Environmental Impacts Assessment Associated with the Decommissioning of Fixed Offshore Platforms Using Life Cycle Analysis

by

Nor Fariza Binti Omar

16706

Dissertation submitted in partial fulfilment of

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Bachelor of Engineering (Hons)

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NOR FARIZA BINTI OMAR

ABSTRACT

Many oil and gas fields are now entering (or already have) into the twilight of their productive lives. Malaysia in particular has about 300 offshore installations in four regions; Peninsular Malaysia, Sarawak, Sabah, and the Malaysia-Thailand Joint Authority (MTJA), whereby 48% out of the total installations have exceeded their 25 years of service design life. However, there is insufficient information regarding the decommissioning of offshore facilities in Malaysia. Life-cycle assessment (LCA) is preferable to be used as it provides quantitative and structure comparisons between decommissioning options, while addressing environmental impacts simultaneously. The main objective of this study is to determine and to quantify the environmental impacts associated with decommissioning of an offshore platform in Malaysia using LCA tools; process LCA and Economic Input Output (EIO-LCA). Two offshore decommissioning options are studied; complete removal and also the re-use platform as an artificial reef. Both methods are studied and compared for their strength and limitations to obtain more reliable, representative and accurate results. The environmental impacts of an offshore decommissioning concerned in this study are the total energy consumption and also gaseous emissions (CO_2, SO_2 and NO_x). Using EIO method, the results of LCA shows that the conversion to an artificial reef is the better decommissioning option in terms of energy consumption and gaseous emissions, whereas the process based LCA shows the opposite results. The decommissioning activity which mostly contributes to energy consumption and gaseous emissions were identified, which is the marine vessel utilization. The findings from this research provide a relative comparison between complete and re-use of the platform as artificial reef that shall help the owners of platform to decide suitable decommissioning option. For future LCA analysis, it is recommended to have a complete set of detailed and up-to-date data to produce a more comprehensive results. To protect it for the future generations, the harm of the environment has to be reduced. In this case the environmental impacts could be less if the suitable decommissioning option is found based on numerous results by using LCA tools.

Keywords: Environmental Impacts; Comparative Life Cycle Assessment; Decommissioning of Offshore Fixed Platforms; Process Based LCA, EIO-LCA

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Rapidly rising trends of fuel consumption indicate huge energy crisis of global proportions in near future. Following the trend, Malaysia's fuel consumption has been increasing day by day. Due to serious depletion of reserves in various onshore locations, the exploration process is expanded to offshore deeper waters. Seven sedimentary basins belonging to Malaysia, in South China Sea, show great promise to be excellent sources of hydrocarbons. However, every platform has its own end of life period, no matter if it is onshore or offshore. Therefore, some of the fields on the South China Sea have already ceased production or will soon do so, and the installations will have to be decommissioned.

Offshore decommissioning operations are highly complex, often even more so than the original installation itself. The condition of the platform, utility/safety systems, its residual strength and actual weight must all be assessed and taken into consideration. Hence, to construct an early detailed planning is the way forward in a successful decommissioning project. Referring to Oil & Gas UK (2012), environmental aspect is highlighted and is strongly subjected to decommissioning planning apart from health and safety, cost, and technological challenges.

One of the major environmental impacts associated with offshore decommissioning is harmful gaseous emissions, especially carbon dioxide emission which is the main culprit for global warming (OGP Discussion Paper, 1996). Therefore, it is very important to assess and to quantify the environmental impacts associated with offshore installations decommissioning.

Currently, the Environmental Impact Assessment which is required by the law is the Best Practical Environmental Option. However, another approach is Life Cycle Analysis (LCA) method used to quantify the environment impacts in this study which better reflects the wide range of the Environmental Impact. (E.P.A., 2014). The LCA tools utilized in the present study are process based method and EIO method. Based on their respective strength and limitations of the both methods, the results evaluated will be compared and combined to get a more reliable, more representative and accurate outcome. process based method can be used to identify the particular decommissioning activity causing the greatest amount of total energy consumption and gaseous emission in order to be able to recommend options to minimise the environmental impacts. On the other hand the EIO method eliminates two major issues of the process based method which are the defined boundaries and circularity effects, while including the estimation of direct and indirect energy costs which may give a better overview of the environmental impacts of offshore decommissioning. With that, the results obtained from the comparative analysis will determine and show a clearer view on which option of decommissioning that is less likely to have a tremendous impact on the environment.

In the present study, two options for offshore decommissioning were analysed: the complete removal and the re-use platform as an artificial reef.

1.2 Problem Statement

By their very nature, resource extraction activities, in the oil and gas and mining sectors in particular, have the potential to generate negative environmental, social, health and safety (ESHS) impacts. Many of these impacts endure after the conclusion of commercial exploitation. If not properly addressed and mitigated, these impacts can result in significant legal and financial burdens to the operator(s), the local population, and the host countries once exploitation ends (COCPO, 2010).

Decommissioning of offshore installations absolutely will bring impacts to the environment as mention before. The waste substances produced, gaseous emission, noise pollutions and vibrations from the decommissioning works are good examples for the environment impacts of offshore decommissioning (Gibson, 2002). The environmental impacts that caused by offshore decommissioning are the total energy consumption and gaseous emissions (CO2, NOx and SO2), and also impact to the marine environment.

With the increased awareness on environmental issues, it is very important to ensure that decommissioning activities would not bring drastic damages or harms to the environment or to check whether gaseous emissions are within the limit set by the authorities. Environmental, social, health and safety impacts associated with decommissioning, when addressed during the early stages of the project life-cycle (i.e., design phase), can be significantly reduced at lower costs. These are all reasons why governments across the globe are realizing that they – along with their private and public sector counterparts– must understand and proactively manage the environmental, social and economic issues associated with the end of an extractive project's life cycle as early as possible (COCPO, 2010).

LCA is preferable to be used as it could provide quantitative and structured comparisons between decommissioning options, while addressing the environmental impact simultaneously. In addition, the decommissioning activity that is the major contributor for total energy consumption and gaseous emissions could be identified by using LCA analysis. Recommendations could be proposed to minimize the environmental impacts of that particular decommissioning activity. For this study, the aim is to produce a comprehensive LCA analysis to determine and to quantify the environmental impacts of decommissioning of a local offshore platform.

1.3 Objectives

The objectives of the study are:

i. To quantify the environmental impacts associated with the decommissioning of local fixed offshore platform using Life Cycle Assessment (LCA).
ii. To establish the two LCA tools: process based method and EIO method.
iii. To evaluate any apparent differences in LCA results to the previous work done of a different type of platform in Malaysia.
iv. To suggest relevant mitigation measures for environmental concerns that arises in connection with the decommissioning of offshore platforms.

1.4 Scope of study

According to the Climate and Pollution Agency, Norway (2011), there were options that can be used for decommissioning of offshore installation. Currently, conventional decommissioning alternatives fall into four general categories; complete removal, partial removal, toppling (either as in-situ disposal of the structure or as artificial reefs), and also reusing. Malaysia has no governing legislation for decommissioning. However, based on the regulating 2008 PETRONAS Guidelines for Decommissioning of Upstream Installations, they make complete removal mandatory for all offshore installations.

A comparative analysis concerning environmental impacts by the decommissioning options chosen will be conducted with the aid of two LCA tools – process based method and EIO method. Besides that the environmental impacts concerned in this study are total energy consumption and the gaseous emissions (CO2, NOx and SO2) produced during the decommissioning and the transportation process. Besides, this study also cover the economic impact and also the estimation cost for decommissioning activity towards the selected platform.

1.5 Relevancy and Feasibility of the Project

Decommissioning of old oil and gas facilities is a new challenges to Malaysia nowadays. Each offshore platform soon will reaches the end of its lifetime at some point and this necessitates decommissioning work which must be done safely, cost effectively and with as little environmental impact as possible. While the life spans of these installations cover several years, they have not generally been designed with efficient decommissioning in mind. In Malaysia, there were about 300 platform are approaching the end of their services (Na, Wan Abdullah Zawawi, Liew, & Abdul Razak, 2012).

There are only a few offshore platform, which have been decommissioned in Malaysia so far due to lack of regulatory framework and also weak decommissioning (Gorges, 2014). Therefore, the aim for this study is to produce a basic framework for future assessment of environmental impacts of offshore decommissioning activities in Malaysia based on the case study on decommissioning of an offshore platform in North Sea.

With an uprising number of platform that need to be decommissioning in future, it is necessary to conduct this study to assess the awareness and the current capacity of the local services provider in Malaysia. This study may add knowledge to scholarly research and literature and provide a basic on the further study in field.

This project is feasible within the scope and the given time frame. The scope and main objectives had been clearly defined and narrowed, so that the author managed to complete the study within the time frame. LCA analysis for both complete and partial removal could be completed within the time frame with the defined boundaries and scope.

CHAPTER 2
LITERATURE REVIEW

2.1 Decommissioning of Offshore Installation

The UK Offshore Operators Association (UKOOA) defines decommissioning as "The process which the operator of an offshore oil and gas installation goes through to plan, gain government approval and implement the removal, disposal or re-use of a structure when it is no longer needed for its current purpose." Decommissioning can be, and usually will be, a long-term process. According to OGP's Environmental, Social, Health Risk and Impact Management Process, decommissioning is the termination of oil and gas production operations. "Sustainable" in this decommissioning context, means that the legacy of the operation, during the project life cycle, from and environmental, social (including health and safety) and economic perspective, is balanced and at least neutral or positive. It is also being understood as the consideration and inclusion of the various components that are dealt with during decommissioning and closure (i.e., economic, social, environmental, technical, financial, health and safety) and the need to balance the outcomes of these components during the project's life-cycle (World Bank Multi-stakeholder, 2010).

In the worldwide context of oil and gas industry, decommissioning is nothing new and it became a concern after the 1995 Brent Spar controversy. During 1991 to 1993, Shell inspected several disposal options and decided to dump the oil platform, which was weighed around 14500t at the Atlantic Ocean (Shell International Limited, 2008). When production of oil or gas from a field becomes uneconomical that the well is too costly to be maintained or low production volume, a decision may be made by the relevant regulatory agencies in conjunction with the platform operator to cease production, abandon the field and decommission the platform. Most of the experience to date comes from the relatively shallow water of the Gulf of Mexico. Around 1000 offshore structures had been removed from the Gulf of Mexico (Evans, 2008).

For instance Malaysia exhibits only three platforms decommissioning performed by PETRONAS. Based on the necessity of decommissioning of platforms which are going to reach the end of their productive life time it is essential to benefit from the experience of world-wide decommissioning and to research the possible options. The same applies for offshore installations in the Malaysian Sea, where decommissioning activities are predicted to be increased in the near future. In Malaysia 48 % of the platforms have exceeded their 25-year design life. About 28 % of these installations are located off Sarawak (SKO), 12 % off Sabah region (SBO), and the remaining 8 % off Peninsular Malaysia (PMO) (Twomey, 2010). Hence, it is important to have a basic framework to assess the offshore decommissioning activities in Malaysia, particularly regarding the environmental impact assessment as environmental issues are a big concern around the globe now due to arising of global warming and ocean pollutions.

2.2 Decommissioning Options

There are various options of decommissioning offshore structures and it has to be considered which option is the most suitable in the specific case regarding the structure of the offshore platform (OGP Discussion Paper, 1995).

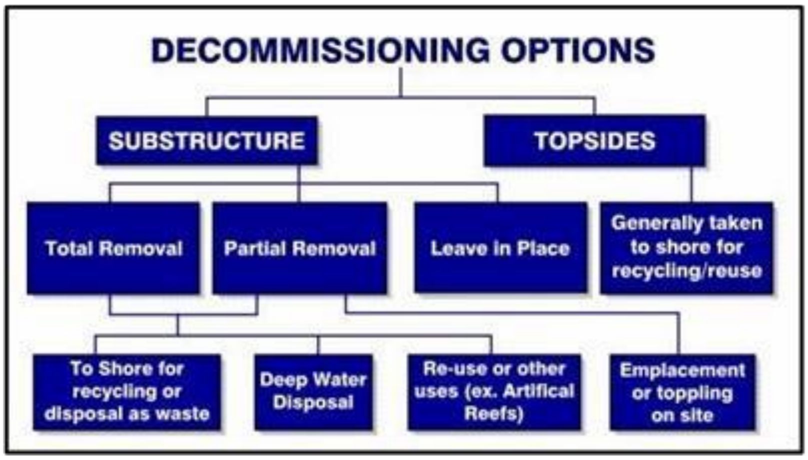


FIGURE 1 Decommissioning options for offshore structures

As mention by Gibson (2002), there are some points that have to be taken into consideration in order to choose the best decommissioning option in any particular case, which are the potential impact on the environment as well as human health and safety, the technical feasibility of the decommissioning plan. Moreover, the economic impact and public concerns have to be taken into account also.

In the present study, two decommissioning options which are complete removal in connection with the transportation onshore for recycling or disposal and the re-use as an artificial reef are compared by using LCA tools.

The complete removal requires the structure to be entirely removed by lifting either in one piece or in section, depending on the size of the structure and the lift vessel's capacity. The foundation piles are left in place from about 5 meter below the seabed. All components removed as parts (Christmas tree, wellhead, tubing, casings, conductor and risers) may be transported into deep water for subsea disposal or brought ashore to a fabrication yard for dismantling (Anthony et al., 2000). Recovered materials, which can be recycled (e.g. structural steel), may be sold to third party recycling concerns or dispatched for smelting and usable facilities are reused. Generally facilities, which cannot be reused or recycled, will be disposed of in accordance with applicable legal and PCSB Waste Management requirements (PETRONAS Research & Scientific Services Sdn. Bhd., 2006).

An artificial reef is a submerged structure placed on the seabed to emulate some functions of a natural reef such as protecting, regenerating, concentrating and enhancing populations of living marine resources. The objectives of an artificial reef may include the protection and restoration of aquatic habitants. The categories artificial reefs are able to be grouped based of their functions are as follows (London Convention and Protocol, 2009):

- Environmental purposes (ecosystem management, restoration, water quality management)
- Living marine resources: attraction, enhancement, production, protection
- Scientific research and education
- Promotion of tourism and leisure activities
- Multi-purpose structures

The Rigs-to-Reef (RTR) is generally understood as the use of a decommissioned offshore oil and gas structures, which have been complete or partially submerged in-situ, or another selected location for the specific purpose of making an artificial reef (Ruivo & Morooka). Studies indicated that oil and gas platforms have proven themselves to be excellent artificial reef materials because they have the characteristics including function, compatibility, durability, stability and availability require for this purpose (PETRONAS Research & Scientific Services Sdn. Bhd., 2006).

For the conversion to an artificial reef there are three methods; platform tow and place, platform topple in place and platform partial removal as shown in Figure 2 (Dauterive, 2000). However, according to IMO, offshore structure that provides a water depth less than 55 m the partial removal of the structure is not an allowable option.

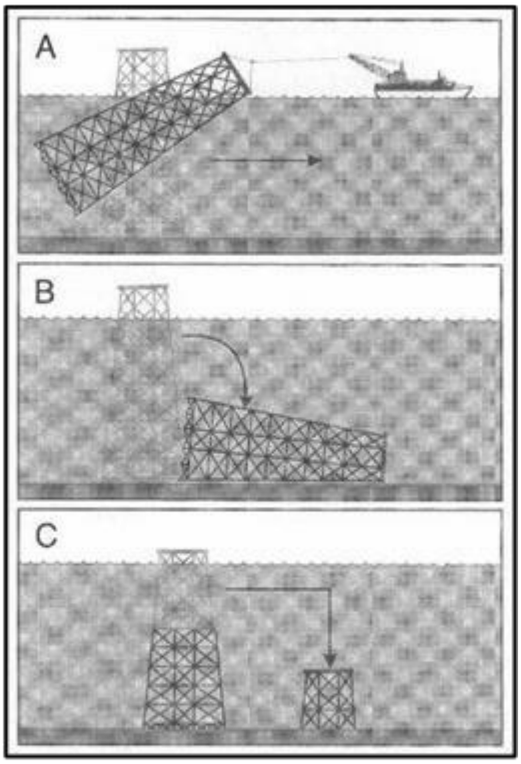


FIGURE 2 Methods of rig-to-reef

The decommissioned platforms are ideal as artificial reefs as their open design attract fish and increase the amount of hard substrate required for coral communities. This results in a more complex food chain, leading to better fishery exploitations. On the other hand, environmentalists claim this practice as a simple excuse for the disposal of used oil rig into the ocean which would lead to a certain degree of habitant damage, localised contamination and spreading of hydrocarbon invasive. However, Malaysia holds much potential in the conversion to artificial reef due to its relatively shallow water depths.

2.3 Environmental Impacts of Decommissioning

Decommissioning of offshore installations has definitely impacts on marine life and the environmental.

- Impacts on Marine Environment
  - Vibration and noise due to machinery
  - "reef habitant" and fauna living on the jacket
- Emissions to the Atmosphere
  - Carbon Dioxide (CO_2)
  - Nitrogen Oxide (NO_x)
  - Sulphur Dioxide (SO_2)
- Effects on the Soil
  - Dredging and anchoring operations at the seabed
- Discharges and Impacts on Water Quality
  - Disturbance of sediments during dredging and debris removal operations (oily waste)
  - Accidental events as vessels grounding, collisions, dropped objects (fuel, chemicals)
- Impacts associated with cleaning or removing chemicals from installation (Offshore)
  - Chemical injection
  - Drilling fluids
- Impact of Re-use, Recycling (Onshore)
  - Material and waste disposal
  - Atmospheric emissions (material transport, material recovery processes)
- Consumption of natural resources and energy

It is clear that decommissioning of offshore platforms will have amounts of negative impacts to the marine environment, thus their estimation could be helpful in order to be able to choose the most suitable decommissioning option to minimise the negative environmental impacts.

In the study, it is focused on the total energy consumption and gaseous emissions (CO_2, SO_2 and NO_x) which are determined by using LCA tools for two options mentioned above, the complete removal and the re-use as an artificial reef.

2.4 Life Cycle Assessment

In this modern days, public environmental awareness increases and industries or businesses are assessing how their activities would affect the environment. Society becomes concerned for depletion of natural resources and arouse of environment issues. Some manufacturers start to produce greener products or use green energy to increase the companies' public image. The environmental impacts of products or processes have become a hot issue that the companies are investigating ways to minimize their environment effects and adopting LCA to assess their products.

In the 1960s and 1970s, life cycle assessment were used to calculate total energy consumption and predict future supplies of raw materials or resources. For some cases, they were combined with economic input-output models and became hybrid LCA to estimate environment emissions and economic costs over their life cycle. In the early 1990s, LCA was being used for external purposes like marketing. Then, the focus of LCA was shifted back to environmental optimization as LCA provides quantitative and structured comparison between alternatives or options to identify the preferred solution, while addressing environmental concerns simultaneously (Leontief, Input-output economics, 1996).

There are different methods for LCA. Process LCA is the most popular method amongst others. There are several tools such as GaBi, Umberto or SimaPro existing in the market which are suitable for conducting this type of LCA. These tools provide data from previous researchers on the environmental impact of materials and processes which can be used by the user to form a system (Lehtinen, H. et al., 2011; Gorges, C., 2014). Besides, EIO-LCA is the second method which utilizes economic input-output table and industry-level environment data to construct a database of environmental impact with reference to a selected economic value (Green Design Institute). This method capture the interrelations of all economic sectors.

To provide an overview on the advantages and disadvantages of the described LCA methods, they are stated in table format (Green Design Institute):

TABLE 1 Advantages of process based LCA and EIO-LCA

	Process-Based LCA	EIO-LCA
Advantages	results are detailed, process specific	results are economy-wide, comprehensive assessments
	allows for specific product comparisons	allows for systems-level comparisons
	provides for future product development assessments	provides for future product development assessment
	Identifies areas for process improvements, weak point analysis	uses publicly available, reproducible results
		Provides information on every commodity in economy

TABLE 2 Disadvantages of process based LCA and EIO-LCA

	Process-Based LCA	EIO-LCA
Disadvantages	setting system boundary is subjective	product assessment contain aggregate data
	time intensive and costly	process assessment difficult
	difficult to apply to new process design	must link monetary values with physical units
	use proprietary data	imports treated as products created within economic boundaries
	cannot be replicated if confidential data are used	availability of data for complete environmental effects
	uncertainty in data	uncertainty in data

2.5 Decommissioning Laws and Regulations

The decommissioning of oil and gas installations in Malaysia is primarily governed by the PETRONAS Decommissioning Guidelines which is based on recognized international guidelines such the 1989 International Marine Organization Guidelines and Standards and the 1982 UN Convention on the Law of the Seas (UNCLOS) which is pro-complete removal of the all structures in water depths less than 100 meters and substructures weighing less than 4000 tonnes (Na, Wan Abdullah Zawawi, Liew, & Abdul Razak, 2012).

In addition, International Maritime Organization (IMO) had developed a guidelines for offshore decommissioning in 1989, named “Guidelines and Standards of the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone” (Hoyle & Griffin, 1989). The guidelines stated that all abandoned or disused installations and structures standing in less than 75m of water and weighing less than 4000 tonnes in air, excluding the deck and superstructure, should be entirely removed. Besides, all abandoned or disused installations and structures, which were installed on or after January 1998 standing in less than 100m of water and weighing less than 4000 tonnes in air, excluding the deck and superstructure, should be entirely removed. In the case where complete removal is not technically practicable or would involve extreme cost or an unacceptable risk to personnel or the marine environment, the coastal state may determine that the installations need not be entirely removed. For partial removal, an unobstructed water column sufficient to ensure safety of navigation, but not lesser than 55m should be provided above any parts remaining on the seabed (Hoyle & Griffin, 1989).

2.6 Researched Offshore Platform

2.6.1 Case Study: Platform X, Malaysia

In this paper a case study is used to identify the Environmental Impacts based on a decommissioning Process of a specific fixed offshore platform using the LCA tools which are process based method and EIO-LCA method. By reference to this case study, it should be pointed out which Environmental Impacts take place during the decommissioning process and in which amount.

The Offshore Structure, used as case study, named Platform X was a four pile wellhead drilling platform located at Tembungo Field, a part of Sabah Operations (SBO). It was installed approximately 80 km northwest of Kota Kinabalu, Sabah in Malaysia with a water depth about 86.0m. It had been constructed in March 1993. This platform was designed as unmanned platform which uses natural flow to transport the oil from wells to the main platform. The production capacity of the field for oil was about 6500 barrel per day and for gas approximately 13 million standard cubic feet per day (Ramasamy, 2014).

FIGURE 3 View of Platform X (Ramasamy, 2014)

In the present study the selected option complete removal and the option re-use as an artificial reef will be compared concerning the Environmental Impacts of decommissioning Platform X. This study may be beneficial for future decommissioning projects. This study takes quantitative measures of atmospheric emissions and the energy consumption into account by using LCA tools: process based method and EIO method. Subsequently, from the results of life cycle assessment, we can select the best option for the decommissioning project that produce less environment impact.

CHAPTER 3
METHODOLOGY/PROJECT WORK

3.1 Research Problem

Offshore installations decommissioning would definitely bring along environmental impact and with increased public awareness on environment issues, it is very important to assess and quantify the environmental impacts associated with of offshore decommissioning. However, there is minimal information and framework published to assess the environmental impacts of offshore decommissioning. LCA analysis is used as it provides quantitative and structural comparison between different decommissioning options. Therefore, the goal of this research is to develop a basic framework to assess environmental impacts associated with offshore decommissioning.

3.2 Research Objective

The objective of this study are:

a) To quantify the environmental impacts associated with the decommissioning of local offshore installations using Life Cycle Assessment (LCA).

   Platform X, a Jacket Platform located offshore Sabah in the South China Sea, is selected as a case study. The environmental impacts produced during offshore decommissioning are quantified by performing life cycle assessment based on two decommissioning options; complete removal and reuse of platform. Gaseous emissions produced (CO_2, SO_2, and NO_x) are the main concern.

b) To establish two LCA tools: process based method and EIO method.

   The retrieved results by conducting the two LCA tools process based and EIO method respectively will be compared and the applicability for this study be evaluated.

c) To suggest relevant mitigation measures for environmental concerns that arises in connection with the decommissioning of offshore platforms.

Based on the results attained by both method of LCA, the decommissioning activity, which is the main contributor for energy consumption and gaseous emissions could be identified and mitigation measures and recommendations proposed in the following chapter to reduce the environmental impacts associated with decommissioning of offshore structures.

3.3 Project Flow Chart

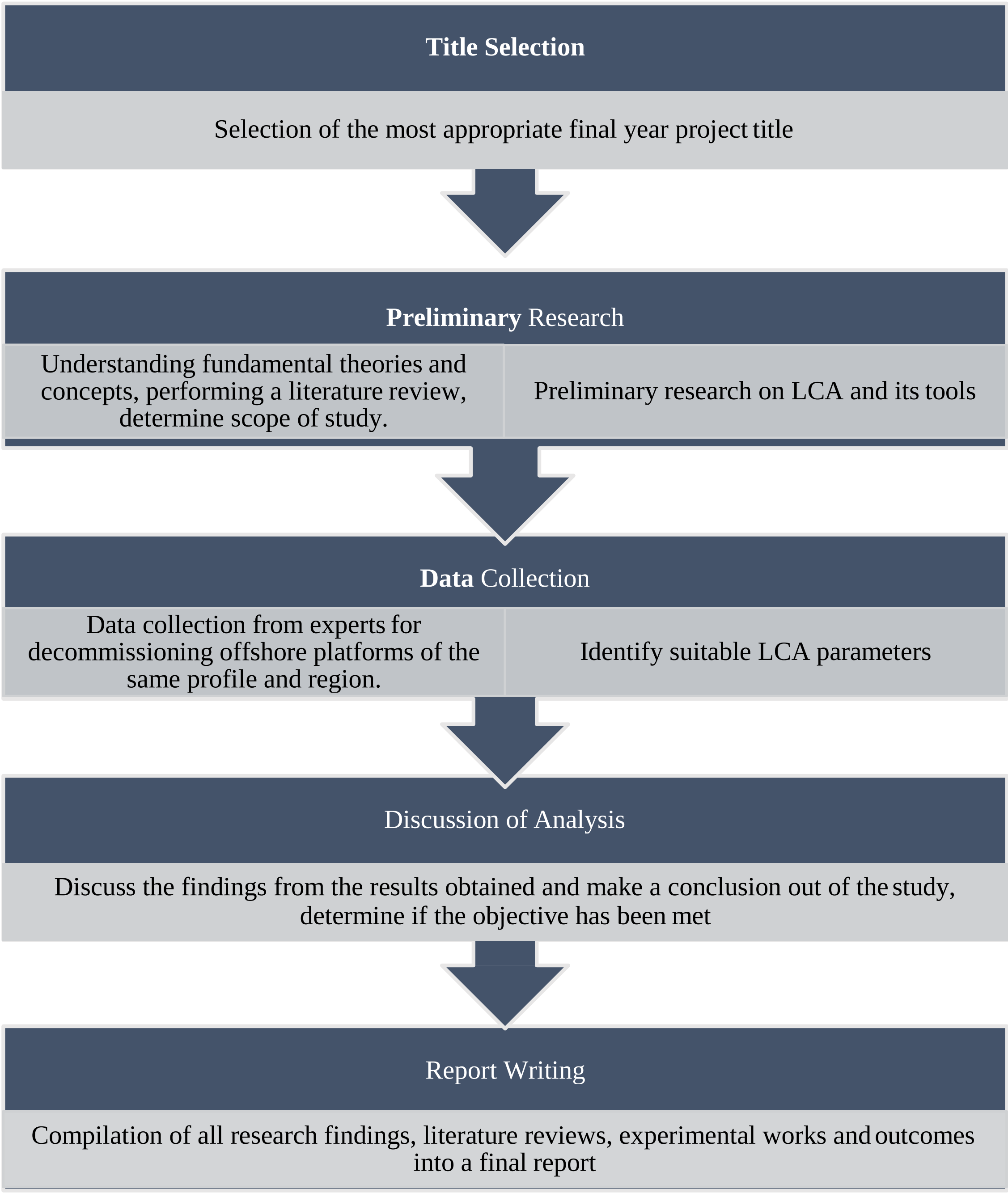


FIGURE 4 Project activities flow

3.4 Research Methodology

After the selection of the project title, the main relevant and feasible objective and scope of the study were identified. Then, the author researched online and read through journals and published papers on life cycle analysis, decommissioning options for offshore structures, their environmental impacts, as well as the LCA tools (EIO method and process based method), which will be used in this thesis. Subsequently, the data and information required for the analysis will be collected by using internet and available resources provided by the university. Afterwards, the collected data will be analysed using the LCA tools mentioned above. The output results are then compared and discussed regarding the two LCA tools, the differences between the Environmental Impacts of decommissioning in dependence of the location of the Offshore Structures and the possible mitigation measures. After that, a conclusion will be made.

The research methodology applied in this study is presented in Figure 5.

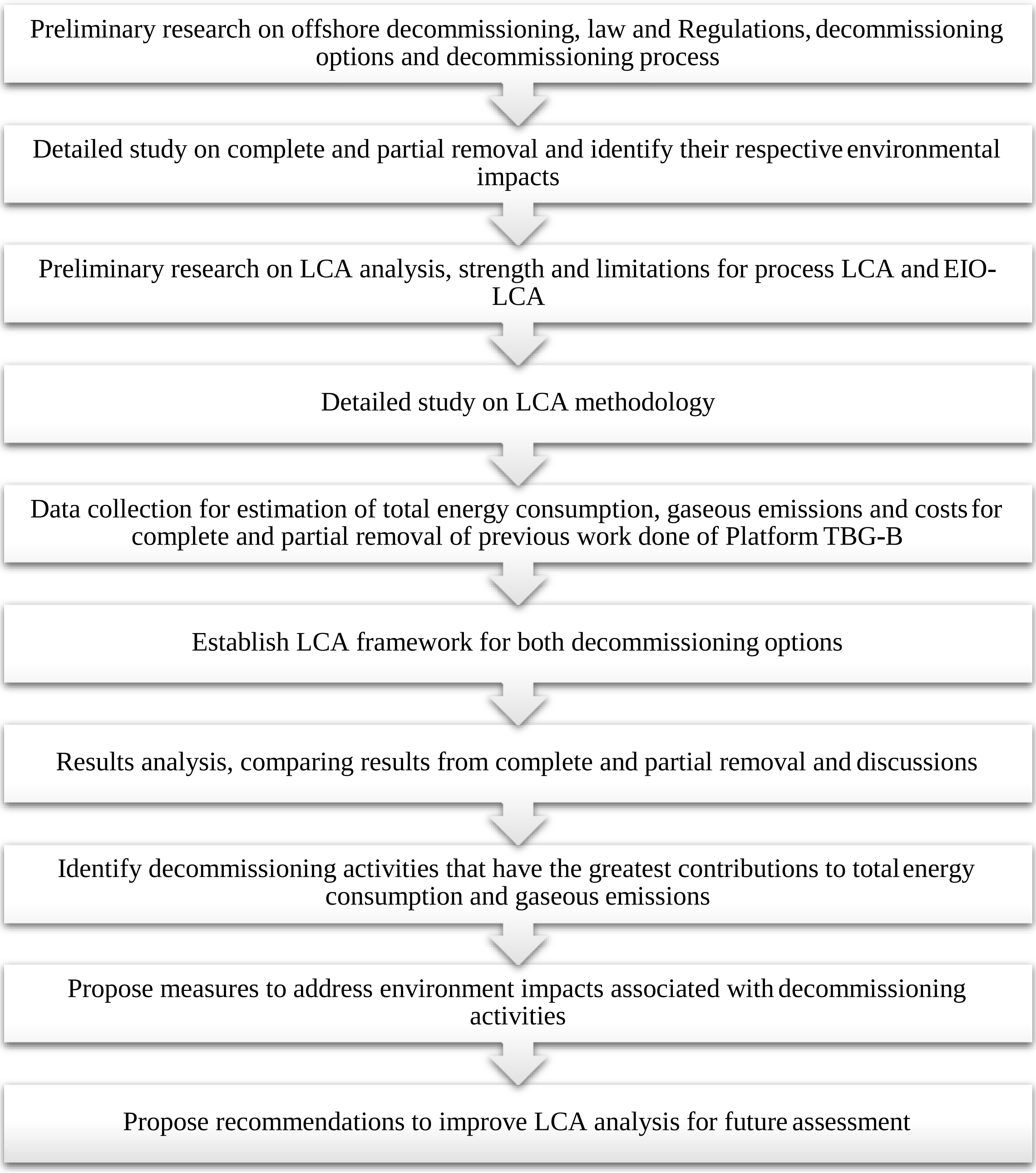


FIGURE 5 Research methodology used in this study

3.5 Gantt chart

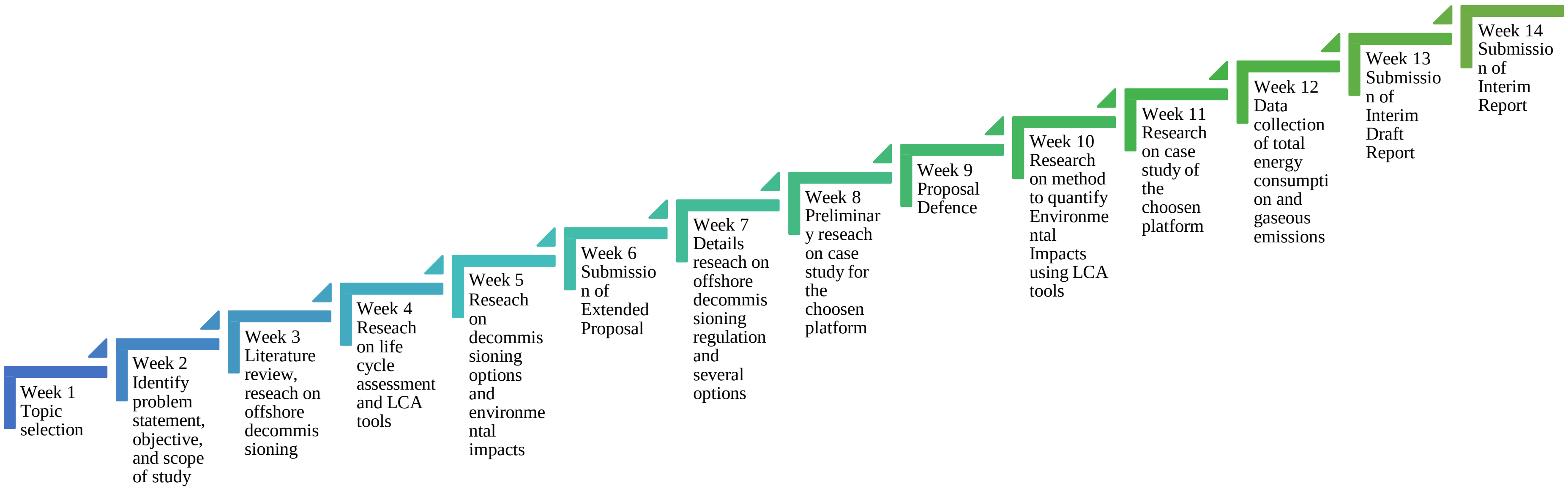
		FYPI														FYPII														
No.	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Selection of project title																													
2	Determination of problem statement, objective and scope of study																													
3	Research on decommissioning options, procedures, regulations and identify type of waste materials produced and the environment impacts																													
4	Submission of extended proposal																													
5	Research on LCA tools for their respective strength and limitations																													
6	Proposal defense																													
7	Research on procedures to conduct process LCA and online models of EIO																													
8	Submission of interimdraft report																													
9	Submission of interimreport																													
10	Conduct process LCA for complete and partial removal																													
11	Research on online EIO models and their assumptions or limitations																													
12	Conduct EIO analysis for complete and partial removal																													
13	Life cycle interpretation and discussions																													
14	Submission of progress report																													
15	Propose recommendations or measures to address environment impacts																													
16	Propose recommendations for LCA improvement																													
17	Pre-Sedex																													
18	Submission of draft report																													
19	Submission of technical report and dissertation																													
20	Oral presentation																													
21	Submission of hardbound dissertation																													

Administrative requirement

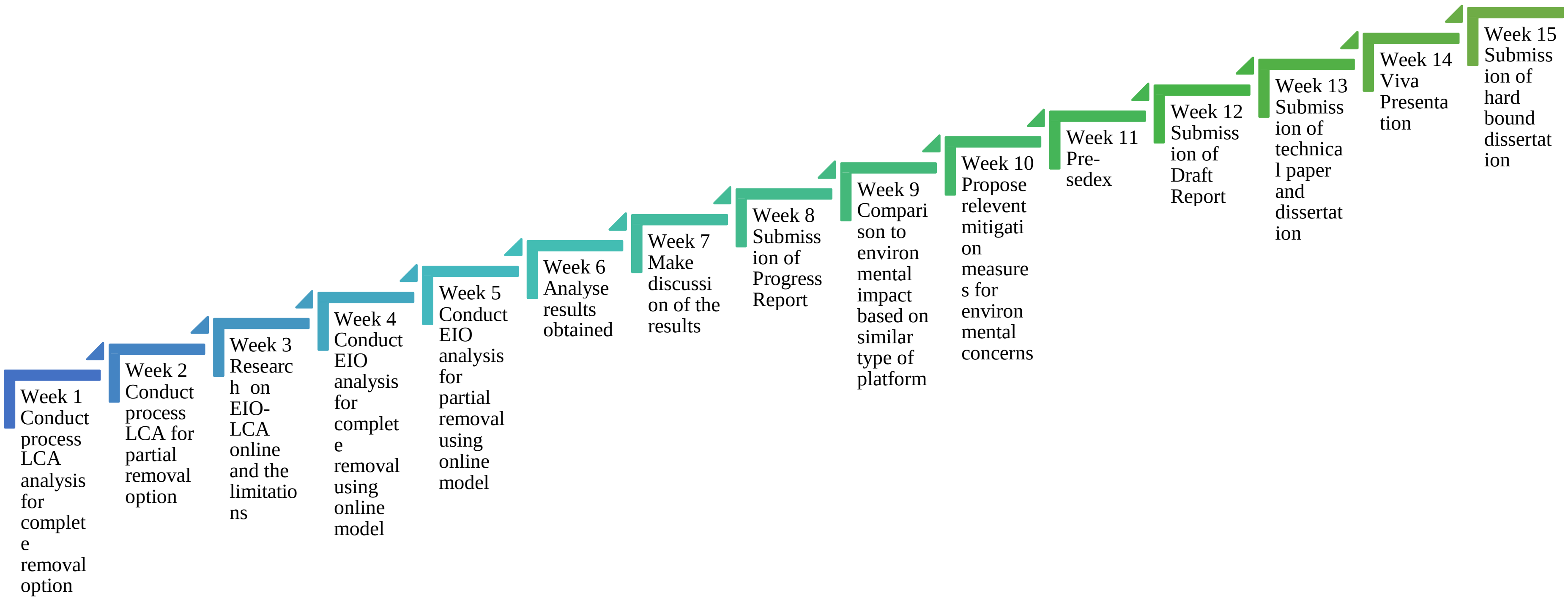
Milestone

3.6 Key Milestone

The planned schedules for Final Year Project I are as follows:



The planned schedules for Final Year Project II are as follows:



3.7 LCA Methodology

3.7.1 Process Based LCA Analysis

It has to be taken into account that the author set some assumptions and boundaries for this study due to limited available data and to adapt to the LCA analysis conducted for the decommissioning process of Platform X. The data used for process based LCA are retrieved from the PETRONAS for Platform X and several documentations of the decommissioning process such as the published BPEO Study for local platform. Due to limited detailed data for environment impacts, particularly gaseous emissions associated with offshore installations decommissioning, the author had to utilize the data available. Most of the data used for process LCA were retrieved from Side, Kerr, & Gamblin (1997). Refer to the Appendices for the unit conversion factors and constants for energy consumption and gaseous emissions related to onshore and scrap vessel haulage round trip distance, marine vessels, engine and helicopter usage, recycling process and fuel consumption during decommissioning process used in process LCA and their respective references. The quantification of energy consumption associated with the platform facilities dismantling based on unit fuel consumption per tonne dismantled was obtained from the demolition contractor based on their decommissioning experience (Side, Kerr & Gamblin, 1997). Data variables involved due to assessing two decommissioning options, complete removal and conversion to an artificial reef which influence the total energy consumption and gaseous emissions are developed.

3.7.2 EIO-LCA Analysis

The data incorporated into the EIO-LCA model is compiled from surveys and forms submitted by industries to the government for national statistical purposes, which leads to uncertainties in sampling and incomplete data or estimates. The data implemented in the online model is based on the US 2002 Benchmark model, where 428 industry sectors where each of them represents a collection of several industry types, are involved. The data associated with each model are representative of the year of the model including the economic input-output matrix and the environmental data. Thus, in using the model to replicate current conditions, it has to be taken into account that the changes in data could vary widely over the time. Since the data applied in the EIO model is based on the year 2002 the model documentation was observed and it was discovered that the Green Design

Institute revised the model with latest economic-input-output coefficients in 2009. Hence the results would be valid.

For EIO-LCA, the EIO online model from www.eiolca.net, where a database is already implemented as stated before, is conducted to assess the total energy consumption and gaseous emissions associated with offshore decommissioning. The US 2002 Purchaser Price Model is chosen, Mining and Utilities as Broad Sector Group and Support activities for oil and gas operations as detailed industry sector selected. This U.S. industry involves support activities on a contract or fee basis for oil and gas operations (except site preparation and related construction activities). Services included are exploration (except geophysical surveying and mapping); excavating slush pits and cellars; well surveying; running, cutting, and pulling casings, tubes and rods; cementing wells; shooting wells; perforating well casings; acidizing and chemically treating wells; and cleaning out, bailing, and swabbing wells (Green Design Institute). The amount of economic activity is assumed to be one million US Dollar.

3.7.3 Stage 1: Goal and Scope Definition

As stated by the ISO Standards, the goal of the LCA has to be defined firmly with the reasons, field of application and groups involved. For this assessment, the goal is conform to the objectives of this study, which require the identification and quantification of the environmental impacts associated with the decommissioning of fixed offshore platforms in Malaysia, and the proposal of relevant mitigation measures for environmental concerns arising with this process.

The scope of this study was limited to two decommissioning options: complete removal and re-use as an artificial reef that is removal of jacket for 55m below the sea level. Platform X was selected as the functional unit or case study for this project. The following boundaries had been made to ensure no energy is being counted twice and consistency in data evaluation (Side, Kerr, & Gamblin, 1997)

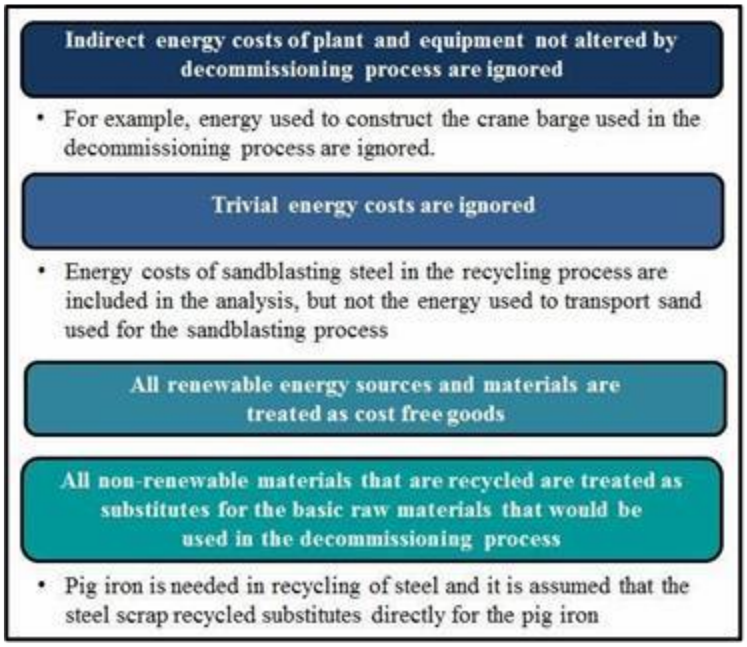


FIGURE 6 Defined boundaries for consistency in data evaluation

3.7.4 Stage 2: Life Cycle Inventory for Process Based LCA

The Life Cycle Inventory (LCI) analysis includes the data collection and calculation to estimate relevant inputs and outputs of the system (Poremski, 1998). For offshore decommissioning the input is the energy consumption, whereas the outputs are the produced gaseous emissions. The four inventory parameters concerned in this paper are Carbon Dioxide (CO2), Nitrogen Oxides (NOx) and Sulphur Dioxide (SO2) and Equivalent Carbon Dioxide due to their significance in the contribution for emissions associated with offshore installations decommissioning.

The LCA methods used in this project are process based- and EIO-LCA. For the LCI implemented in process based method, used to estimate the total energy consumption and gaseous emissions associated with decommissioning of Platform X, the data were obtained from a paper published by Side et al. (1997), the BPEO Study for local platform and from documentation documents about the decommissioning process.

For the ease of data evaluation in process based LCA, the decommissioning activities for Platform X is divided into several discrete aspects, consisting of:

TABLE 3 Decommissioning activities

Marine vessel utilisation	• Product of vessel utilisation and corresponding fuel consumption
Platform Dismantling	• Removed platform materials, fuel consumption for dismantling operations
Platform Material Recycling	• Product of recycling materials
Platform Materials left at Sea	• Product of materials left at sea (for re-use as artificial reef)
Transportation Onshore	• Removed materials of dismantling operations: transportation of materials for recycling and disposal onshore

For EIO-LCA on the other hand, the standard unit economic value outcome can be taken from the EIO online model and database from www.eiolca.net provided by the Green Design Institute whereby relevant cost input data of a project shall be keyed into the online model. This model will then project out estimations of impacts by the sector based on an economic value (US dollar). One million USD is referred as the standard unit economic value implemented in the purchaser price model for oil and gas operations which values will be referred and used to calculate the total energy consumption and gaseous emissions. The total energy consumption and gaseous emissions data for the standard unit of one million USD are as attached in the Appendices. The cost input data to perform LCA analysis, using the EIO online model, was retrieved from a cost estimation for complete removal for local platform located in the South China Sea, from the PETRONAS Petroleum Management Unit.

As for the conversion to an artificial reef there is no suitable cost information available, they are assumed based on the comparison between the costs of complete removal and the conversion to an artificial reef calculated for three Offshore Structures in the Gulf of Mexico. By comparing the costs obtained from a paper published by Twatchman Snyder & Byrd, Inc. (2000) for decommissioning the Platform Hidalgo, Gail and Harmony, the average difference between the costs for the different decommissioning options could be taken, which results in 35 %. As the cost data was attained in Ringgit Malaysia, the author converted the cost to US Dollar in order to be able to use the value in the EIO model. Although the currency rate changes every day, the result might not be affected much, as the fluctuation rate is insignificant compared to the amount of decommissioning costs.

For EIO-LCA, the EIO online model from www.eiolca.net, where a database is already implemented as stated before, is conducted to assess the total energy consumption and gaseous emissions associated with offshore decommissioning. The US 2002 Purchaser Price Model is chosen, Mining and Utilities as Broad Sector Group and Support activities for oil and gas operations as detailed industry sector selected. This U.S. industry involves support activities on a contract or fee basis for oil and gas operations (except site preparation and related construction activities). Services included are exploration (except geophysical surveying and mapping); excavating slush pits and cellars; well surveying; running, cutting, and pulling casings, tubes and rods; cementing wells; shooting wells; perforating well casings; acidizing and chemically treating wells; and cleaning out, bailing, and swabbing wells (Green Design Institute). The amount of economic activity is assumed to be one million US Dollar.

3.7.5 Life Cycle Impact Assessment

Life Cycle Impact Assessment consist of the evaluation of the significance of potential environmental impacts based on the results obtained by performing the previous stage. After the inventory data is classified into their respective impact category the data is modelled within those categories and finally prioritised and weighted. The impact categories applicable in this conducted LCA are global warming (CO2 and Equivalent CO2) and acidification (SO2 and NOx) according to the Scientific Applications International Corporation (2006).

CHAPTER 4
RESULT AND DISCUSSION

4.1 Introduction

In this chapter, the results from process LCA and EIO-LCA are obtainable in the tables and graphs. The results are then further discussed and interpreted in this chapter. In the last part of this chapter, the author recommends few measures to reduce environmental impacts associated with offshore decommissioning and recommendations on improvement of LCA analysis.

4.2 Results and Discussion

4.2.1 Process Based LCA

Data for process LCA was gained from a published work by Side, Kerr & Gamblin (1997) on the estimation of energy consumption and gaseous emissions and also from several documentations of the decommissioning process. The detailed input data including unit conversion factors, constants, distances, average fuel consumptions and executed calculations are attached in the Appendices. Total energy consumption and gaseous emissions were assigned to several decommissioning aspects for the ease of evaluation and to be able to identify the aspect with the greatest contribution.

Table 4 indicates the quantitative results for total energy consumption and gaseous emissions obtained by process LCA using EXCEL Software for both decommissioning options Platform X; complete removal and partial removal.

The details results for each aspect are also shown in Appendix K.

TABLE 4 Percentage difference between complete and partial removal of Platform X in energy consumption and gaseous emissions.

Variable	Complete Removal	Artificial Reef	Difference [%]
Energy Consumption [GJ]	56,922.25	72,814.10	21.83
SO_2 Emissions [kg]	49,838.30	50,912.60	2.13
NO_x Emissions [kg]	49,171.32	50,127.80	1.91
CO_2 Emissions [kg]	3,916,775.33	6,000,443.26	34.73
Equivalent CO_2 Emissions [kg]	2,077,504.87	2,116,724.37	1.85
Overall CO_2 Emissions [kg]	5,994,280.20	8,117,167.63	26.15

From the table, we can conclude that partial removal (artificial reef) option consumes more energy (21.83% more), emits more SO_2 (2.13% more), NO_x (1.91% more), CO_2 (34.73% more), Equivalent CO_2 (1.85% more), and Overall CO_2 (26.15% more) than complete removal.

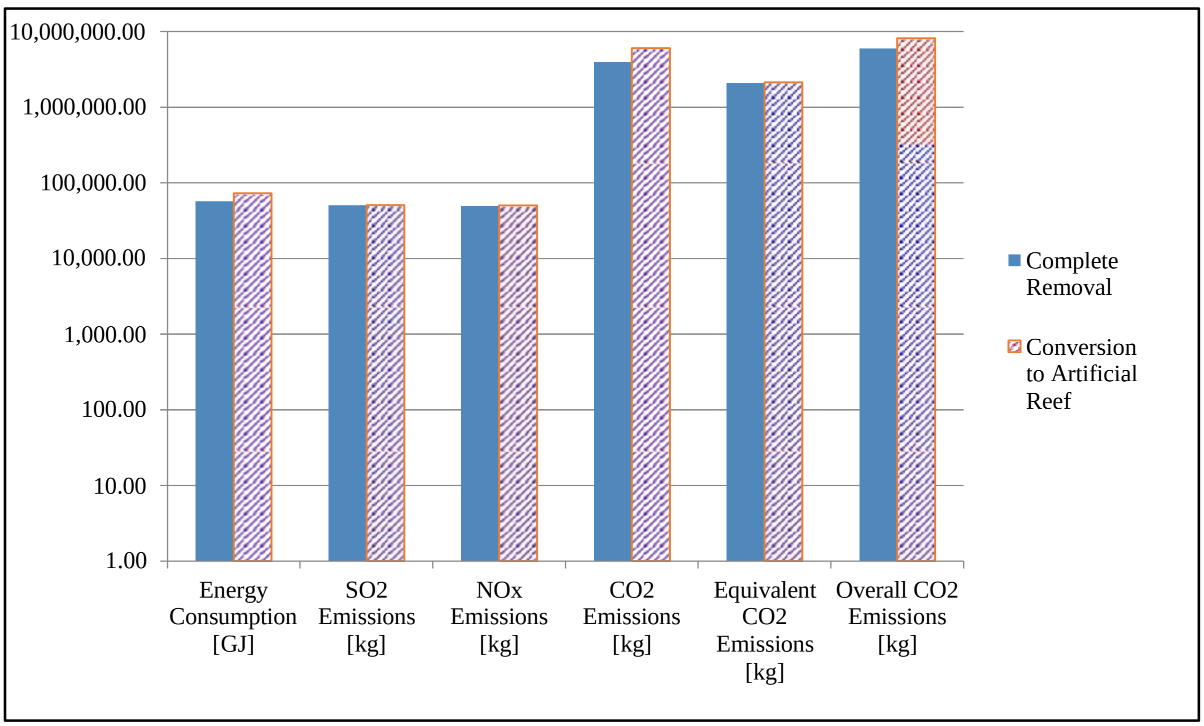


FIGURE 7 Comparison between total energy consumption and gaseous emissions depending on decommissioning option for Platform X

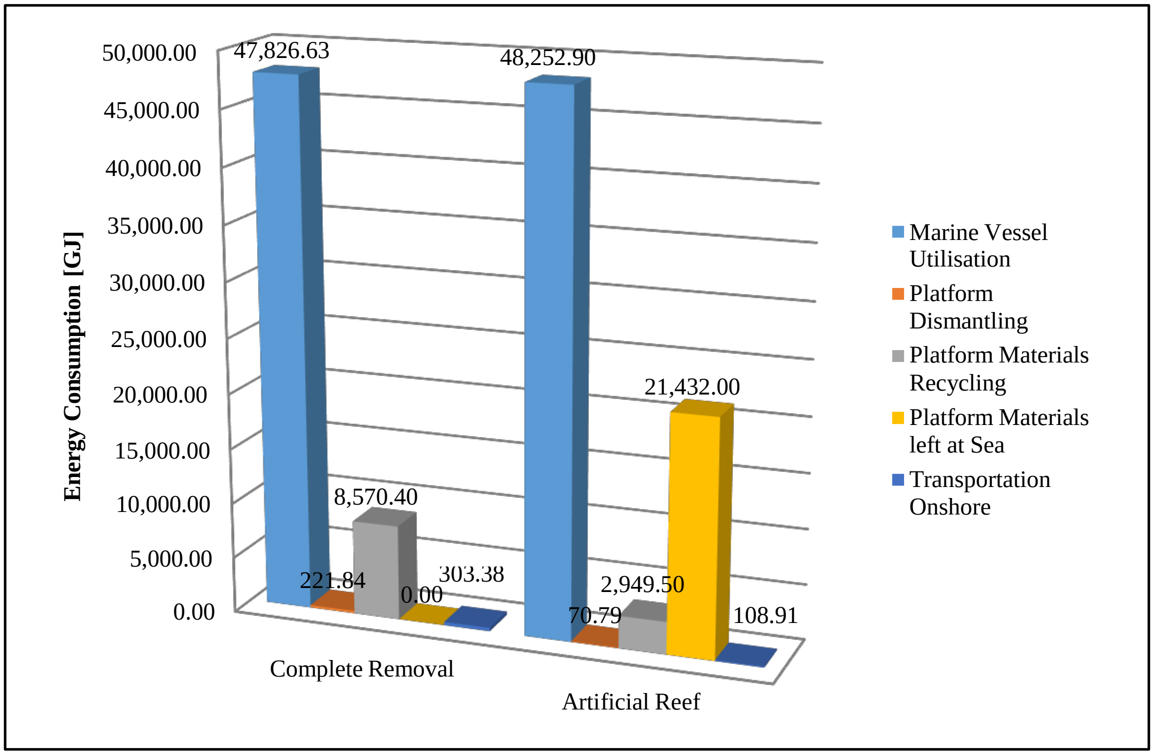


FIGURE 8 Breakdown of energy consumption [GJ] with respective decommissioning activities for complete removal and partial removal (Artificial reef) for Platform X

As illustrated in Figure 8 above, it becomes clear that the energy consumption in the case of partial removal (artificial reef) is higher than in performing complete removal. The higher energy consumption arises since the amount of steel which is left at sea to create the artificial reef is replaced by steel production from ore, which requires big amounts of energy. Besides, it is also considered that the topside is brought onshore for recycling, which results in a greater marine vessel utilization than in the case of complete removal.

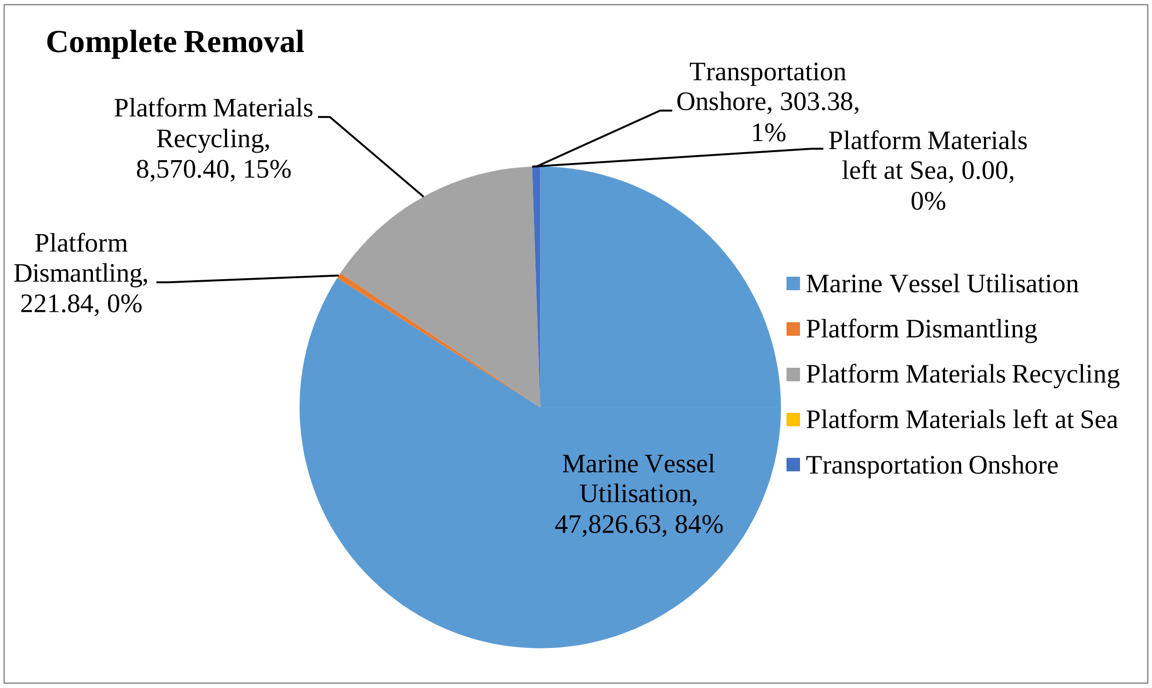


FIGURE 9 Energy consumption [GJ] of complete removal depending on decommissioning activities for Platform X

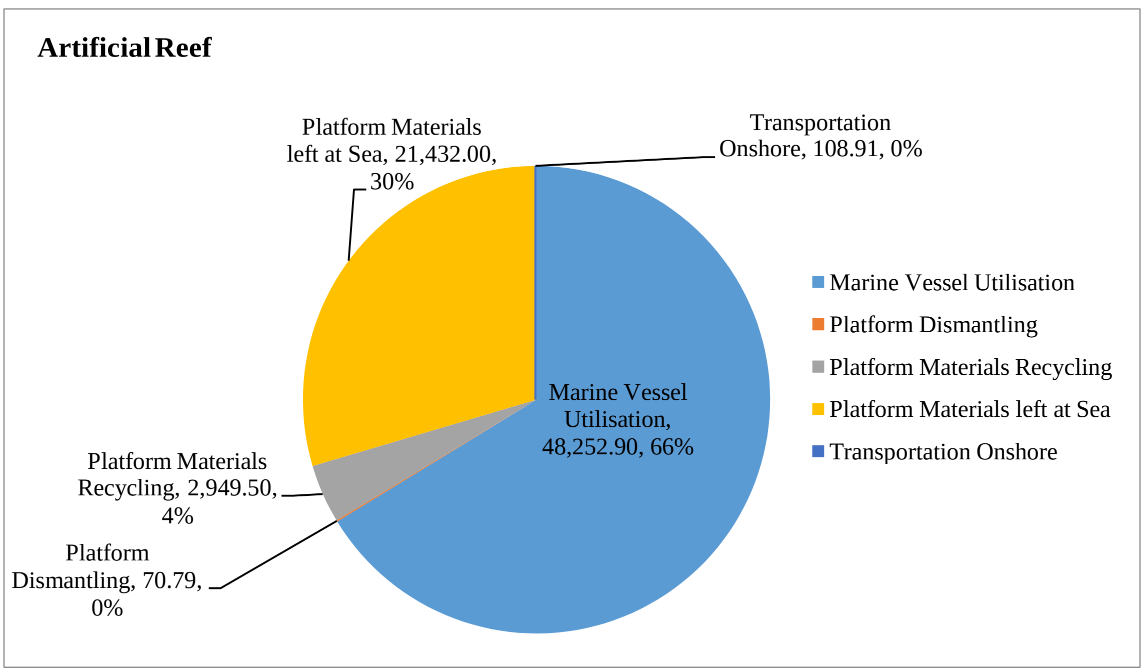


FIGURE 10 Energy consumption [GJ] of conversion to partial removal (Artificial reef) depending on decommissioning activities for Platform X

The pie charts in Figures 9 and 10 show that the marine vessel utilization is the largest energy consuming activity during complete removal (84 %) and conversion to an artificial reef (66 %). The energy consumption due to platform dismantling, recycling and transport onshore are proportional insignificant. Just the materials left at sea in case of conversion to an artificial reef (partial removal) contribute slightly due to the consideration as steel produced from ore as mentioned before. It indicates the energy wasted as the material is not recycled.

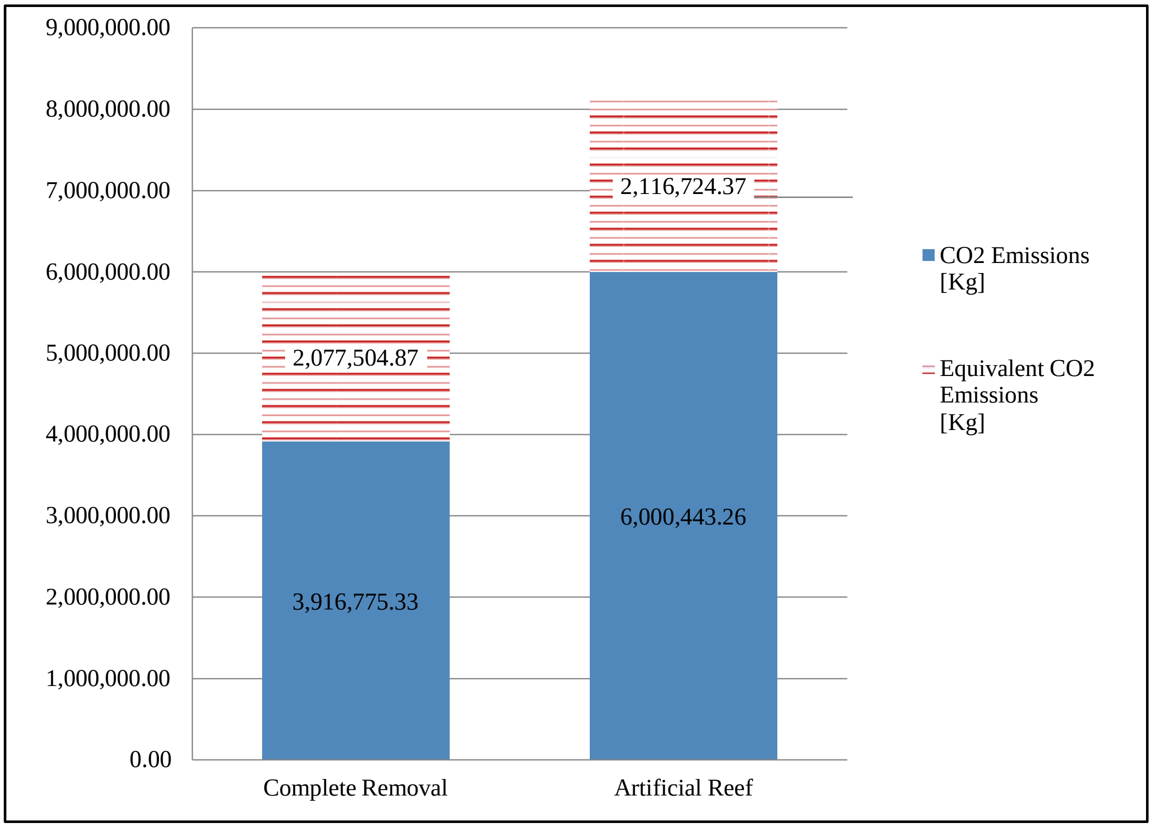


FIGURE 11 Overall CO_2 emissions [kg] depending on decommissioning option for Platform X

The CO_2 and Equivalent CO_2 emissions are designated as the main factors for global warming resulting in an increase of the sea level at heat waves. In order to investigate which decommissioning option contributes more to global warming it is focused on the overall CO_2 emissions. Based on Figure 11, it is obvious that the amount of overall CO_2 emissions is similar regarding the two different decommissioning options with a percentage difference of 26.15%. However, it is illustrated, that conversion to an artificial reef produces more CO_2 emissions with 34.73% more compared to complete removal. The greater production of those emissions is traceable to the greater amount of fuel by the marine vessels used for transport of the jacket and boat landing to the artificial reef site as well as the topside onshore for recycling.

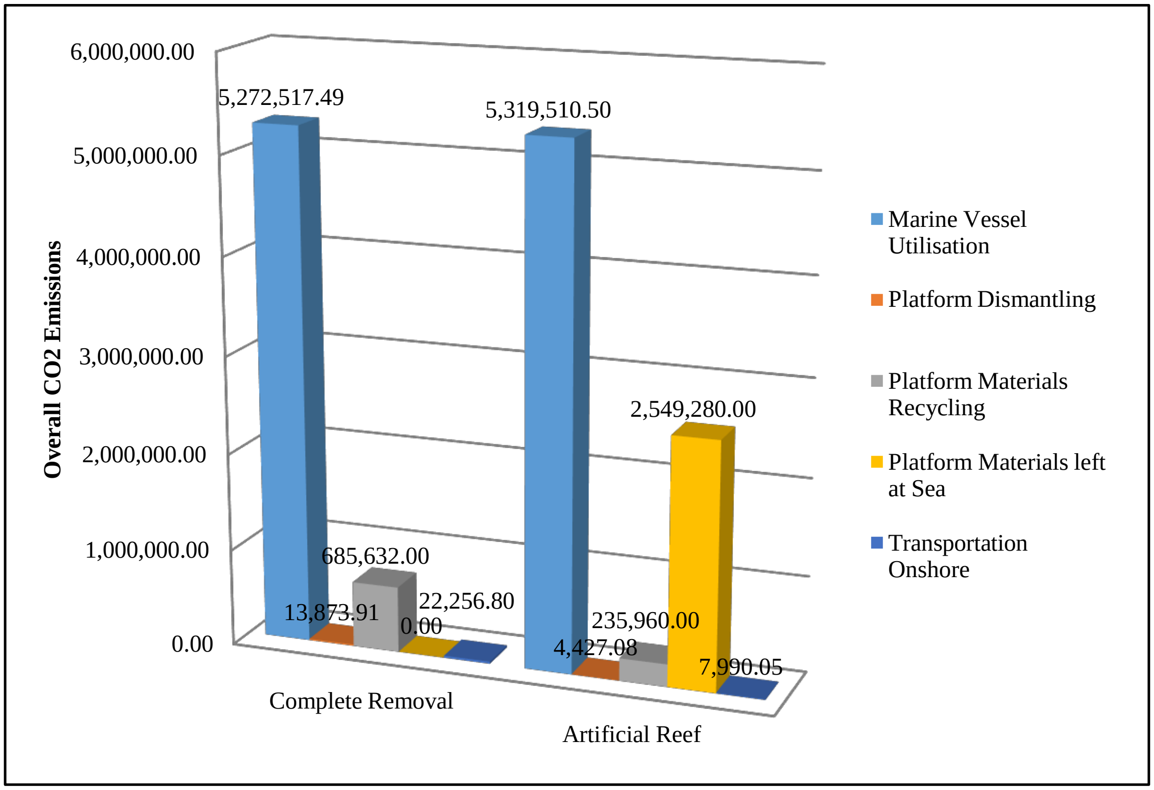


FIGURE 12 Breakdown of overall CO_2 emissions [kg] with respective decommissioning activities for complete and partial removal for Platform X

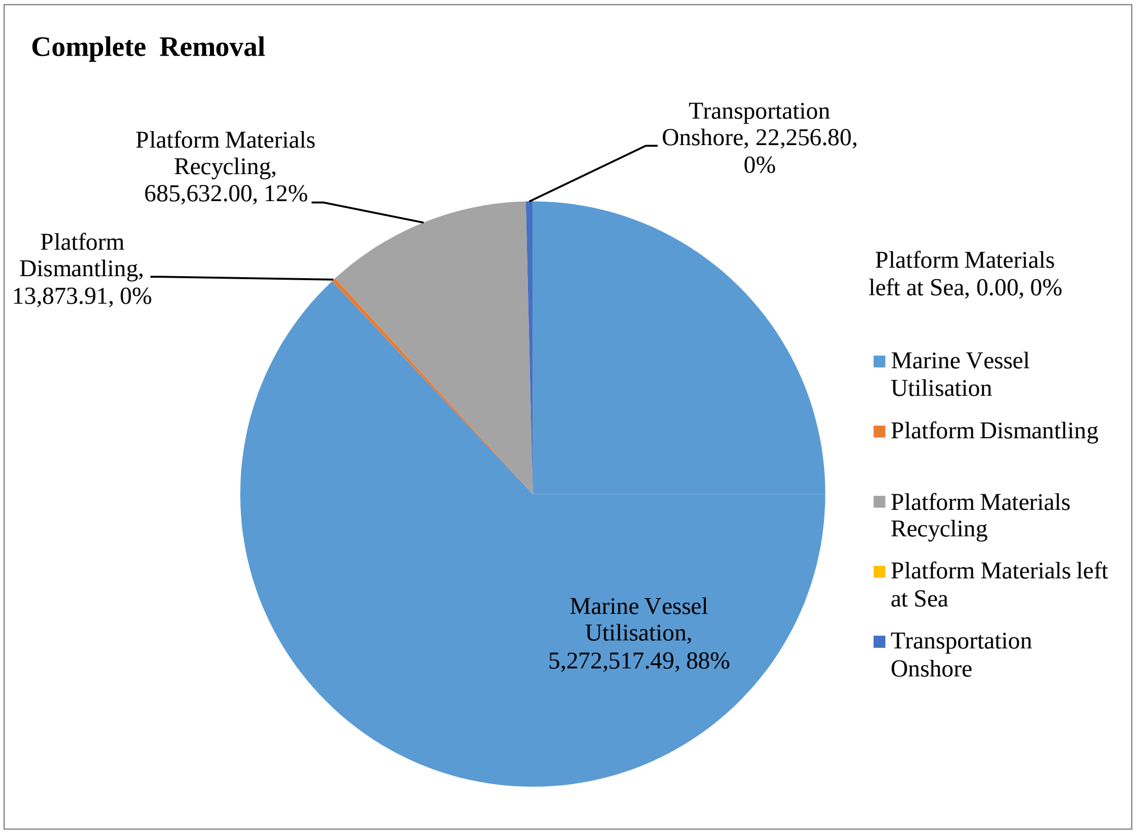


FIGURE 13 Overall CO2 emissions [kg] of complete removal depending on decommissioning activities for Platform X

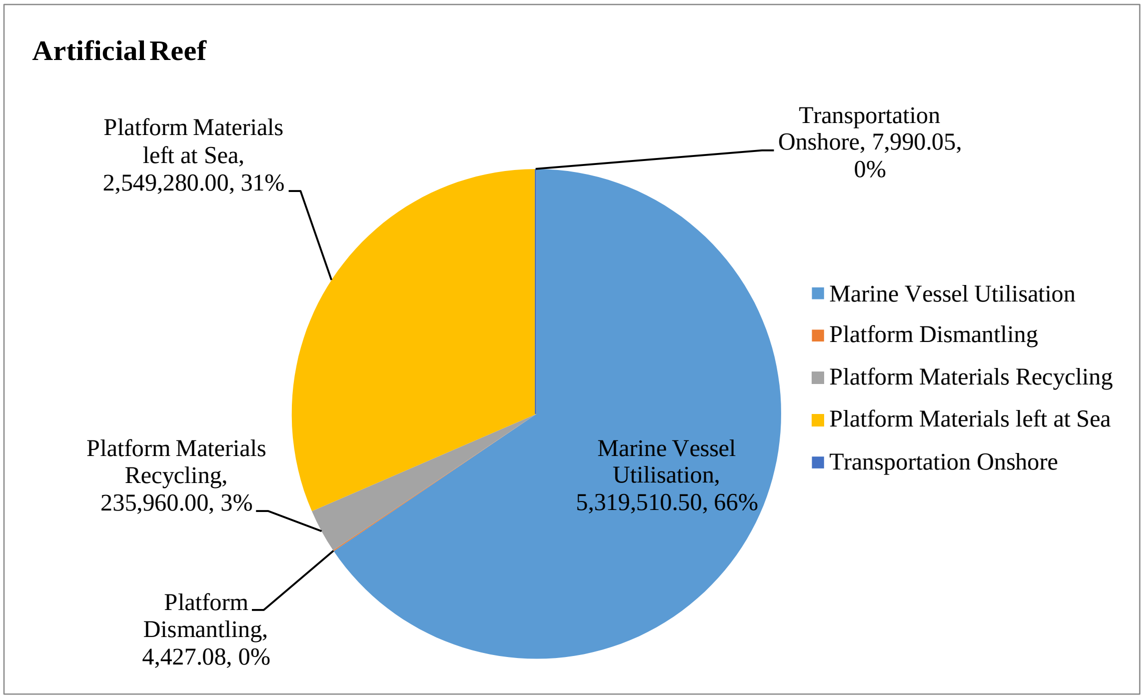


FIGURE 14 Overall CO_2 emissions [kg] of partial removal depending on decommissioning activities for Platform X

From Figure 12, 13 and 14, it can be observed that the greatest contribution to the overall CO_2 emission for complete removal and partial removal (artificial reef) with the percentage of 88% and 66% respectively, is the marine vessel utilisation. The CO_2 emissions due to platform dismantling, recycling and transport onshore are here as well proportional insignificant. Just the materials left at sea in case of conversion to an artificial reef contribute slightly due to the consideration as steel produced from ore as mentioned before. As stated before, this indicates the energy wasted as the material is not recycled.

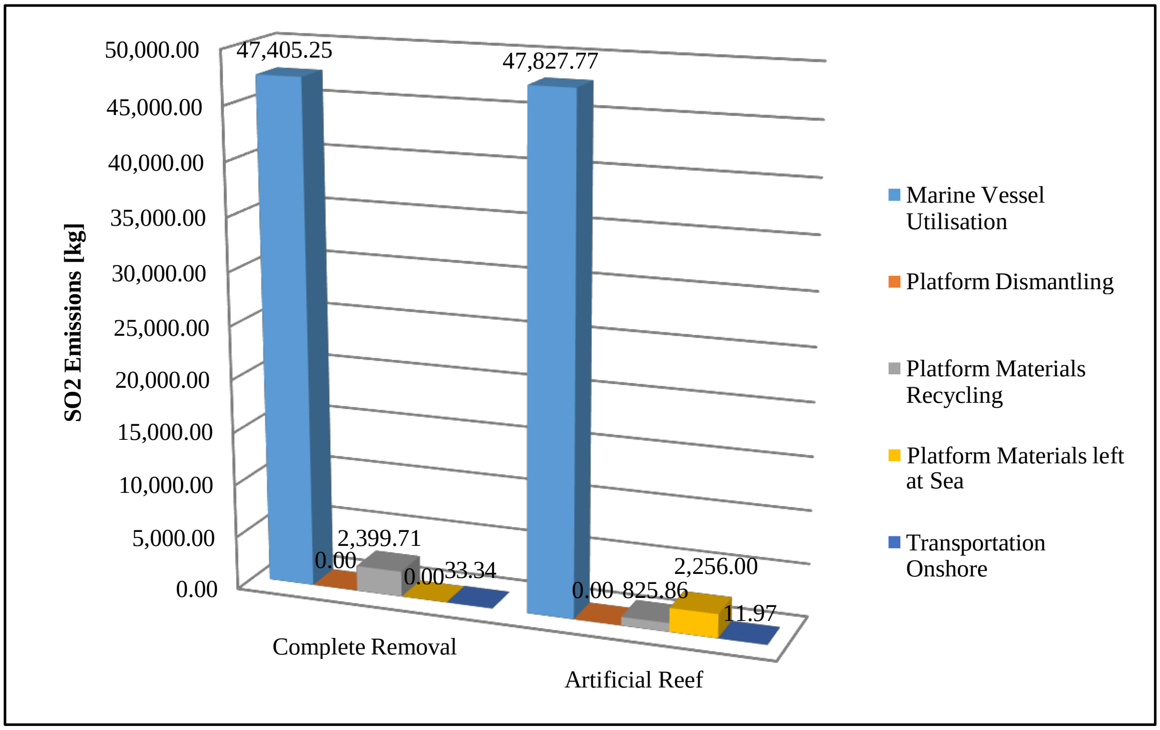


FIGURE 15 Breakdown of SO2 emissions [kg] with respective decommissioning activities for complete removal and partial removal (artificial reef) for Platform X

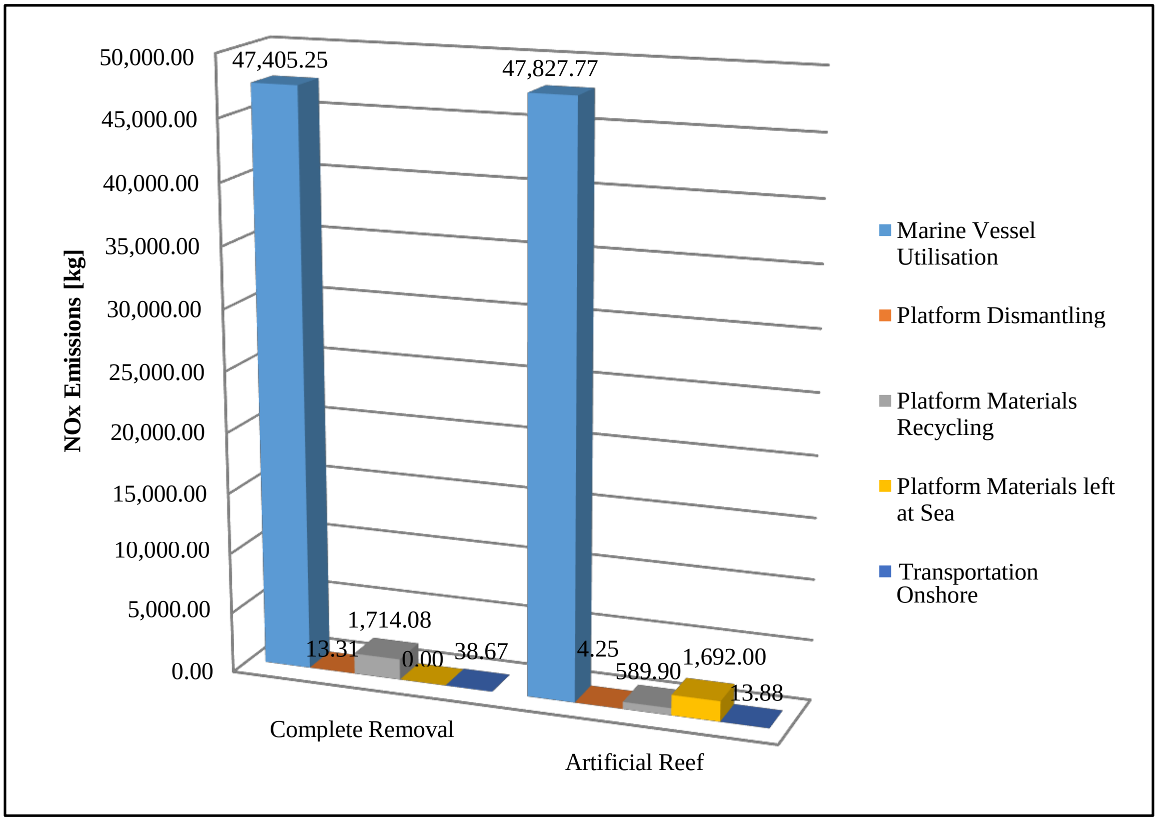


FIGURE 16 Breakdown of NOx emissions [kg] with respective decommissioning activities for complete removal and partial removal (artificial reef) for Platform X

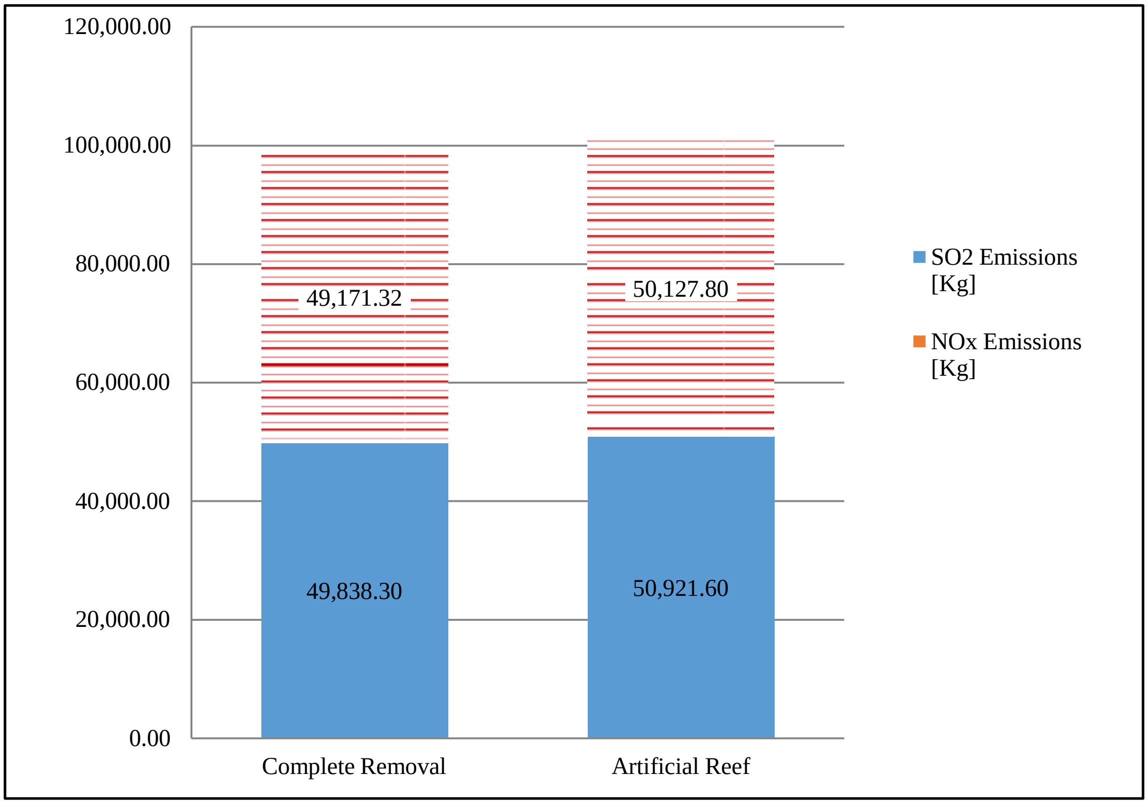


FIGURE 17 SO_2 and NOx emissions [kg] depending on decommissioning option for Platform X

SO_2 and NO_x are the main culprits for acid rain which is dangerous to human's health and harms the agriculture and buildings. As shown in Figure 15, 16 and 17, the amount of SO_2 and NO_x emissions released by complete removal and conversion to an artificial reef are quite similar with about 1% difference. The activity which contributes the most to those emissions is marine vessel utilisation followed by platform material recycling in case of complete removal. On the other hand the conversion of Platform X to an artificial reef (partial removal) produces less SO_2 and NOx regarding the material recycling, but overall more emissions due to greater usage of marine vessels and the emissions produced during the amount of steel produced which replaces the amount of steel left at sea.

Based on the results obtained from process based LCA using EXEL Software, it is evident that marine vessel utilisation is the major factor for the energy consumption and the quantity of CO_2, NO_x and SO_2 emissions followed by far by material recycling and the steel production considered for the amount of steel which is left at sea in order to create an artificial reef. From this point it can be concluded, that marine vessel utilisation should be reduced in order to minimise the environmental impacts offshore decommissioning. Marine vessels consume great amounts of fuel (energy) and release a large amount of the greenhouse gas CO_2 and also harmful gases SO_2 and NO_x.

From these results, it can be summarised that the partial removal has a greater energy consumption and produces more gaseous emissions. This contradicts initial expectations as this option is considered as more environmental friendly and beneficial for the marine environment. The higher amount of vessel utilisation and greater travel distances due to material transport both to the artificial reef site and to the selected fabrication yard for further recycling purposes leads to the higher energy consumption and discharge of gaseous emissions compared to complete removal. Although the complete removal option provides the greater amount of steel which is recovered for recycling purposes, it does not compensate the marine vessel utilisation and the steel production required due to materials left at sea in case of the conversion to an artificial reef. Otherwise the results received for complete removal and the conversion to an artificial reef correspond in the identification of the decommissioning activity which contributes most to the investigated issues which is in both cases the vessel utilisation.

In conclusion, for decommissioning Platform X, the re-use as an artificial reef is not an appropriate and beneficial option due to large travel distances disproportionate to the size of the platform. In further studies, it could be examined if the result would be different in terms of total energy consumption and gaseous emissions, if the ratio of the amount of the removed material to the travel distances is smaller.

4.2.2 EIO-LCA

By using the total removal cost of Platform SM-4 (previous platform structure that has been decommissioned), the data applied for assumed complete removal of Platform X is USD 8.86 million. Meanwhile for the partial removal by towing to a reef site option cost is assumed as 35% of the estimated total removal cost of Platform X. The calculations on the total energy consumption and gaseous emissions are referred to the standard economic value of one million USD implemented in the purchaser price model under support activities for oil and gas operations sector, whereby its values associated with total energy and gaseous emission are as per attached in the Appendices.

TABLE 5 Results of complete removal and partial removal of Platform X in terms of energy consumption and gaseous emissions using EIO-LCA

Variable	Standard Unit (1 million US Dollar)	Complete Removal (8.86 million US Dollar)	Conversion to an Artificial Reef (3.10 million US Dollar)
Total Energy Consumption [GJ]	7790	69,019.40	24,149.00
SO2 Emissions [kg]	1890	16,745.40	5,859.00
NOx Emissions [kg]	6330	56,083.80	19,623.00
Overall CO2 Emissions [kg]	649000	5,750,140.00	2,011,900.00

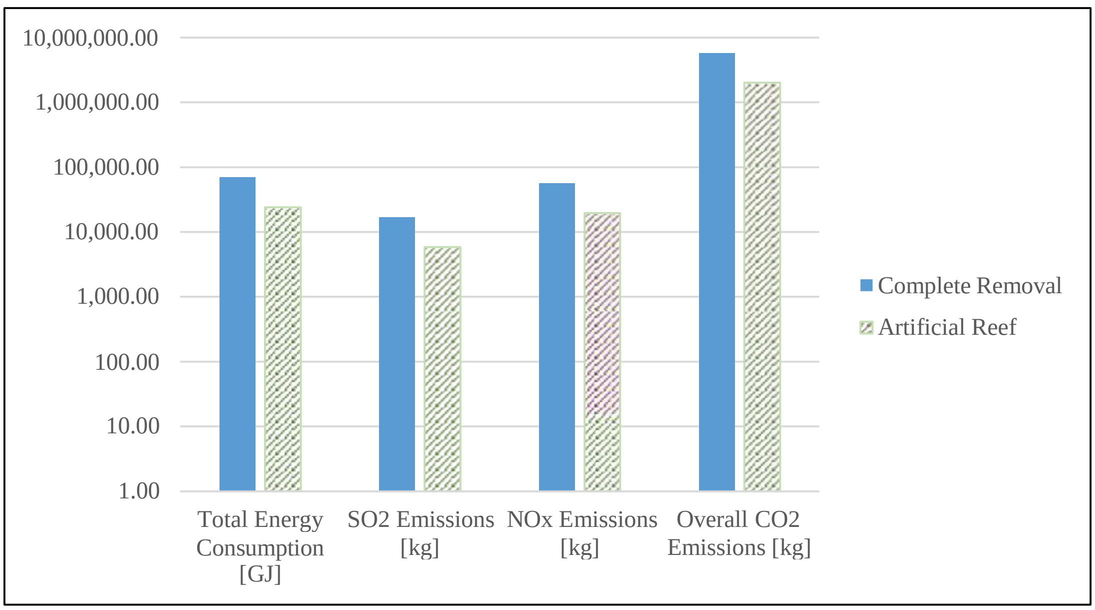


FIGURE 18 Comparison between total energy consumption and gaseous emissions depending on decommissioning option for Platform X

Basically, the obtained results and as consequence of the applied calculation model with dependence on the respective option costs, it is straightforward that complete removal requires about 65% more energy and releases about 65% more harmful gaseous emissions. In contrast to process based LCA, by using EIO-LCA analysis, partial removal is the more appropriate decommissioning option in terms of energy consumption and gaseous emissions due to lower cost assumed based on empirical estimations which consider the re-use as an artificial reef as more cost-effective.

4.2.3 Comparison Process Based LCA and EIO-LCA

In the present study, by conducting the two different LCA tools process based method and EIO method, the outcome is totally different. Using process based LCA complete removal of Platform X is the better decommissioning option in terms of energy consumption and gaseous emissions. Meanwhile, by performing EIO-LCA partial removal requires less energy and produces less harmful gaseous emissions. Besides, the difference between the values estimated using the EIO online model are much higher corresponding to the assumed cost difference of 65% between complete removal and conversion to an artificial reef. For this LCA analysis more assumptions were made in terms of vessel utilisation and travel distances due to limited information available.

TABLE 6 Percentage difference between the results of process-based LCA and EIO-LCA

Variable	Complete Removal (PB)	Complete Removal (EIO)	Artificial Reef (PB)	Artificial Reef (EIO)	Difference in Complete Removal for Platform X (%)	Difference in Partial Removal for Platform X (%)
Energy Consumption [GJ]	56,922.25	69,019.40	72,814.10	24,149.00	18	67
SO2 Emissions [kg]	49,838.30	16,745.40	50,921.60	5,859.00	66	88
NOx Emissions [kg]	49,171.32	56,083.80	50,127.80	19,623.00	12	61
Overall CO2 Emissions [kg]	5,994,280.20	5,750,140.00	8,117,167.63	2,011,900.00	4	75

From Table 6 it becomes clear, that there are huge differences between the calculated values for energy consumption and gaseous emissions related to the two different decommissioning options. The results vary in the range of 4 % and 70 % in case of complete removal and between 60% and 90% for partial removal. Those differences between the tools occur due to the made assumptions for process based as well as for EIO-LCA analysis. Different input data is required for conducting the two LCA analyses, which are estimated cost for EIO method and for process based method the vessel utilisation, travel distances, conversion factors as well as the quantity of materials for recycling, left at sea and transported onshore. Furthermore, the different perspectives of the tools contribute to the varying numerous outcomes obtained for complete removal and partial removal. Whereas, for EIO method economic values based on experiences and retrieved by industrial surveys are implemented, process based LCA analysis takes the several decommissioning processes into account.

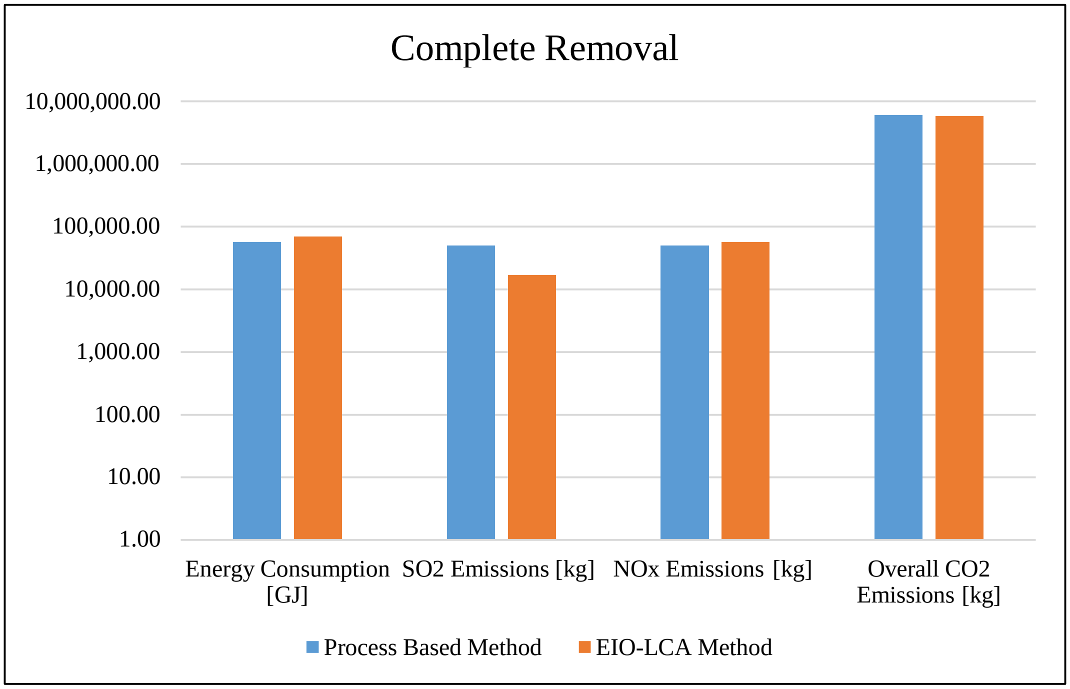


FIGURE 19 Comparison between the results of process based- and EIO-LCA for complete removal

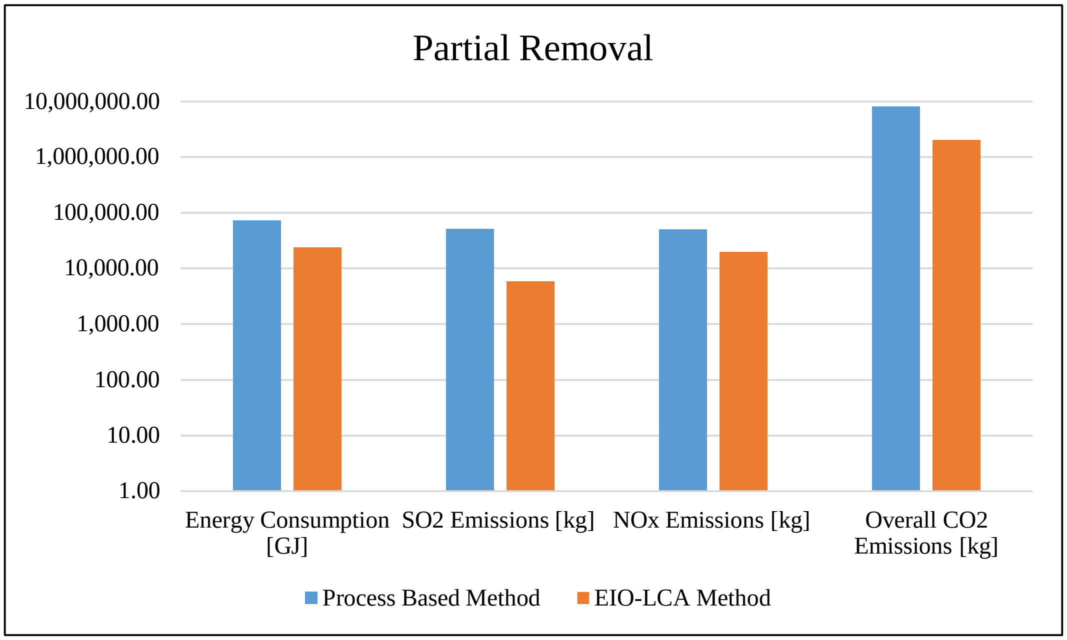


FIGURE 20 Comparison between the results of process based- and EIO-LCA for partial removal

However, as it can be observed in Figure 19 and 20 that the trend is quite similar. For both considered decommissioning options, the amounts of energy consumption as well as for SO_2 and NOx emissions are closely on the same level using each of the LCA tools. For both analyses, the CO_2 emissions are the major emissions and much higher than the other gaseous emissions. Although the numerous differences are partly huge the observed trend of distribution is similar for the two performed LCA tools.

4.3 Economic Analysis

In this assessment cost comparison was made based on expected activities involve in each option. For option 1 (partial removal), the pipelines or vent lines are to be left in place and required to be capped and their ends buried 3 feet below the mudline or covered with protective mats.

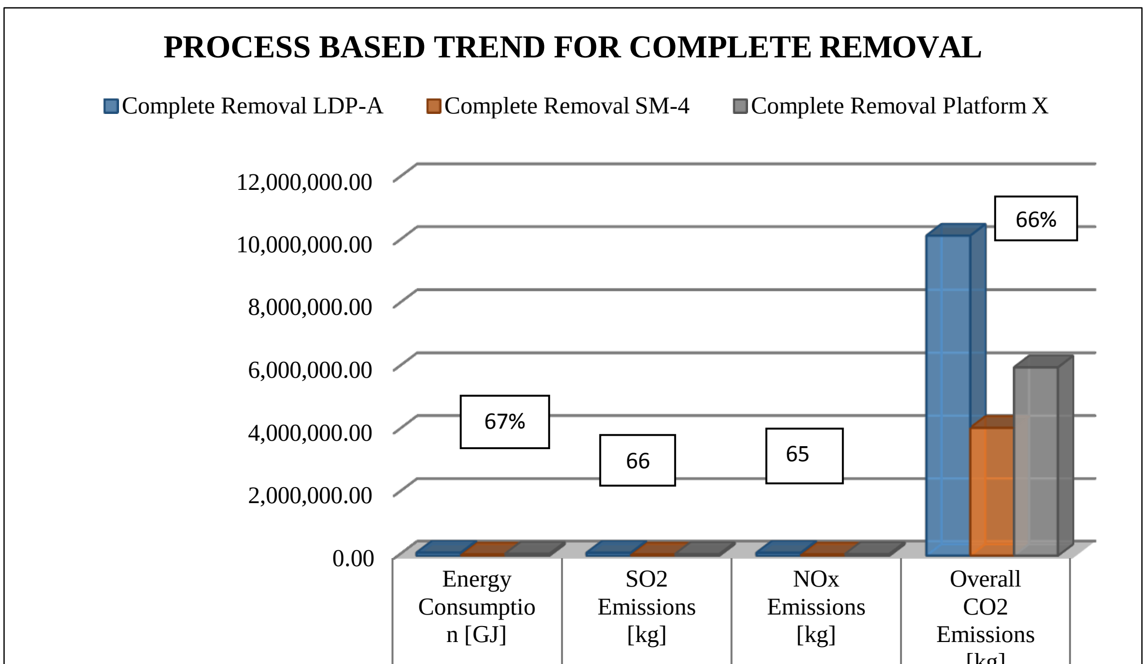
In option 2 (complete removal), typically the line need to be cut into lengths as short as it is convenient for transportation to shore and disposal site. Obviously, option 2 would acquire very much higher cost than option 1. Removing lines could escalate costs sharply more that 50% compared to option 1.

The schedule estimation is based on work activities requires for both options. We are considering renting of the decommissioning cutting equipment and underwater diving equipment on board the construction work barge or jack up rig.

By using the cost estimation data from Platform SM-4, the cost estimation applied for performing the decommissioning of Platform X using work barge is RM 29,112,822.40. Meanwhile, for using jack up rig, it is cost by RM 34, 615, 542.40. Therefore, by using construction work barge is cheaper than the jack up and we can utilize it for platform decommissioning as well as pipeline abandonment activities. The economic analysis based on the RM 29,112,822.40 and will erode the Tembungo PSC at 10 % NPV.

The detailed are attached in Appendix O and P.

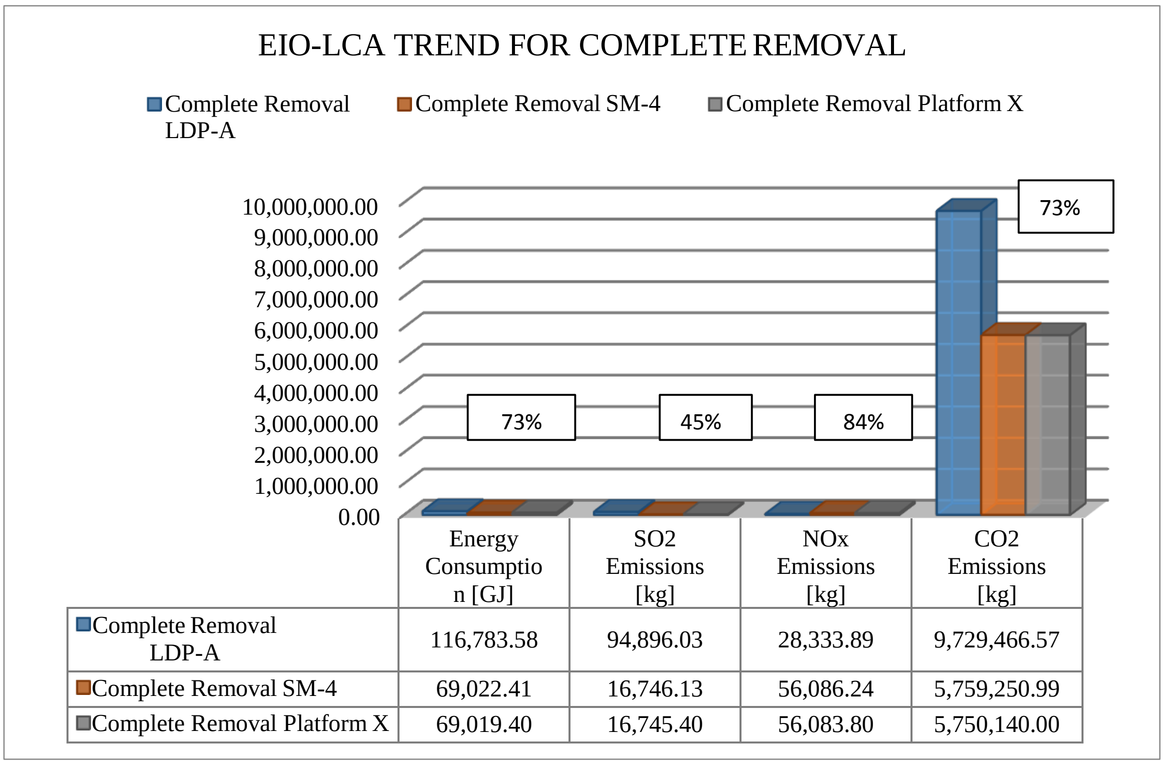
4.4 Comparison between Platform X and Other Local Platforms (LDP-A & SM-4)



	Energy Consumptio n [GJ]	SO2 Emissions [kg]	NOx Emissions [kg]	Overall CO2 Emissions [kg]
Complete Removal LDP-A	93,592.53	89,181.78	89,500.60	10,178,455.82
Complete Removal SM-4	37,105.26	36,408.59	36,372.19	4,074,794.03
Complete Removal Platform X	56,922.25	49,838.30	49,171.32	5,994,280.20

FIGURE 21 Comparison of results from Process Based Method for complete removal of Platform X, LDP-A, and SM-4

From the results of energy consumption and gaseous emissions for complete removal of Platform X, LDP-A, and SM-4 respectively, which are presented in Figure 20 it becomes clear that the average percentage difference is about 65 %. This difference in results occurs due to great structural differences such as total height, number of modules, usage, the weight of several components and the water depth as well as the location. Hence, for decommissioning of LDP-A a bigger amount of vessels and cranes with higher capacity, different quantity and type of equipment and more personnel are required which affects the energy consumption and the produced gaseous emissions compared to the much smaller jacket installation Platform X and SM-4. To state similarities, from Figure 20, a trend can be observed. The values for energy consumption, NOx and SO2 emissions vary in a similar range for Platform X, LDP-A and SM-4 respectively and also the numbers of Overall CO2 exhibit in a much higher range for both of the platforms. Although the location, conditions, objectives and challenges of the decommissioning process and the assumptions for the calculations are different the trend of the amount of energy used and emissions produced are comparable.



	Energy Consumptio n [GJ]	SO2 Emissions [kg]	NOx Emissions [kg]	CO2 Emissions [kg]
Complete Removal LDP-A	116,783.58	94,896.03	28,333.89	9,729,466.57
Complete Removal SM-4	69,022.41	16,746.13	56,086.24	5,759,250.99
Complete Removal Platform X	69,019.40	16,745.40	56,083.80	5,750,140.00

FIGURE 22 Comparison of results from EIO-LCA Method for complete removal of Platform X, LDP-A, and SM-4

The outcome retrieved by conducting EIO method for complete removal of Platform X, LDP-A, and SM-4 shows the average percentage different is about 68%. The percentage differences of total energy consumed and quantity of emissions produced by SM-4 and Platform X are almost equal due to input data and the concept of the EIO online model based on the standard unit value for one million US dollar.

Based on the performance of two different LCA tools it becomes clear that the numerous results for energy consumption and gaseous emissions produced during complete removal obtained, independent if process based or EIO-LCA and which input data is used. However, it has to be taken into account, that the present study only assessed the environmental impacts of those three stated structures and that the comparison is done one by one. On this basis it is not possible to issue an accurate statement if this found similarity is overall applicable to estimate the energy consumption and gaseous emissions of future decommissioning projects by using a local unit rate. More information would have been available in order to evaluate apparent differences, boundaries and similarities between decommissioning of local platforms in Malaysia regarding the energy consumption and gaseous emissions. Besides that, more studies and comparisons based on other local offshore structures have to be established to get an accurate result for justification of a comment regarding the coherences and differences of energy consumption and emissions in the different regions.

CHAPTER 5
CONCLUSION

5.1 Conclusion

Following the trend, Malaysia's fuel consumption has been increasing day by day. Due to serious depletion of reserves in various onshore locations, the exploration process is expanded to offshore deeper waters. Seven sedimentary basins belonging to Malaysia, in South China Sea, show great promise to be excellent sources of hydrocarbons. However, every platform has its own end of life period, no matter if it is onshore or offshore. Therefore, some of the fields on the South China Sea have already ceased production or will soon do so, and the installations will have to be decommissioned.

Offshore decommissioning operations are highly complex, often even more so than the original installation itself. The condition of the platform, utility/safety systems, its residual strength and actual weight must all be assessed and taken into consideration. Nonetheless, offshore installations decommissioning brings along environmental impacts that arise the concern of the society. There is minimal published works on environmental impact assessment for offshore decommissioning and framework to quantify the environmental impacts. By using LCA analysis, the decommissioning activity, which is the major contributor for total energy consumption and gaseous emissions could be identified. The main objective of this study was to determine and quantify the environmental impacts associated with offshore installations decommissioning using LCA tools, process LCA and EIO-LCA. The scope of this study was limited to two offshore decommissioning options, complete removal and partial removal. The environmental impacts focused in this study were total energy consumption and gaseous emissions (CO2, SO2 and NOx).

For this paper, there are very limited data available regarding the decommissioning Platform X in Tembungo field. Hence, few assumption was made based on several decommissioning documents and published paper. The cost estimation and as well as various documentation documents about its decommissioning process can be used as input data to perform LCA analysis. Besides, the EIO model is considered as more detailed, reliable and accurate since it has broad boundaries and takes the circularity effects, which should be counted in the real industry, into account. The outcome using this tool is that the energy consumption and the discharge of gaseous emissions are higher for the decommissioning option complete removal. Meanwhile, by conducting process based LCA analysis the opposite results were found, whereas conversion to an artificial reef consumes more energy and produces more harmful gases especially due to the bigger amount of vessel utilisation, which is identified as the decommissioning activity with the greatest contribution to the concerned parameters.

Due to limited availability of data and lack of samples for decommissioning in Malaysia it is not possible to issue an accurate statement if the found similarity is overall applicable to estimate the energy consumption and gaseous emissions for other decommissioning projects by simple use of a local unit rate. The results gathered from the two LCA analyses follow a similar trend although different data were input and the tools provide different perspectives. Both LCA tools are capable for evaluating the environmental impacts associated with offshore decommissioning depending on the availability of data. Process based method may be the more appropriate LCA tool in the present study, as the assumptions considered the real conditions, the size and existing materials of the selected case study, and several decommissioning activities were implemented.

Based on the detailed results from process LCA, the decommissioning activities, which contribute the greatest value for energy consumption and gaseous emissions, are marine vessel utilization, platform material recycling and platform running. Marine vessel utilization was found out to be the main contributor for energy consumption and gaseous emissions.

In conclusion, all the objectives of this study were achieved that the environment impacts associated with offshore decommissioning were identified, quantified and assessed using LCA tools and both complete removal and partial removal of Platform X were compared in the previous chapter. Furthermore, several recommendations were proposed to reduce the environmental impacts and improve LCA analysis. The results obtained provides relative comparison for the energy consumption and gaseous emissions associated with complete and partial removal of offshore installations that shall help the platform owners to decide the appropriate decommissioning option. The findings from this research could serve as a basic framework for future LCA analysis to assess the environmental impacts of offshore decommissioning in Malaysia.

This project has provided a clear review of the literature associated with decommissioning offshore installations' environmental evaluation using Life Cycle Assessment. Life cycle assessment is an important and appropriate tool to quantify the environmental impacts of decommissioning of offshore structures.

5.2 Recommendations

During conducting the LCA analysis, marine vessel utilization was found out to be the main contributor for energy consumption and gaseous emissions. In order to minimize the environmental impacts associated with marine vessels utilization, the operators shall plan and manage the usage of vessels properly beforehand, make sure the operation days are in good weather, practice weather routing, increase the efficiency of vessels by performing propeller upgrading and hull cleaning.

Furthermore, by adequately planning and executing the removal of the offshore structure the owner would not been exposed to undesired events or any future residual liability and maintenance needs would be eliminated (Gorges, 2013). The rigs to reef concept had been introduced and applied by several operators for offshore decommissioning operators as it was considered as the more appropriate option (Wan Abdullah Zawawi et al., 2012). Previous studies mention that the conversion to an artificial reef reduces costs, energy and gaseous emissions due to reduction of marine vessel utilisation and fuel consumption. Furthermore it is considered as more environmental friendly as the structural material which is left at sea provides habitant and protection for marine life (Gorges, 2013).

Further researches need to be executed to study the benefits, side effects and environmental effects caused by this decommissioning option subject on the platform size, location, surrounding conditions as well as the effects of monitoring and maintenance issues. It does not matter if the decommissioning planning takes time but as long as it does not prolong for too long as decommissioning projects are expensive especially in conducting reverse engineering for the platforms that do not have decommissioning planned earlier before being commissioned (Khashim, 2013).

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APPENDICES

PROCESS BASED METHOD

APPENDIX A: UNIT CONVERSION FACTORS & REFERENCES

Conversion	Unit Conversion Factor			Source / Reference
Steel Plate and Shape From Ore	Energy Consumption	19	GJ/t	Ogivile (1992), Iron and Steel Institute (1990), Philip et al (1995)
	SO_2 Emissions	2	kg/t	
	NO_x Emissions	1.5	kg/t	
	Equivalent CO_2	60	kg/t	
	CO_2 Emission	2200	kg/t	
Steel Plate and Shape From Scrap	Energy Consumption	5	GJ/t	Ogivile (1992), Iron and Steel Institute (1990), Philip et al (1995)
	SO_2 Emissions	1.4	kg/t	
	NO_x Emissions	1	kg/t	
	Equivalent CO_2	40	kg/t	
	CO_2 Emission	360	kg/t	
Engine Diesel	Calorific Value	45.5	GJ/t	Munday and Farrar (1989), Brown and Root (1993)
	SO_2 Emissions	5	kg/t	
	NO_x Emissions	5.8	kg/t	
	Equivalent CO_2	238	kg/t	
	CO_2 Emission	3100	kg/t	
Marine Diesel	Calorific Value	45.4	GJ/t	Munday and Farrar (1989), Bouscaren (1990), Van Der Most (1990), Alexandersson (1990), Melhus (1990)
	SO_2 Emissions	45	kg/t	
	NO_x Emissions	45	kg/t	
	Equivalent CO_2	1905	kg/t	
	CO_2 Emission	3100	kg/t	
Propane	Calorific Value	50	GJ/t	Munday and Farrar (1989)
	SO_2 Emissions	0	kg/t	
	NO_x Emissions	3	kg/t	
	Equivalent CO_2	120	kg/t	
	CO_2 Emission	3007	kg/t	

APPENDIX B: DATA VARIABLES

Transportation Offshore (Workbarge, Anchor Handling Tug, Support Vessel, Dumb Barge, Supply Boat)	Travel Distance
	Use Duration
Section Cuttings	Oxy-Acetylene Cutting
	Abrasive Water Jet Cutting
	Diamond Wire Cutting
Boat Landing Dismantling Offshore [tonnes]	Structural Steel
	Marine Growth
Topside Dismantling Offshore [tonnes]	Structural Steel
	Timber
	Miscellaneous Materials
Jacket Dismantling Offshore [tonnes]	Sructural Steel
Jacket Dismantling Onshore [tonnes]	Marine Growth
Total Dismantling [tonnes]	Structural Steel
	Timber
	Marine Growth
	Miscellanous Materials
Recycling Onshore [tonnes]	Steel
Disposal Onshore [tonnes]	Timber
	Marine Growth
	Miscellaneous materials
Materials left at Sea	Jacket
	Boat Landing
	Marine Growth
	Mudmat (Timber)
Transportation Onshore	Travel Distance

APPENDIX C: HAULAGE CONSTANTS AND FACTORS

	Value		
Onshore Haulage Roundtrip Distance			
Kota Kinabalu Port (Sabah) to Fabrication Yard [miles]	16.47	26.5	km
Fabrication Yard to Scrap Dealer [miles]	6.59	10.6	km
Fabrication Yard to Landfill for Disposal (Kota Kinabalu) [miles]	3.04	4.9	km
Onshore Haulage Factors			
Average truck fuel consumption [litre /mile]	1.8		
Average truck fuel weight [t/litre]	0.00085		
Average truck load [tonne]	20		
Additional percentage fuel consumption allowance for loading and offloading [%]	10		
Offshore Roundtrip Distance			
Singapore Port to Kota Kinabalu Port [miles]	805.33	1296	km
Port (Kota Kinabalu) to Platform Site [miles]	49.712	80	km
Platform Site to Artificial Reef Site [miles]	279.63	500	km
Platform Site to Fabrication Yard (Kota Kinabalu) [miles]	49.712	80	km
Offshore Haulage Factor			
Average vessel fuel consumption [tonne marine diesel oil/mile]	0.035		
Maximun cargo capacity [tonnes]	500		
Additional percentage fuel consumption allowance for loading and offloading [%]	20		

Scrap Dealer
NCT Forwarding and Shipping Sdn. Bhd.
Mile 5.5, Tuaran Road
Off Kolombong Road
BDC/SEDCO Industrial Estate
88853 Kota Kinabalu, Sabah, Malaysia
5° 55' 36.5226"N 116° 3' 10.7994"E

Fabrication Yard
UEC Engineering Fabrication Yard
Kota Kinabalu, Sabah
Malaysia
6°7'38"N 116°8'52"E

Landfill
Kayu Madang Sanitary Landfill
Telipok (Kota Kinabalu landfill)

APPENDIX D: UNIT CONVERSION FACTORS DISMANTLING

	Propane Consumption [kg/tonne]
Topsides Piecesmall Dismantling Offshore	
Structural steel	2.40
Timber	0
Miscellaneous materials	0
Jacket Dismantling Offshore	
Steel	2.40
Marine Growth	0
Boat Landing Dismantling Offshore	
Steel	2.40
Removal of Marine Growth Onshore	2.40

APPENDIX E: AVERAGE DAILY FUEL CONSUMPTION OF VESSELS

	In Port	In Transit	Working	Waiting on Weather (W.O.W)
Anchor Handling Tug (AHT)	2	10	10	10
Support Vessel	2	20	25	25
Workbarge	2	10	10	10
Dumb Barge	2	15	15	15
Supply Boat	2	10	5	5

APPENDIX F: CALCULATION MARINE VESSEL UTILISATION

COMPLETE REMOVAL

			in Port			in Transit			Working			Waiting on Weather (W.O.W)			
	Number	Duration [days]	Duration [days]	Fuel Consumption [t/day]	Fuel Consumption [t]	Duration [days]	Fuel Consumption [t/day]	Fuel Consumption [t]	Duration [days]	Fuel Consumption [t/day]	Fuel Consumption [t]	Duration [days]	Fuel Consumption [t/day]	Fuel Consumption [t/day]	Total Fuel Consumption [t/type]
WorkBarge	4	10	0	2	0	2	10	20	8	10	80	0	10	0	400
Anchor Handling Tug (DB)	1	25	8	2	16	1	10	10	16	10	160	0	10	0	186
Anchor Handling Tug (WB)	1	10	7	2	14	1	10	10	2	10	20	0	10	0	44
Support Vessel	1	13	3	2	6	1	20	20	9	25	225	0	25	0	251
Dumb Barge	1	25	1	2	2	16	15	240	8	15	120	0	15	0	362
Supply Boat	1	10	0	2	0	10	10	100	0	5	0	0	5	0	100

Total Fuel Consumption [t]	1343

	Number	Average vessel Fuel Consumption [t/mile]	Port (KK) to Platform Site [miles]	Platform Site to Port (Johor) [miles]	Port Johor to Port KK [miles]	Number of Ways: KK to Site	Number of Ways: Site to Johor	Number of Ways: Johor to KK	Travel Distance [miles]	Fuel Consumption [t]
WorkBarge	4	0.035	49.712	891.709	891.709	2	0	0	99.424	13.91936
Anchor Handling Tug (DB)	1	0.035	49.712	891.709	891.709	4	1	1	1982.266	69.37931
Anchor Handling Tug (WB)	1	0.035	49.712	891.709	891.709	4	0	0	198.848	6.95968
Support Vessel	1	0.035	49.712	891.709	891.709	2	0	0	99.424	3.47984
Dumb Barge	1	0.035	49.712	891.709	891.709	1	1	1	149.136	5.21976
Supply Boat	1	0.035	49.712	891.709	891.709	20	0	0	994.24	34.7984

Total Fuel Consumption [t]	74.82

ARTIFICIAL REEF

			in Port			in Transit			Working			Waiting on Weather (W.O.W)			
	Number	Duration [days]	Duration [days]	Fuel Consumption [t/day]	Fuel Consumption [t]	Duration [days]	Fuel Consumption [t/day]	Fuel Consumption [t]	Duration [days]	Fuel Consumption [t/day]	Fuel Consumption [t]	Duration [days]	Fuel Consumption [t/day]	Fuel Consumption [t/day]	Total Fuel Consumption [t/type]
WorkBarge	4	25	0	2	0	16	10	160	9	10	90	0	10	0	1000
Anchor Handling Tug (DB)	1	15	8	2	16	1	10	10	6	10	60	0	10	0	86
Anchor Handling Tug (WB)	1	25	8	2	16	1	10	10	16	10	160	0	10	0	186
Support Vessel	1	13	3	2	6	1	20	20	9	25	225	0	25	0	251
Dumb Barge	1	15	1	2	2	6	15	90	8	15	120	0	15	0	212
Supply Boat	1	10	0	2	0	10	10	100	0	5	0	0	5	0	100

Total Fuel Consumption [t]	1835

	Number	Average Vessel Fuel Consumption [t/mile]	Port (KK) to Platform Site [miles]	Platform Site to Port (Johor) [miles]	Port Johor to Port KK [miles]	Platform Site to Artificial Reef Site [miles]	Artificial Reef Site to Port KK [miles]	Number of Ways: KK - Site	Number of Ways: Site - Johor	Number of Ways: Johor - KK	Number of Ways: Platform Site - Artificial Reef Site	Number of Ways: Artificial Reef - KK Port	Travel Distance [miles]	Fuel Consumption [t]
WorkBarge	4	0.035	49.712	891.709	891.709	279.63	279.63	1	1	1	0	0	149.14	20.88
Anchor Handling Tug (DB)	1	0.035	49.712	891.709	891.709	279.63	279.63	3	0	0	1	1	708.40	24.79
Anchor Handling Tug (WB)	1	0.035	49.712	891.709	891.709	279.63	279.63	3	1	1	0	0	248.56	8.70
Support Vessel	1	0.035	49.712	891.709	891.709	279.63	279.63	2	0	0	0	0	99.42	3.48
Dumb Barge	1	0.035	49.712	891.709	891.709	279.63	279.63	1	0	0	1	1	608.97	21.31
Supply Boat	1	0.035	49.712	891.709	891.709	279.63	279.63	20	0	0	0	0	994.24	34.80

Total Fuel Consumption [t]	113.96

Overall Fuel Consumption (Marine Vessel Utilisation) [t]	**Total Energy Consumption [GJ]**	**SO_2 Emissions [kg]**	**NO_x Emissions [kg]**	**CO_2 Emissions [kg]**	**Equivalent CO_2 Emissions [kg]**	**Overall CO_2 Emissions [kg]**	
1417.82	64,368.87	63,801.75	63,801.75	4,395,231.34	2,700,940.55	7,096,171.88	**Complete Removal**
1948.96	88,483.00	87,703.41	87,703.41	6,041,790.76	3,712,777.87	9,754,568.62	**Artificial Reef**
531.15	24,114.13	23,901.67	23,901.67	1,646,559.42	1,011,837.32	2,658,396.74	**Difference [unit]**
27.25	27.25	27.25	27.25	27.25	27.25	27.25	**Difference[%]**

APPENDIX G: CALCULATION PLATFORM DISMANTLING

COMPLETE REMOVAL

Offshore

Component	Material	Weight [t]	Cutting Method	Propane Consumption [kg/t]	Propane Consumption [kg]
Boat Landing	Steel	16.00	Oxy-Acetylene Cutting	2.40	38.40
Topside	Steel	562.00	Abrasive Water Jet Cutting	2.40	1348.80
	Timber	5.60	Saw	0	0.00
	Miscellaneous	1.00	Others	0	0.00
Jacket	Steel	1112.00	Diamond Wire Cutting	2.40	2668.80
Conductor	Steel	27.90	Diamond Wire Cutting	2.40	66.96

Onshore

Component	Weight	Cutting Method	Propane Consumption [kg/t]	Propane Consumption [kg]
Marine Growth	130.77	Abrasive Water Jet Cutting	2.40	313.85

Total Propane Consumption [kg]	Total Propane Consumption [t]
4436.81	4.44

ARTIFICIAL REEF

Offshore

Component	Material	Weight [t]	Cutting Method	Propane Consumption [kg/t]	Propane Consumption [kg]
Boat Landing	Steel	16.00	Oxy-Acetylene Cutting	TOWED TO AR-SITE	
Topside	Steel	562.00	Abrasive Water Jet Cutting	2.40	1348.8
	Timber	5.60	Saw	0	0
	Miscellaneous	1.00	Others	0	0
Jacket	Steel	1112.00	Diamond Wire Cutting	TOWED TO AR-SITE	
Conductor	Steel	27.90	Diamond Wire Cutting	2.40	66.96

Onshore

Component	Weight	Cutting Method	Propane Consumption [kg/t]	Propane Consumption [kg]
Marine Growth	130.77	NO REMOVAL	----	----

Total Propane Consumption [kg]	Total Propane Consumption [t]
1415.76	1.42

Total Propane Consumption [t]	Total Energy Consumption [GJ]	SO_2 Emissions [kg]	No_x Emissions [kg]	CO_2 Emissions [kg]	Equivalent CO_2 Emissions [kg]	Overall CO_2 Emissions [kg]	
4.44	221.84	0.00	13.31	13,341.49	532.42	13,873.91	**Complete Removal**
1.42	70.79	0.00	4.25	4,257.19	169.89	4,427.08	**Artificial Reef**

3.02	151.05	0.00	9.06	9,084.30	362.53	9,446.83	**Difference [unit]**
68.09	68.09	0.00	68.09	68.09	68.09	68.09	**Difference[%]**

APPENDIX H: CALCULATION PLATFORM MATERIALS RECYCLING

COMPLETE REMOVAL

Topside Weight (incl. Timber, Miscellaneous) [t]	Jacket Weight (incl. Marine Growth) [t]	Boat Landing Weight [t]	Conductor Weight [t]	Timber [t]	Marine Growth [t]	Miscellaneous [t]	Steel Recycling [t]
568.60	1112.00	16.00	27.9	5.60	3.82	1.00	1714.08

ARTIFICIAL REEF

Topside Weight (incl. Timber, Miscellaneous) [t]	Jacket Weight (incl. Marine Growth) [t]	Boat Landing Weight [t]	Conductor Weight [t]	Timber [t]	Marine Growth [t]	Miscellaneous [t]	Steel Recycling [t]
568.60	---	---	27.9	5.60	3.82	1.00	589.90

Total Steel Recycling [t]	Total Energy Consumtion [GJ]	SO_2 Emissions [kg]	No_x Emissions [kg]	CO_2 Emissions [kg]	Equivalent CO_2 Emissions [kg]	Overall CO_2 Emissions [kg]	
1714.08	8,570.40	2,399.71	1,714.08	617,068.80	68,563.20	685,632.00	**Complete Removal**
589.90	2,949.50	825.86	589.90	212,364.00	23,596.00	235,960.00	**Artificial Reef**

1,124.18	5,620.90	1,573.85	1,124.18	404,704.80	44,967.20	449,672.00	**Difference [unit]**
65.59	65.59	65.59	65.59	65.59	65.59	65.59	**Difference[%]**

APPENDIX I: CALCULATION PLATFORM MATERIALS LEFT AT SEA

COMPLETE REMOVAL

Assumptions:

- Mudmat (Timber) is left at the Sea -> not considered in the calculation

ARTIFICIAL REEF

Assumptions:

- Mudmat (Timber) is left at Sea -> not considered in the calculation
- Marine Growth not removed and left at sea -> not considered in the calculation
- Jacket and Boat Landing are towed to the Artificial Reef Site and left at sea

-> Considered in the calculations using conversion factors "Steel Plate and Schape from Ore"

Topside Weight (incl. Timber, Miscellaneous) [t]	Jacket Weight (incl. Marine Growth) [t]	Boat Landing Weight [t]	Conductor Weight [t]	Timber [t]	Marine Growth [t]	Miscellaneous [t]
568.60	1112.00	16.00	27.9	5.60	3.82	1.00

Steel left at Sea [t]
1128.00

Total Steel Left at Sea [t]	Total Energy Consumption [GJ]	SO_2 Emissions [kg]	NO_x Emissions [kg]	CO_2 Emissions [kg]	Equivalent CO_2 Emissions [kg]	Overall CO_2 Emissions [kg]	
0.00	0.00	0.00	0.00	0.00	0.00	0.00	**Complete Removal**
1128.00	21,432.00	2,256.00	1,692.00	2,481,600.00	67,680.00	2,549,280.00	**Artificial Reef**

1,128.00	21,432.00	2,256.00	1,692.00	2,481,600.00	67,680.00	2,549,280.00	**Difference [unit]**
100.00	100.00	100.00	100.00	100.00	100.00	100.00	**Difference[%]**

APPENDIX J: CALCULATION TRANSPORTATION ONSHORE

COMPLETE REMOVAL Truck Load: 20 tonnes

Topside Weight (incl. Timber, Miscellaneous) [t]	Jacket Weight (incl. Marine Growth) [t]	Boat Landing Weight [t]	Conductor Weight [t]	Timber [t]	Marine Growth [t]	Miscellaneous [t]
568.60	1112.00	16.00	27.9	5.60	130.77	1.00

Steel Recycling [t]	Disposal [t]	Number of Trucks Recycling	Number of Trucks Disposal	Distance Port KK to Fabrication Yard [miles]	Distance Fabrication Yard to Scrap Dealer [miles]	Distance Fabrication Yard to Disposal Site [miles]	Total Distance for Recycling [miles]	Total Distance for Disposal [miles]
1587.13	137.37	80	7	16.47	6.59	3.04	3688.63	273.17

Average Truck Diesel Consumtion [litre/mile]	Average Weight Engine Diesel [t/litre]	Additional Pecentage [%]	Total Distance for Recycling [miles]	Total Distance for Disposal [miles]	Total Diesel Consumption [tonnes]
1.8	0.00085	10	3688.63	273.17	6.67

ARTIFICIAL REEF

Topside Weight (incl. Timber, Miscellaneous) [t]	Jacket Weight (incl. Marine Growth) [t]	Boat Landing Weight [t]	Conductor Weight [t]	Timber [t]	Marine Growth [t]	Miscellaneous [t]
568.60	TOWED TO AR-SITE	TOWED TO AR-SITE	27.9	5.60	NO REMOVAL	1.00

Steel Recycling [t]	Disposal [t]	Number of Trucks Recycling	Number of Trucks Disposal	Distance Port KK to Fabrication Yard [miles]	Distance Fabrication Yard to Scrap Dealer [miles]	Distance Fabrication Yard to Disposal Site [miles]	Total Distance for Recycling [miles]	Total Distance for Disposal [miles]
589.90	6.60	30	1	16.47	6.59	3.04	1383.24	39.02

Average Truck Diesel Consumtion [litre/mile]	Average Weight Engine Diesel [t/litre]	Additional Pecentage [%]	Total Distance for Recycling [miles]	Total Distance for Disposal [miles]	Total Fuel Consumption [tonnes]
1.8	0.00085	10	1383.236	39.02	2.39

Total Diesel Consumption [t]	Total Energy Consumtion [GJ]	SO_2 Emissions [kg]	No_x Emissions [kg]	CO_2 Emissions [kg]	Equivalent CO_2 Emissions [kg]	Overall CO_2 Emissions [kg]	
6.67	303.38	33.34	38.67	20,669.89	1,586.91	22,256.80	**Complete Removal**
2.39	108.91	11.97	13.88	7,420.36	569.69	7,990.05	**Artificial Reef**

4.27	194.47	21.37	24.79	13,249.53	1,017.22	14,266.75	**Difference [unit]**
64.10	64.10	64.10	64.10	64.10	64.10	64.10	**Difference[%]**

APPENDIX K: VARIATION OF ENERGY CONSUMPTION AND GASEOUS EMISSION DEPENDING ON DECOMMISSIONING ASPECT AND OPTION

Variable	Decommissioning Aspect	Complete Removal	Artificial Reef
Energy Consumption [GJ]	Marine Vessel Utilisation	47,826.63	48,252.90
	Platform Dismantling	221.84	70.79
	Platform Materials Recycling	8,570.40	2,949.50
	Platform Materials left at Sea	0.00	21,432.00
	Transportation Onshore	303.38	108.91
	All Decommissioning Aspects	56,922.25	72,814.10
SO_2 Emissions [Kg]	Marine Vessel Utilisation	47,405.25	47,827.77
	Platform Dismantling	0.00	0.00
	Platform Materials Recycling	2,399.71	825.86
	Platform Materials left at Sea	0.00	2,256.00
	Transportation Onshore	33.34	11.97
	All Decommissioning Aspects	49,838.30	50,921.60
NO_x Emissions [Kg]	Marine Vessel Utilisation	47,405.25	47,827.77
	Platform Dismantling	13.31	4.25
	Platform Materials Recycling	1,714.08	589.90
	Platform Materials left at Sea	0.00	1,692.00
	Transportation Onshore	38.67	13.88
	All Decommissioning Aspects	49,171.32	50,127.80
CO_2 Emissions [Kg]	Marine Vessel Utilisation	3,265,695.15	3,294,801.71
	Platform Dismantling	13,341.49	4,257.19
	Platform Materials Recycling	617,068.80	212,364.00
	Platform Materials left at Sea	0.00	2,481,600.00
	Transportation Onshore	20,669.89	7,420.36
	All Decommissioning Aspects	3,916,775.33	6,000,443.26
Equivalent CO_2 Emissions [Kg]	Marine Vessel Utilisation	2,006,822.34	2,024,708.79
	Platform Dismantling	532.42	169.89
	Platform Materials Recycling	68,563.20	23,596.00
	Platform Materials left at Sea	0.00	67,680.00
	Transportation Onshore	1,586.91	569.69
	All Decommissioning Aspects	2,077,504.87	2,116,724.37
Overall CO_2 Emissions [Kg]	Marine Vessel Utilisation	5,272,517.49	5,319,510.50
	Platform Dismantling	13,873.91	4,427.08
	Platform Materials Recycling	685,632.00	235,960.00
	Platform Materials left at Sea	0.00	2,549,280.00
	Transportation Onshore	22,256.80	7,990.05
	All Decommissioning Aspects	5,994,280.20	8,117,167.63

APPENDICES

EIO-LCA METHOD

APPENDIX L: ENERGY CONSUMPTION FOR EIO STANDARD UNIT MODEL

	Sector	Total Energy TJ
	Total for all sectors	*7.79*
213112	Support activities for oil and gas operations	2.11
221100	Power generation and supply	1.46
331110	Iron and steel mills	0.785
211000	Oil and gas extraction	0.493
327310	Cement manufacturing	0.412
324110	Petroleum refineries	0.259
484000	Truck transportation	0.211
325190	Other basic organic chemical manufacturing	0.172
322130	Paperboard Mills	0.135
486000	Pipeline transportation	0.113

APPENDIX M: OVERALL CO2 EMISSIONS FOR EIO STANDARD UNIT MODEL

	Sector	Glob Warm kg CO2e
	Total for all sectors	*650000*
213112	Support activities for oil and gas operations	139000
221100	Power generation and supply	120000
211000	Oil and gas extraction	82300
327310	Cement manufacturing	71200
331110	Iron and steel mills	67700
484000	Truck transportation	15500
324110	Petroleum refineries	15500
212100	Coal mining	12500
325120	Industrial gas manufacturing	10400
486000	Pipeline transportation	9410

APPENDIX N: SO_2 AND NO_x EMISSION FOR EIO STANDARD UNIT MODEL

	Sector	NOx t	SO2 t
	Total for all sectors	*6.33*	*1.89*
213112	Support activities for oil and gas operations	5.03	0.886
331110	Iron and steel mills	0.050	0.038
532400	Commercial and industrial machinery and equipment rental and leasing	0.005	0.002
211000	Oil and gas extraction	0.152	0.010
327310	Cement manufacturing	0.196	0.144
221200	Natural gas distribution	0.006	0.002
484000	Truck transportation	0.136	0.003
331200	Iron, steel pipe and tube manufacturing from purchased steel	0.007	0.005
33131A	Alumina refining and primary aluminum production	0.002	0.015
333920	Material handling equipment manufacturing	0.011	0.000

APPENDICES

ECONOMIC ANALYSIS

APPENDIX O: ESTIMATED EXECUTION COST USING CONSTRUCTION WORK BARGE FOR SM-4

3) Decommissioning planning				
Environmental study (RM)				
- Environmental Baseline Study	237,000.00		488,000.00	
- Post Decommissioning Environmental Monit	202,000.00			
- Environmental Management Plan (EMP)	49,000.00			
Onshore Preparation (hotel)				
- IPOP session & pre-mob HSE briefing	10,000.00		20,000.00	
- Workpack review session	10,000.00			
4) Execution, Monitoring & Control				
PRE-REMOVAL SURVEY				
- underwater & ROV survey	0.00		0.00	
- topsite	0.00		0.00	
PRE-DECOM				
- Environmental sampling	633,169.00		633,169.00	
- HUC marine spread		11.00	11,604,500.00	
Days required	10.00	1.00		
Cost (RM/day) for workboat / AHT / crew boat	565,000.00			
Mob / Demob for workboat / AHT / crew boat	5,389,500.00			
DECOMMISSIONING				
- Environmental sampling	2,679,676.00		2,679,676.00	
POST DECOMMISSIONING				
- Environmental sampling	633,169.00		633,169.00	
- Transportantion to shore and offload at yard				
Days required	7.00		2,084,000.00	
Cost (RM/day) for workboat / AHT / crew boat	12,000.00			
Mob / Demob for workboat / AHT / crew boat	2,000,000.00			
- Scrapping				
SM-4	53,000.00		53,000.00	
Total execution cost			18,195,514.00	
Project Management Consultant (EPRD)		0.20	3,639,102.80	
- Conceptual engineering				
- Engineering design for removal				
- Project execution plan				
- Risk assessment				
- Decommissioning Plan				
- Waste management				
- market surveys				
Scope growth		0.10	1,819,551.40	
Miscallenous		0.10	1,819,551.40	
Contingency		0.20	3,639,102.80	
			10,917,308.40	29,112,822.40

APPENDIX P: ESTIMATED EXECUTION COST USING JACK UP RIG FOR SM-4

3) Decommissioning planning				
Environmental study (RM)				
- Environmental Baseline Study	237,000.00		488,000.00	
- Post Decommissioning Environmental Monit	202,000.00			
- Environmental Management Plan (EMP)	49,000.00			
Onshore Preparation (hotel)				
- IPOP session & pre-mob HSE briefing	10,000.00		20,000.00	
- Workpack review session	10,000.00			
4) Execution, Monitoring & Control				
PRE-REMOVAL SURVEY				
- underwater & ROV survey	400,000.00		400,000.00	
- topsite	200,000.00		200,000.00	
- side sonar scan	500,000.00		500,000.00	
PRE-DECOM				
- Environmental sampling	633,169.00		633,169.00	
DECOMMISSIONING				
- Environmental sampling	2,679,676.00		2,679,676.00	
- Heavy lifting (Cat 3 / 2 /1)		10.00	13,943,700.00	
Days required	5.00	5.00		
Cost (RM/day)	807,450.00			
Mob / Demob	5,869,200.00			
POST DECOMMISSIONING				
- Environmental sampling	633,169.00		633,169.00	
- Transportantion to shore and offload at yard			2,084,000.00	
Days required	7.00			
Cost (RM/day) for workboat / AHT / crew boat	12,000.00			
Mob / Demob for workboat / AHT / crew boat	2,000,000.00			
- Scrapping				
SM-4	53,000.00		53,000.00	
Total execution cost			21,634,714.00	
Project Management Consultant (EPRD)		0.20	4,326,942.80	
- Conceptual engineering				
- Engineering design for removal				
- Project execution plan				
- Risk assessment				
- Decommissioning Plan				
- Waste management				
- market surveys				
Scope growth		0.10	2,163,471.40	
Miscallenous		0.10	2,163,471.40	
Contingency		0.20	4,326,942.80	
			12,980,828.40	34,615,542.40