×10^{-9}, 6.64×10^{-9}, 4.23×10^{-9}, 3.89×10^{-8} kg CFC-11 eq, respectively.

Human toxicity indicator: The contribution of electricity, amine, and the refinery process to human toxicity had greater than other factors. The value of the factors was 25.68, 1.89, and 0.66 1,4-dB kg eq, respectively.

Water ecotoxicity indicator: The freshwater ecotoxicity indicator was affected by electricity, the refinery process, and amine with values of 0.09, 0.03, and 1.44×10^{-3} 1,4-dB kg eq, respectively.

Marine water ecotoxicity indicator: The greater contributor factors to the marine water ecotoxicity indicator were electricity, electronic devices, the refinery process, amine, sodium sulfite, steel, copper, and polyethylene with values of 335.27, 325.52, 29.71, 21.88, and 7.30 kg 1,4-DB eq, respectively.

Terrestrial ecotoxicity indicator: The electricity, refinery process, steel, and electronic devices were the most effective factors on the terrestrial ecotoxicity index. The value of the factors was 7.91, 2.20×10^{-3}, 2.71×10^{-4}, and 2.33×10^{-4} kg 1,4-DB eq, respectively.

Photochemical oxidation indicator: The photochemical oxidation indicator was affected by the electricity, refinery process, and electronic devices factors with a magnitude of 0.39, 3.60×10^{-3}, and 2.88×10^{-3}, respectively.

Acidification potential indicator: Electricity and the refinery process factors had the highest share in the acidification potential indicator. The value of the factors was 10.00, 6.30×10^{-4} kg SO2 eq, respectively.

Eutrophication indicator: The greatest impact on the eutrophication index was exerted by electricity, refinery process, and electronic devices with the amount of 2.61, 0.07, and 1.46×10^{-4} kg PO4 eq, respectively,

This subsection showed the main contributor factors to the environmental indicators. The main factors in the gas refinery process which had high shares in approximately all of the environmental indicators were emissions of the electricity, refinery process, and electronic devices. Also, the share of amine, steel, sodium sulfite, diesel, gasoline, sodium sulfite, copper, polyethylene, chlorine gas, and activated carbon was high in some of the environmental indicators.

4. Conclusion

Due to the high importance of the environment and preservation of the environment, natural gas as an important energy source, and the gas refinery process to deliver usable natural gas, environmental impacts of the gas refinery process is one of the main tasks in this sector. Hence, 11 environmental impact categories in the processes were studied based on the CML-IA baseline model in the present manuscript. The normalization step showed that the highest impact value was related to fossil abiotic depletion and global warming indicators. After those, acidity, eutrophication, and terrestrial ecotoxicity were ranked as the third to fifth main indicators and the ozone layer depletion had the lowest impact value.

The refinery process and some inputs including electricity, refinery process, electronic devices, amine, steel, sodium sulfite, diesel, gasoline, sodium sulfite, copper, polyethylene, chlorine gas, and activated carbon were determined as the main effective factors in the environmental indicators. The main tasks to reduce the values of the environmental indicators are applying the proper and efficient management strategies to optimize and so reduce the consumption of the inputs and optimize refinery processes to reduce the emissions. In this regard, reusing, or recycling some materials such as scrap steel, polyethylene, and copper are recommended because the recycled materials are not considered company emissions and therefore the values of the relevant environmental indicators can be reduced.

The LCA method can be used in future years to compare the environmental impacts of the refinery process in different years. Also, the methodology can be utilized in the gas refinery companies after applying new technology, strategy, and or management programs to study the effect of those decreasing the environmental impacts.

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