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Quantification of Carbon Footprint in Petroleum Refinery Process

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The emission of greenhouse gases (GHG) resulting from the petroleum refinery process leads to a significant negative impact, necessitating the measurement and accounting of carbon levels. Currently, there is a lack of specific guidelines or frameworks addressing carbon footprint accounting for petroleum refinery processes. This study aims to develop a framework for quantifying and assessing carbon footprint accounting in the petroleum refinery process in Malaysia. The framework involves establishing indicators and parameters to quantify and assess the carbon footprint, ultimately obtaining an approximate measure for carbon footprint accounting. The study focuses on the main process units involved in kerosene production within the petroleum refinery, following the standards set by the Intergovernmental Panel on Climate Change (IPCC). It specifically concentrates on two greenhouse gases, namely Carbon Dioxide (CO_2) and Methane (CH_4), and limits carbon accounting to Tier 1 of the IPCC standards. The methodology of the study comprises seven steps, starting with familiarization of the plant and kerosene production, followed by the determination of parameters and indicators, greenhouse gas mapping, data collection, carbon footprint accounting, and analysis of GHG profile and results, Based on the calculated carbon emissions throughout the study, using a basis of 1,000 kg of feed per year, the results indicate that the carbon emissions in kerosene production are dependent on the production rate. This is evident from the data in 2020, during the pandemic, where the total carbon emissions were at their lowest, measuring 220.81 kg per 1000 kg of feed per year. As the world began to recover in 2021, the total carbon emissions increased to 252.07 kg per 1,000 kg of feed per year. As market demand continues to rise, the total carbon emissions are expected to increase accordingly, underscoring the importance of carbon footprint accounting to quantify emissions and the need for the implementation of mitigation strategies to reduce the overall carbon footprint.

1. Introduction

Petroleum refining is a downstream industry that focuses on transforming crude oil into higher-value products. From the nature of the refining process, it contributes to the increasing amount of CO_2 emissions. In 2020, CO_2 emission in Malaysia was 262,200 million kg, and one of the top contributors of CO_2 emissions is the oil and gas industry (Ahmad et al., 2022). With increasing demands of petroleum refinery products, the processes are further developed and improved to cater for the demands and to obtain high profitability in business. The development has caused the emission of greenhouse gases (GHGs) which will gradually lead to climate issues. It is important for companies in the petroleum refinery sector to measure carbon levels, or to conduct carbon footprint accounting. Based on the review conducted, no specific guidelines or framework has been done to address carbon footprint accounting for petroleum refinery processes. In Malaysia, the development of the oil and gas industry started back in September 2010. The launch of the Economic Transformation Programme (ETP) aimed to achieve a developed nation by the year 2020. Through this programme, the oil and gas industry has contributed to one-fifth of the national Gross Domestics Products (GDP). A new programme was launched to oversee and assess the performance of ETP which is the Performance Management and Delivery Unit (PEMANDU). Through assessment under PEMANDU, the oil and gas industry has been classified as one of the

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twelve growth areas to spearhead rapid economic development in Malaysia. The rapid advancement of petroleum refining processes has had a detrimental impact on the environment, particularly in terms of greenhouse gas (GHG) emissions. It is crucial to engage in carbon footprint accounting to accurately measure and quantify the carbon footprint associated with petroleum refinery operations. This study aims to assess GHGs emissions, quantification and assessment of carbon footprint and accounting in the petroleum refinery process. The study focuses on Carbon Dioxide (CO_2) and Methane (CH_4) as these two gases are the main greenhouse gases (GHGs) expressed as CO_2 equivalent, (CO_2e) produced in the petroleum refinery process. Accounting for the carbon footprint is crucial for industries such as petroleum refineries as it allows them to evaluate greenhouse gas (GHG) emissions, improve process parameters, and determine actions to reduce emissions. The development of a specific framework for carbon footprint accounting in the petroleum refinery process is essential for these industries to achieve their set goals. With the increasing threat of climate change, carbon footprint assessment is being widely used to quantify anthropogenic environmental impacts and assist in addressing this threat (Xining et al., 2018). Petroleum refineries are significant contributors to GHG emissions, highlighting the need for carbon footprint accounting in this sector. The main objective of this study is to establish a framework for quantifying and assessing the carbon footprint and accounting in the petroleum refinery process in Malaysia. This framework will involve the identification of relevant indicators and parameters to obtain an approximate measure of carbon footprint accounting. The scope of this study is confined to greenhouse gas (GHG) emissions originating from process facilities within the petroleum refinery process, including the wastewater treatment plant. The project's focus is specifically on indicators and parameters related to the primary process units involved in kerosene production within the petroleum refinery. The calculations and measurements performed will adhere to the standards set by the Intergovernmental Panel on Climate Change (IPCC), with a specific emphasis on carbon dioxide (CO_2) and methane (CH_4) as the two GHGs of interest. The study's primary objective is to conduct carbon accounting activities, limited to Tier 1 of the IPCC standard, for the petroleum refinery's kerosene production.

2. Literature review

Huang et al. (2021) conducted a study aiming to construct a comprehensive Life Cycle Assessment (LCA) model specifically focused on the carbon footprint of oil product pipelines. The research framework established an LCA by examining the life cycle inventory of the petroleum products pipeline system, with the exclusion of the petroleum refining process. Clabeaux et al. (2020) worked to evaluate the carbon footprint of Clemson University's campus using a streamlined life cycle assessment approach. This model framework developed is suitable for public buildings such as universities only and can't be applied for petroleum refinery processes. Guo et al. (2020) carried out an investigation of variability in well-to-wheel (WTW) GHG emissions in oil refineries with respect to bitumen. This model has been developed for the refinery process but only focuses on bitumen production. Amanda et al. (2010) conducted a case study on a petroleum refinery in Malaysia to explore the preparation for the future carbon market. The study only considered the air quality factor in relation to the carbon parameter. Ramanath et al. (2023) have introduced a new technique that combines enterprise input-output analysis (EIOA) for carbon calculation but the application is limited to the edible oil refinery. Malakahmad et al. (2017) carried out a study to alert Malaysian stakeholders on the uneven danger of carbon footprint emissions from waste technologies. The study assessment was conducted based on three scenarios: the first scenario considered waste dumping in sanitary landfills equipped with a gas recovery system. The second scenario involved anaerobic digestion of organics and recycling of waste, while the third scenario considered waste incineration. Jamaludin et al. (2020) conducted an extensive study that integrated a mitigation model with sustainability and carbon assessment, specifically focusing on the palm oil mill area. It should be noted that their findings may not be directly applicable to the petroleum refinery industry. Jusoh et al. (2018) developed a general framework for greenhouse gas emissions accounting for industry reporting, although certain parameters may not be suitable for the petroleum refinery industry. Based on the literature conducted there have yet to be a comprehensive framework specifically developed for petroleum refinery processes. As petroleum refining industry is one of the biggest GHG emitters (Ahmad et al., 2022) this study is required to be conducted to develop a framework for quantifying and assessing carbon accounting specifically tailored for petroleum refineries in Malaysia. By addressing the carbon accounting in the petroleum refinery sector, this study will provide valuable insights into the industry's environmental impact, facilitate the preparation for future carbon markets, and assist stakeholders in making informed decisions for sustainable and low-carbon practices.

3. Methodology

This study was conducted by separating the methodology into a two-part process with seven steps in total. Throughout Part 1 of the study, the main focus was to familiarize and conduct data collection related to the study of carbon footprint accounting in petroleum refineries for the production of kerosene. While Part 2 was mainly focusing on analyzing and suggesting proper mitigations to encounter the emissions produced by petroleum refinery processes of all related data obtained throughout the study on quantification and assessment of carbon footprint accounting shown. The overall methodology framework is presented in Figure 1.

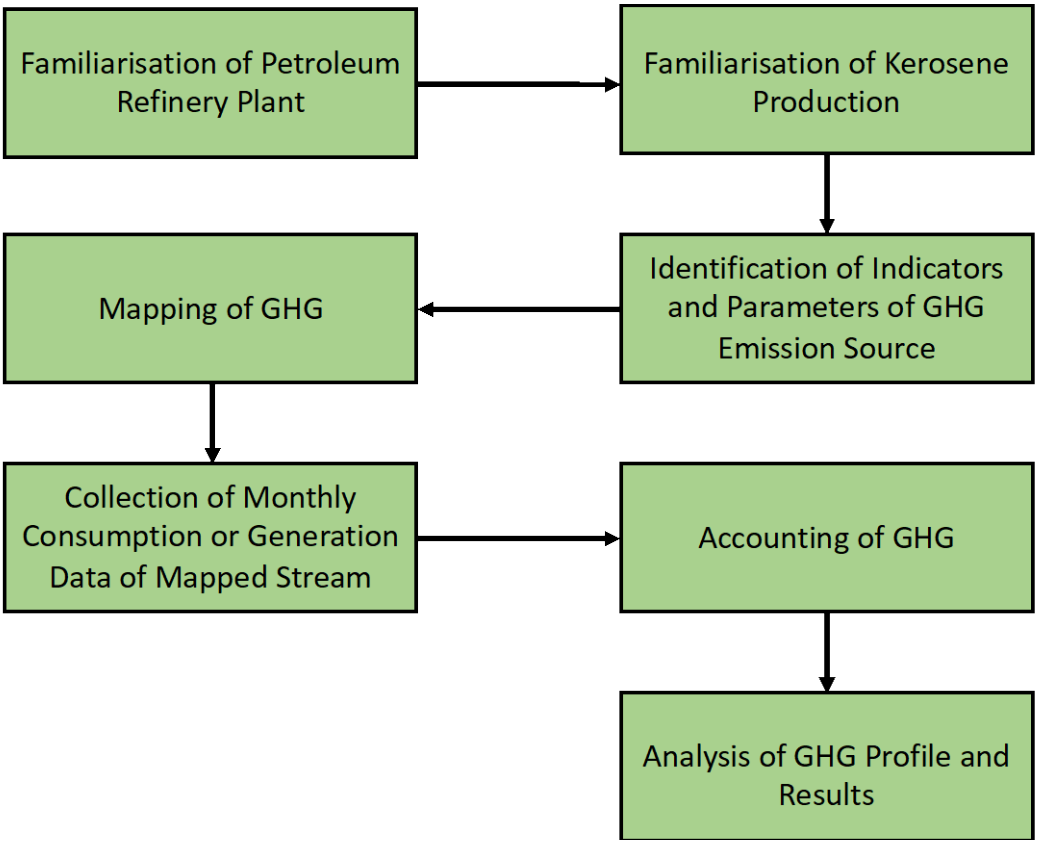

Figure 1 Overall methodology for Kerosene Production Carbon Accounting

3.1 Part 1: Development of carbon footprint accounting for petroleum refinery process for kerosene production

The first part involved the development of petroleum refinery carbon footprint accounting, understanding the kerosene production in the refinery and determining the parameters and indicators to conduct carbon footprint accounting of petroleum refinery for Kerosene production. The main process units determined in the petroleum refinery process were the crude oil tankage, crude distillation unit, secondary process unit, product treatment unit and the final product tankage. For identification of parameters and indicators there are five carbon footprint accounting parameters identified, water consumption for the process, boiler emission, wastewater generated and diesel consumption. Following that is the mapping of GHGs which was conducted by determining which unit in the Kerosene production produced emission of GHGs and the units will be used in accounting of GHGS emissions. According to the mapped units the data of monthly consumption for each mapped unit was identified. Data collection was done with reference to Petronas Penapisan Terengganu (PPT) Sdn. Bhd. and Malaysian Refining Company Sdn. Bhd. (MRCSB). Based on the GHG parameter, the emission factor is obtained from the IPCC standard. Based on this the accounting of greenhouse gas emissions can be completed.

3.2 Part 2: Carbon footprint accounting analysis for petroleum refinery process

The second part of the methodology consists of analyzing and suggesting proper mitigations to encounter the emissions produced by petroleum refinery processes. Based on obtained values in Part 1 of the study, a detailed analysis was performed to discover the unit with the biggest emission then a proper discussion is made to reevaluate the performance of the process to be improved. In order to reduce the GHG emissions, mitigation strategies are developed.

4. Results and discussion

In this paper, five parameters and five indicators were identified for carbon footprint accounting, using the Intergovernmental Panel on Climate Change (IPCC) and MyCarbon as references, as shown in Table 1. The emission factor used in this study was obtained from the Emission Factor Database (EFDB) as the primary reference source. This emission factor accounted for CO_2 and CH_4 gases, expressed in terms of CO2e units. Prior to the calculation of carbon footprint and in the familiarization step, 20 units were determined as the source of emission in kerosene production presented in Table 2.

With the mapping step being done, the data of the emission was collected and a basis of 1,000 kg of feed per year was taken to conduct calculations for carbon footprint accounting for kerosene production in the petroleum refinery. The data of each unit were collected from year 2019 to October 2022. The carbon footprint accounting for main units in kerosene production was calculated using the formula Eq (1).

$$\text{Carbon Emission of Unit (kg)} = \text{Emission from Unit} \times \text{Emission Factor} \tag{1}$$

Table 1: Parameters and Indicators for carbon footprint accounting

Aspect	Parameter, p	Indicator, i	Emission Factor (CO_2e)	Reference
Environment	Water Consumption	Use of Fresh Water	0.34 kg/m^3	EFDB
	Wastewater	Oily Water Sewer	1.9 kg/day	EFDB
	Electric Consumption	Electric Consumption	5,817 kg/TJ	EFDB
	Diesel Consumption	Diesel for Transport	0.000065 kg/m^3	EFDB
	Fugitive Emission	Flaring	12.1 kg/m^3	EFDB

Table 2: Unit label for main units in kerosene production

Unit	Equipment/Operation	Unit	Equipment/Operation
1	Jetty	11	Water Utilities
2	Crude and Condensate Tank	12	Top Pump Around
3	Preheat Train 1	13	Middle Pump Around
4	Desalter	14	Bottom Pump Around
5	Preheat Train 2	15	Main Flare
6	Furnace	16	Sour Flare
7	Crude Distillation Unit	17	Kerosene Stripper
8	Kerosene Treating Unit	18	Wastewater Treatment Unit
9	Kerosene Strainer	19	Water Discharge
10	Kerosene Tank	20	Slop Tank

For each unit, there were five parameters and indicators utilized for carbon footprint accounting. It is necessary to calculate each indicator individually due to variations in the emission factor obtained using Eq (2) and Eq (3). By considering a basis of 1,000 kg of feed per year all carbon emissions for each unit are calculated according to the parameters and indicators and all the values are added to obtain the total carbon emission for kerosene production.

$$\text{Total Carbon Emission for Each Unit} = \sum \text{carbon emission for all parameters for unit} \tag{2}$$

$$\text{Total Carbon Emission for Kerosene Production} = \sum \text{carbon emission for all unit} \tag{3}$$

Based on the results shown in Figure 2, in 2019 the total carbon emission using the basis of 1,000 kg of feed per year was recorded at 221.01 kg. In the year 2020, there was a slight decrease in the total emission due to the outbreak of Covid-19. Due to the outbreak of the pandemic, the demand for kerosene has significantly decreased. As a result, the production of kerosene in 2020 was reduced to align with the lower demand and avoid oversupply. However, in 2021, with the declaration of Covid-19 as an endemic situation and the easing of travel restrictions, the demand for kerosene has started to increase again. The total carbon emission in 2021 spiked up to 252.07 kg compared to the previous year which was affected by Covid-19. The available data for the year 2022 is limited to 10 months only, resulting in a lower total carbon emission compared to 2021. It is anticipated that once the complete one-year data is available, the total carbon emission for 2022 will either exceed or be similar to that of 2021. Based on the data of carbon emission, the parameters and indicators that contribute to carbon emission will be looked further into.

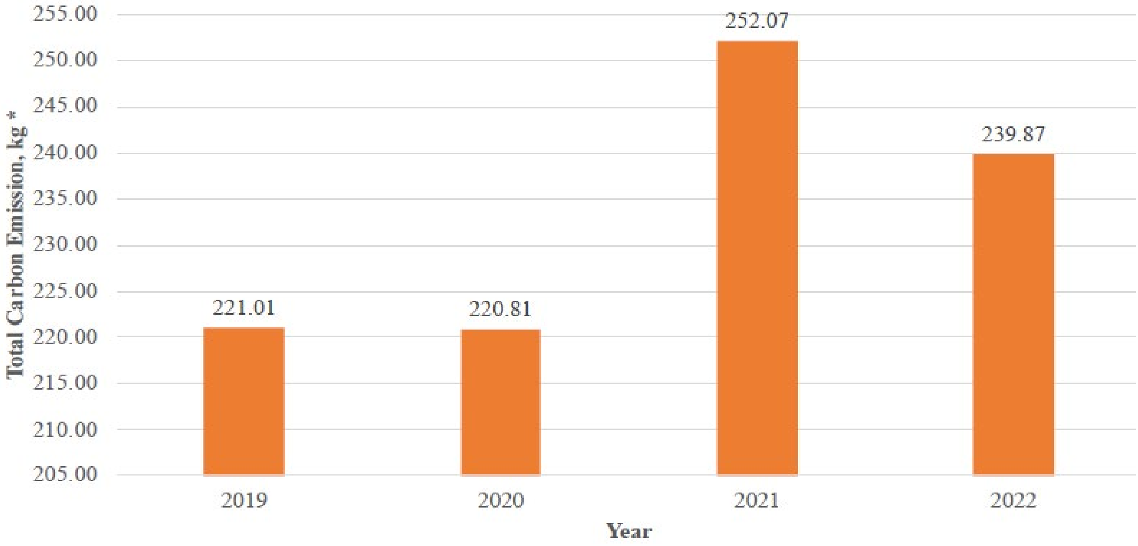

*Figure 2: Carbon emission for kerosene production from 2019 to 2022 (*basis: 1,000 kg of feed per year)*

Examining the data for 2019 to 2022 in Figure 3, the indicator that contributes the most towards carbon emission is oily water sewer with the lowest value of 218.20 kg in 2020 and the highest of value 249.48 kg in 2021. Oily water sewer is the wastewater produced in the refinery. The carbon emission by this indicator is the highest due to exposure of the wastewater to the open air. The second highest contributor is the use of fresh water with the lowest value of 1.75 kg in 2020 and the highest of value 1.92 kg in 2019. In this study, fugitive emissions were found to have the lowest carbon emissions as it only considered flaring as the indicator. In the actual refinery process, it is important to account for leaks and venting as well, which can significantly contribute to higher total emissions. From data of four years, the units that contribute the most to carbon emission are Unit 1, Unit 2, Unit 4, Unit 8, Unit 9, Unit 10 and Unit 19. Further improvement on the technology of the equipment and the process technology needs to be done in order to reduce the total carbon emission.

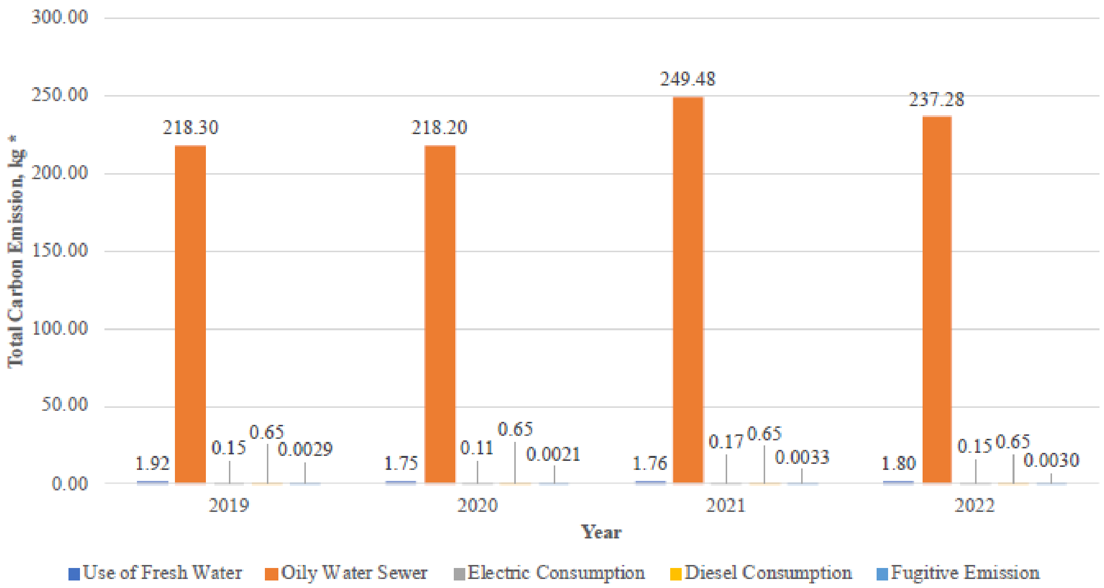

Figure 3: Comparison of carbon emission according to indicators from 2019 to 2022

5. Conclusion and recommendation

This study successfully developed a framework for quantifying and assessing carbon footprint accounting in the petroleum refinery process in Malaysia. The establishment of indicators and parameters allowed for a comprehensive measurement of the carbon footprint, particularly focusing on kerosene production within the refinery. By following IPCC standards and considering CO_2 and CH_4 emissions in Tier 1 accounting, the study provided valuable insights into the carbon emissions associated with the production rate. The results clearly demonstrate that the total carbon emissions in kerosene production are directly influenced by the production rate. The decrease in emissions during the pandemic and the increase afterwards show that it's crucial to accurately track carbon emissions through carbon footprint accounting. This emphasizes the urgent need to implement mitigation strategies to address the issue. To overcome the limitations of this work and enhance carbon footprint accounting in the petroleum refinery industry, several recommendations are proposed. Firstly, future research should aim to develop specific emission factors tailored to refinery processes. This would provide a more accurate measurement of carbon emissions and further refine the understanding of the industry's environmental impact. Additionally, expanding the scope of carbon footprint accounting beyond Tier 1 to consider other greenhouse gases and higher tiers of IPCC standards would provide a more comprehensive assessment. This approach would offer a better understanding of the overall carbon footprint and contribute to more effective mitigation strategies. Furthermore, considering the continuous increase in total carbon emissions alongside production rate growth, investing in advanced technology and equipment for the refinery should be prioritized. Although this may entail significant costs, it is a crucial investment to reduce carbon emissions and align with international goals such as the Paris Agreement and PETRONAS Net Zero Emission.

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References

Ahmad R.W., Salah K., Jayaraman R., Yaqoob I., Omar M., 2022, Blockchain in Oil and Gas Industry: Applications, Challenges, and Future Trends, Technology in Society, 68, 101941.

Amanda H.L.C., Noor Z.M., Raman A.A., 2010, Carbon Accounting Initiatives: Case Study of a Petroleum Refinery in Malaysia to Prepare for Future Carbon Market, Journal of Engineering Science and Technology, 5, 223 – 231.

Clabeaux R., Carbajales-Dale M., Ladner D., Walker T., 2020, Assessing the Carbon Footprint of a University Campus using a Life Cycle Assessment Approach, Journal of Cleaner Production, 273, 122600.

Jamaludin N.F., Ab Muis Z., Hashim H., 2019, An Integrated Carbon Footprint Accounting and Sustainability Index for Palm Oil Mills, Journal of Cleaner Production, 225, 496 – 509.

Jusoh L.S., Hashim, H., 2018, Development of a Framework for Greenhouse Gas Emissions Accounting for Industry Reporting, Chemical Engineering Transactions, 63, 439 – 444.

Malakahmad A., Abualqumboz M.S., Kutty S.R.M., Abunama T.J., 2017, Assessment of Carbon Footprint Emissions and Environmental Concerns of Solid Waste Treatment and Disposal Techniques; Case Study of Malaysia, Waste Management, 70, 282 – 292.

Xining Y., Mingming H., Jiangbo W., Bin Z., 2018, Building-Information-Modeling Enabled Life Cycle Assessment, A Case Study on Carbon Footprint Accounting for A Residential Building in China, Journal of Cleaner Production, 183, 729 – 743.

Tamelarasan R., Dominic C.Y.F., Raymond R.T., Jully T., 2023, Integrated Enterprise Input-Output and Carbon Emission Pinch Analysis for Carbon Intensity Reduction in Edible Oil Refinery, Chemical Engineering Research and Design, 193, 826 – 842.