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A Comparative Life Cycle Assessment of Two Different Crude Oil Types for a Refinery in Sudan

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Crude oil, Environmental impacts, Life cycle assessment, Transport fuels

Abstract

Climate change, caused primarily by fossil fuels used for meeting the increasing energy demand, has become a global concern during the last decade. One of the most important sectors contributing to this demand is transport fuel production. To respond to this global challenge, all parties need to work in an identical pattern, i.e., socially appropriate, technically feasible, economically sustainable, and environmentally friendly. Specifically, the oil refining industry uses vast amounts of raw materials and creates considerable waste that needs to be processed, mainly at refinery sites from where most of the life cycle environmental burdens of all transport fuel types stem. This study compares two different types of crude oil used in Sudan refineries, namely X and Y blend crude oil, in terms of environmental impacts. A detailed Life Cycle Assessment (LCA) defined by the ISO14040/14044 frameworks was carried out via SimaPro software v.8.1.1.16. Both midpoint and endpoint approaches were adopted for the ReCiPe impact assessment method. Based on the selected midpoint impact categories, i.e., climate change, ozone depletion, human toxicity, and terrestrial acidification, the X crude oil impact scores were 282.7 kg CO_2 eq, 2.45E-06 kg CFC-11 eq, 1.05 kg 1,4-DB eq, and 0.145 kg SO_2 eq while the Y crude oil scores were 265.9 kg CO_2 eq, 1.58E-06 kg CFC-11 eq, 0.735 kg 1,4-DB eq, and 0.095 kg SO_2 eq, respectively. From an endpoint approach considering the representative single scores, overall impacts for the X and Y crude oil created an environmental load output of 13.8 and 12.7 Pt, respectively. As expected, both types of crude oil had a direct impact on the environment, where crude oil Y was found to have 10% less impact than crude oil X.

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1 INTRODUCTION

Although it is well known that natural resources, especially fossil fuels, are the most important energy sources of the modern ages, it is clear that the exploitation of these resources is rather a complex operation that can cause environmental pollution. Thus, many types of chemicals could be dispersed to the environment during all of the operational processes including production, refinery, transportation, utilization, and waste disposal. By other means, fossil fuels play a critical role in environmental pollution and human health [1,2].

Consequently, as the world's reliance on crude oil products grows, the issue of oil-environment pollution becomes a major factor that threatens the natural quality of the world's most valuable life supply in a given area [3]. Marine habitat is one of the most vulnerable areas which is strongly affected by crude oil spills, air and soil are also under threat. Soil offers sustainable and profitable cultivation with water, air, and nutrient resources, thus making plants typically germinate, mature, and expand in the surrounding earth. However, regular crude oil spills on agricultural soils, and the resulting fouling impact on all types of life, make the soil toxic and unproductive. Moreover, since petroleum depletes the soil's productivity, most basic nutrients are no longer usable for crop plant use [4].

Therefore, to mitigate or eliminate these impacts, oil producers must take appropriate steps to reduce pollution rates to the usual wedge. To respond to this challenge, all parties need to work in an identical pattern, i.e., socially appropriate, technically feasible, economically sustainable, and environmentally friendly. A condensed but detailed methodology for estimating the environmental impacts of fossil fuels in the various regions of Sudan is discussed in the context of this study. Where applicable, ISO standards for environmental protection and Life Cycle Assessment (LCA) have been adopted [5]. LCA method analyses and calculates a product's cumulative environmental impacts at each point of its life cycle [6]. Several processes or structures that lead to ecological degradation may be analysed and compared via using LCA.

As recorded in the 2008 OECD report [7], Sudan is the third-largest oil producer in Sub-Saharan Africa, and one of the world's premier massive oil producers. Therefore, its economic axis has recently shifted from agriculture to oil exploitation activities. In the period 2008 to 2011, oil exploitation activities accounted for roughly half of the country's Gross Domestic Product (GDP), the majority of its exports (97%), and its government revenue (98%). In 2011, an oil output of 360 thousand barrels a day resulted in strong export earnings, high government receipts, and a lower-middle-income country's income per capita [8].

In this context, this study was focused on the effects of crude oil exploration in Sudan. Based on confidential business information, two different crude exploration regions in Sudan were previously named X and Y, and a comparative LCA was performed. The environmental impacts of crude oil exploration on water, soil, and air were investigated. The effects of exploration on human health were also calculated.

2 MATERIALS AND METHODS

LCA is used to assist in quantifying and analysing a product's or process's environmental performance and determining the basis for making ecological interventions. Each ecological effect, energy, and materials used at each point of the process are among the data required for LCA. A typical LCA is applied in four successive stages as seen in Figure 1 [5].

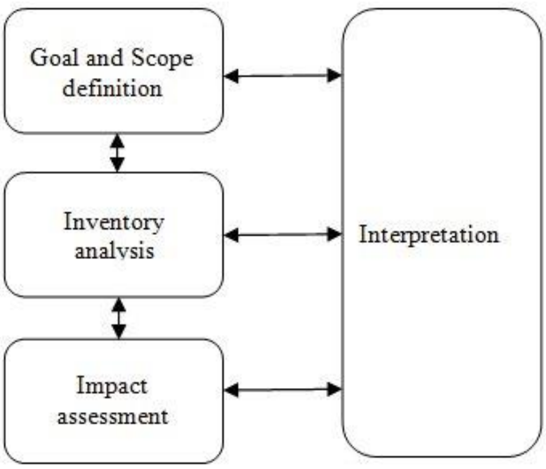

Figure 1. LCA framework [5]

Based on the LCA framework, the first stage is defining the objective and scope required for the inventory of actions that have a significant environmental effect on particular processes. In this study, the goal was defined as comparing two different types of crude oil used in Sudan refineries, namely X and Y blend crude oil, in terms of their impacts on environmental and human health. The functional unit is selected as the production output of the oil exploration industry for one ton. The scope of this study is gate-to-gate, an LCA perspective that examines just one specific value phase in the whole supply chain, in this case, regarding only the exploitation phase of the product's life cycle. The gate-to-gate module can also subsequently be connected to form a full cradle-to-gate assessment in their respective supply chain.

Inventory analysis is the second stage of LCA that includes collecting fuel or raw material requirements (input flows), and also pollution and waste production (output flows). At this stage, the inventory data was taken from real petroleum extraction sites. In the case of specific flows that cannot be gathered, background data was compiled from the online ecoinvent database along with previously published studies. During the exploration phase, geological conditions are investigated along with estimating the oil and gas reserves in the given area. Sudan has two main oil extraction regions, namely Al-Fulah and Heglig. Al-Fulah is in the White Nile region with a hot semi-arid (steppe) climate type according to the Köppen classification while Heglig is in the North Kordofan region with a hot desert climate. In this study, the refineries using the oil extracted from Al-Fulah and Heglig were named X and Y, respectively – due to data privacy reasons. It should be noted that the refineries have the same processes to extract oil from different origins.

The first stage is to extract the crude oil from natural resources using the drilling machine. Next, crude oil is pumped into the electrical desalting and decalcification processes using the feedstock pump on the tank farm, which swaps heating to 130°C. Then, semi-processed oil is fed to the electrical desalter in the second step. Here, alternating current (AC) and direct current (DC) desalination in three phases and decalcification processes for crude desalination are implemented, with three levels of demulsified infused. For the first and second phases, the decalcification pumped the drain water of the third phase is fed back to the first phase. Then the feed entered two heat exchangers to prepare it to move to the flash drum, where the feed separated into gas and liquid. The gas continues to the fractionator tower. The liquid is going to a vis-breaking pump to enter the furnace, reach 430°C, and then sent to the vis-breaking reactor to break the long series hydrocarbon into a short one; after that, the crude oil is joined to the fractionator. From the fractionator, the gas goes to the flair unit and storage tanks after liquefaction. Figure 2 shows the system boundaries for both refineries (X and Y).

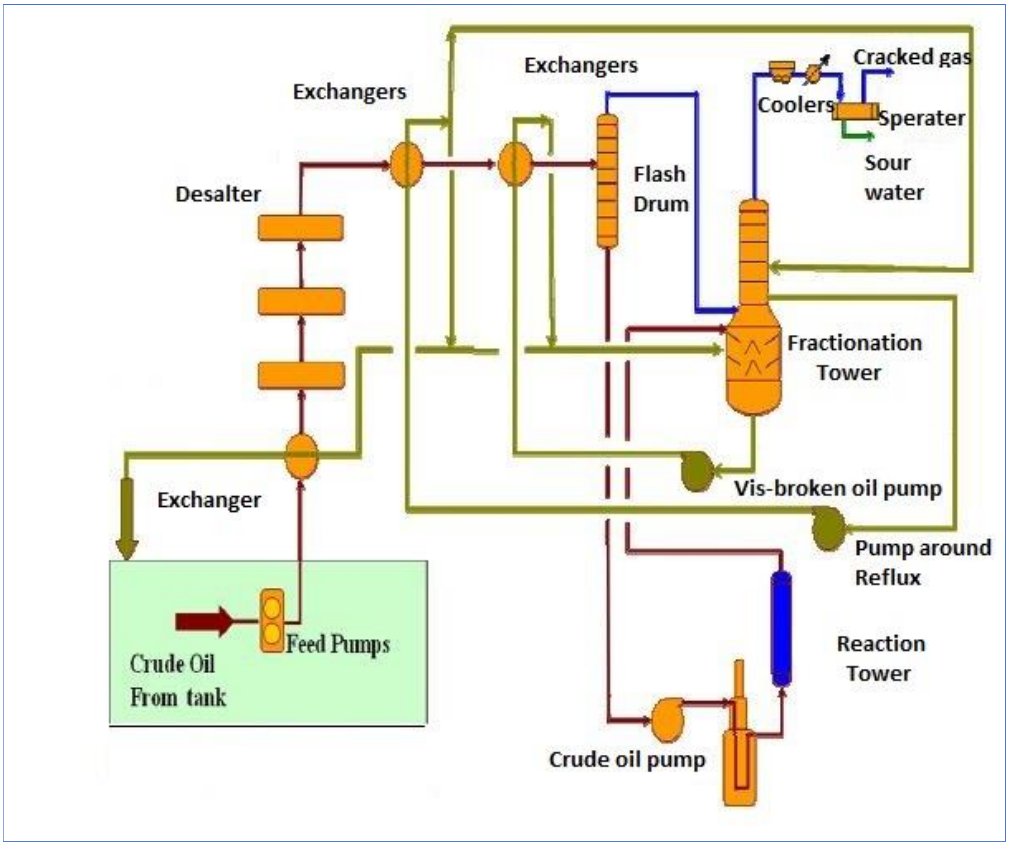

Figure 2. The system boundaries for both extraction fields (X and Y oil types)

Impact assessment is the third stage of LCA that evaluates the environmental and public health effects of a quantitatively evaluated procedure in the inventory study. Inventory data, including a material balance between the raw material used and the product generated to evaluate the impacts of the analyzed processes, is required to be introduced to the software program at this stage to calculate the impacts from a life cycle perspective, and then to determine the processes that affect the ecosystem most. The environmental impacts were calculated via SimaPro v8.1.1.16 software [9] with already available assessment methods. The ReCiPe impact assessment method and its midpoint and endpoint approaches were used in this study. The midpoint process assesses compounds' environmental impact, causing changes in the ecological aspects. Meanwhile, the endpoint approach is a tool that explains ecological impacts on the environment caused by a specific substance [10].

The 18 midpoint categories considered in this study were noted as human toxicity, natural land transformation, climate change, urban land occupation, photochemical oxidant formation, particulate matter formation, fossil fuel depletion, freshwater depletion, marine eutrophication, ozone depletion, terrestrial acidification, agricultural land occupation, ionizing radiation, freshwater eutrophication, freshwater ecotoxicity, mineral's depletion, marine ecotoxicity, and terrestrial ecotoxicity. The three endpoint categories were also categorized as the effects of crude oil on human health, ecosystems, and natural resources.

The last stage of an LCA study is the interpretation where all of the findings from inventory analysis and impact assessment stages are evaluated and discussed in terms of environmental performance and a review of progress efforts are being conducted. The results and conclusion parts of this paper highlight the main findings along with their interpretation.

3 RESULTS

Based on the inventory data, a two-level impact assessment was performed regarding the abovementioned midpoint and endpoint categories. In this section, first, the midpoint category scores are discussed. Then, the endpoint category scores of the effects on human health, ecosystems, and natural resources, are presented. Finally, the representative single scores are also discussed.

3.1 Evaluation of the Midpoint Category Scores

Midpoint characterization considerations are somewhere in the route of the trigger effect, usually at a point after which for any environmental stream attributed to that impact type, the ecological process is equivalent [11]. All of the midpoint category scores are presented in Table 1.

Table 1. The midpoint category scores of X and Y crude oil types

Impact category	Unit	X	Y	Difference
Climate change	kg CO_2 eq	2.83E+02	2.66E+02	6%
Ozone depletion	kg CFC-11 eq	2.45E-06	1.58E-06	35%
Terrestrial acidification	kg SO_2 eq	1.45E-01	9.51E-02	34%
Freshwater eutrophication	kg P eq	9.65E-06	6.24E-06	35%
Marine eutrophication	kg N eq	9.30E-03	6.11E-03	34%
Human toxicity	kg 1,4-DB eq	1.05E+00	7.35E-01	30%
Photochemical oxidant formation	kg NMVOC	2.50E-01	1.66E-01	34%
Particulate matter formation	kg PM10 eq	6.19E-02	4.06E-02	34%
Terrestrial ecotoxicity	kg 1,4-DB eq	1.73E-04	1.12E-04	35%
Freshwater ecotoxicity	kg 1,4-DB eq	1.27E-02	8.71E-03	32%
Marine ecotoxicity	kg 1,4-DB eq	9.71E-03	6.75E-03	30%
Ionising radiation	kBq U235 eq	8.57E-01	5.54E-01	35%
Agricultural land occupation	m^2a	4.22E-02	2.73E-02	35%
Urban land occupation	m^2a	1.11E-03	7.19E-04	35%
Natural land transformation	m^2	5.92E-06	3.83E-06	35%
Water depletion	m^3	1.95E-02	1.26E-02	35%
Metal depletion	kg Fe eq	5.28E-03	3.41E-03	35%
Fossil depletion	kg oil eq	6.11E+00	4.35E+00	29%

The climate change category leads to major shifts that emerge over many centuries or more in global temperature, rainfall, weather cycles, and other climate indicators, and are expressed in kg CO_2 eq. Since the carbon content is similar for both oil types, impact scores on the climate change category are similar, showing a 6 per cent difference. Other midpoint category scores are evaluated together to check if they are statistically different. The category scores except the climate change are ranging from 29% to 35% favouring the oil used in the refinery Y.

In short, regarding the midpoint category results, the environmental burdens associated with the oil type used in refinery X are always higher for each category, when compared to refinery Y.

3.2 Evaluation of the Endpoint Category Scores

The endpoint level considerations usually represent damage to one of three protective zones, namely human health, environmental quality, and natural resources. The midpoint and endpoint methods are compatible because the midpoint characterization has a closer relationship with environmental flows and usually has lower parameter volatility. In contrast, the characterization of the endpoint is more straightforward to understand concerning ecological flows [12]. A comparative assessment of endpoint category scores is given in Table 2.

Table 2. The endpoint category results for both X and Y crude oil types

Damage category	Unit	X	Y
Human Health	DALY	4.13E-01	3.83E-01
Ecosystems	species.yr	2.24E-03	2.11E-03
Resources	$	1.01E+03	7.20E+02

The human health category is described as the years lost or the years lived as handicapped; by combining these two aspects, a representative score is obtained as Disability Adjusted Life Years (DALY) which is the unit of measuring human health scores. The ecosystems category is the decline of biodiversity over a particular region over a specific period and area. The uncertainty model determines the evaluated geographical and temporal frame considered. In this study, the hierarchist perspective, based on the most common policy principles, has been adopted. The unit is species.yr which means the local species loss integrated over time, generally during one year. The resources category scores are described as the potential resource supply excess costs for an end-use period, with continuous yearly output and then a discount rate of 3%; the unit is $. In agreement with the midpoint category scores, refinery X has higher environmental burdens at the endpoint level, similarly. Human health and ecosystem category scores differ less than 10 per cent, not indicating a significant difference across refineries. However, resources category scores show a 40 per cent difference, highlighting a statistically important variation between the refineries.

3.3 Evaluation of the Single Scores

To express all impacts in a consistent single unit Pt (point) is used at the LCI level where 1 Pt represents 1000th of a world average population's annual environmental load. A comparative assessment of representative single scores is given in Figure 3. From an endpoint approach considering the representative single scores, overall impacts for the X and Y crude oil created an environmental load output of 13.8 and 12.7 Pt, respectively.

4 CONCLUSION

One of the most important sectors contributing to the energy demand is transport fuel production. To respond to this global challenge, all parties need to work in an identical pattern, i.e., socially appropriate, technically feasible, economically sustainable, and environmentally friendly. Specifically, the oil refining industry uses vast amounts of raw materials and creates considerable waste that needs to be processed, mainly at refinery sites. In this study, two different types of crude oil used in Sudan refineries, namely X and Y, were compared concerning their environmental impacts. A detailed LCA with the ReCiPe impact assessment method was adopted considering both midpoint and endpoint approaches. As expected, both types of crude oil had a direct impact on the environment, where crude oil in refinery Y was found to have 10% less impact than refinery X.

Based on these findings, the following recommendations might help to mitigate any exploration associated challenges with regard to the Sudan oil production processes in the regions under study:

- In collaboration with the government and local communities affected by oil emissions, oil producers should conduct immediate public health awareness programs in oil-rich regions to educate local people about the dangers of oil pollutants in the environment.

- If achieved correctly, residents' exposure to air contaminants would minimize, and the long-term effects of oil pollutants on the well-being of communities residing around oil fields would be significantly reduced.

- The building of a sewage treatment plant for crude oil wastewater might be useful to undergo a series of treatments (primary, secondary, and specialized treatment processes) in order to meet discharge requirements before being discharged into the ecosystem.

- Any drilling chemicals that have been left in the field to decompose must be collected and disposed of properly.

- All ponds generated water must lock up for the local animals to have no exposure to Resource's whole Environmental and Social Audit (ESA) in all Sudanese petroleum fields must be essential, in the long run, in order to understand the scale of the harm to the environment caused by petroleum exploration.

Note

Initial version of this paper was selected from the proceedings of International Online Conference on Engineering and Natural Sciences (IOCENS'21) which was held on July 05-07, 2021, and was subjected to peer-review process before its publication.

Author Contributions

Gülşah YILAN: Conceptualization, Methodology, Validation, Writing - Review & Editing
Mohammed ABDELGADİR: Conceptualization, Methodology, Validation, Formal analysis, Writing - Original Draft
Gökçen ÇİFTÇİOĞLU: Conceptualization, Methodology, Supervision
All authors read and approved the final manuscript.

Conflict of interest

No conflict of interest was declared by the authors.

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