Decommissioning Offshore Installations' Environmental Evaluation Using Life Cycle Analysis

by

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Civil Engineering

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CERTIFICATION OF APPROVAL

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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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NUR SHILA BINTI KHASHIM

ABSTRACT

In many years to come, the number of offshore oil and gas installations to be decommissioned around the world will increase as the platforms will cease production or may reach the end of their service design life. 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. Hence, measures in terms of cost, environmental, technicality, political, social, safety, and other relevant measures should be studied earlier on before planning a decommissioning. In this study, the author will focus on the environmental aspects to offshore decommissioning options with the aid of Life Cycle Analysis (LCA). The LCA methods used to compare and assess the environmental impacts of decommissioning options in this study will be process-based method and EIO-LCA method. It has to be ensured that the platforms to be compared and assessed are of the similar profile, type, region and water depths. Moreover, the environmental variables concerned in this area of study include the total energy consumptions and gaseous emissions such as carbon dioxide (CO_2), sulphur dioxide (SO_2), and nitrogen oxides (NO_x). Based on the comparison done in the author’s case study, a suitable decommissioning option with the least impact on the environment will be chosen and relevant suggestions will be recommended.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Every platform has its own end of life period, no matter if it s onshore or offshore. No doubt that it is more complex to plan and conduct a decommissioning for offshore installations than for onshore. Besides, compared to the established basins at the Gulf of Mexico and the North Sea, it is high time for offshore activities in Southeast Asia to keep up in decommissioning offshore oil and gas installations (Lyons, 2013). Hence, to construct an early detailed planning is the way forward in a successful decommissioning project. According 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.

However, due to the insufficient or unavailability of the data input from the industry which are material, energy, as well as air emissions makes it difficult to predict and quantify the impacts of each decommissioning alternative (Bernstein & Bressler, 2009). To evaluate each decommissioning option based on the data collected, comparison will be done based on suitable Life Cycle Analysis (LCA) method for each decommissioning option. In one condition, the results to the comparative analysis to be conducted by using LCA will only be fair and logical only if the data provided for platforms to be assessed are of the same location and profile. Examples on platform profile could be the weight of the platform, the depth of the sea water and the type of platform; fixed or mobile (Lyons, 2012).

Process-based LCA and EIO-LCA are the LCA methods to be used to measure the environmental impacts in this study. 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.

1.2 Problem Statement

Environmental impact is one of the ‘decommissioning scenarios’ when it comes to decommissioning insights (Ekins, Vanner, & Firebrace, 2006). To help in reducing any possible contributions to causing environmental impacts, it is crucial to focus awareness on the environmental issue led by offshore decommissioning activities especially in the planning phase.

However, one of the problems faced in Malaysia currently is the uncertainty and lack of resources and information on environmental impacts caused by each decommissioning alternative. It so happens that Malaysia is still new in the world of decommissioning offshore installations used in petroleum exploration and production, and is predicted to rise significantly (Zawawi, Liew, & Na, 2012). With anticipation, LCA is used as a drive for quantitative and structural environmental impact comparison between different decommissioning alternatives.

1.3 Objective

In order to determine which decommissioning alternative is best chosen environmentally, the following objectives have been set:

a) To estimate and quantify the environmental impacts of decommissioning offshore installations using LCA tools; process-based LCA method and EIO-LCA method

b) To provide a comparative analysis between the environmental impacts of decommissioning offshore platforms/installations alternatives to be studied on; complete removal, artificial reef conversion by towing to reef site and by toppling in place, of platforms within the same region in Malaysia

c) To identify the most suitable decommissioning alternative that contributes less environmental impacts

d) To recommend measures to help in reducing environmental impacts of certain decommissioning activities

1.4 Scope of Study

This present study focuses to study and analyse the significant risks of environmental harm by each decommissioning alternatives; complete removal, partial removal and leave-in-place, depending on the selected case study. In order for the author to do so, 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. Gaseous emissions (acidification and green house gases) and energy consumptions produced during decommissioning processes/activities are partly the main scopes for the environmental effects to be covered in this study. Besides that, one of the main aspects to be looked into is the profile of offshore platforms to be decommissioned, where the platforms should be of the similar type, region and water depth. This is to ensure that the selection of the best decommissioning option in terms of the environment from the comparison done will be of a fair and more accurate analysis.

1.5 Significance of Study

According to the article " Environmental Impacts of the Decommissioning of Oil and Gas Installations in the North Sea", the pace of decommissioning is widely racing to catch up all over the world. This activity causes the environmental concerns to arise as well. Malaysia too, is catching up with the trend now. Unfortunately for Malaysia, there is only quite a handful of platforms that have been decommissioned and out of the rough numbers of 300 offshore platforms, sit 48% of them that have exceeded their 25 years of service design life. Hence, this study is undertaken with the aim to increase awareness in terms of environmental impacts of decommissioning activities by determining which decommissioning activities contribute fewer impacts based on the comparison of case study assigned.

The project is within the scope and time frame given. The aims and scope of this study has been stated clearly. Both the LCA methods to be used and the comparative analysis to be conducted on the selected case study’s decommissioning alternatives could be completed within the time frame together with the boundaries set.

CHAPTER 2

LITERATURE REVIEW

2.1 Types of Offshore Platform

Offshore platforms are used for oil and gas exploitation from under the seabed to be processed. It was back in 1947 when the first offshore platform was installed off coast of Louisiana in the open Gulf of Mexico's Ship Shoal Area. As stated by Kurian (2013), currently there are about 10000 offshore platforms worldwide with water depth up to 2280 meters. The sizing of each platform depends on water depths of the area and facilities to be installed for the platform. There are generally three types of water depths; shallow water (less than 500 meters), deepwater (less than 1500 meters), and ultra-deepwater (more than 1500 meters).

The figure below shows several types of offshore platforms used worldwide according to various water depths.

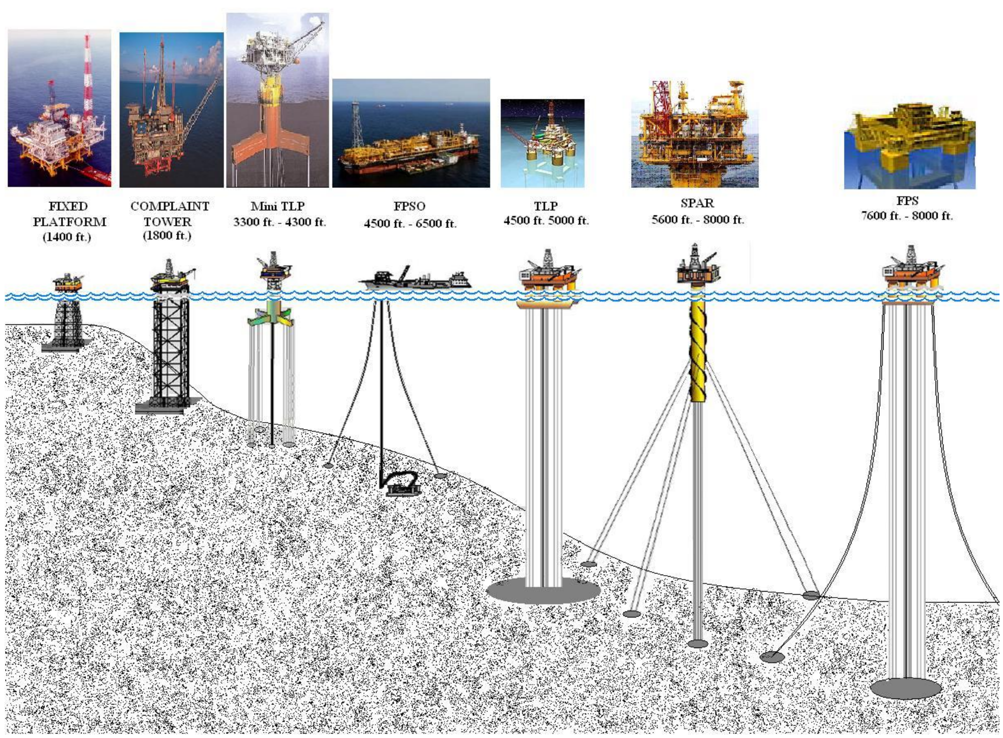


Figure 1: Types of offshore platforms

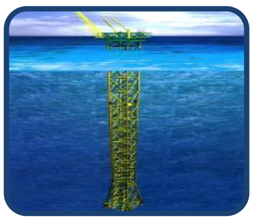
As mentioned by Kurian (2013), offshore platforms are mainly classified into two; fixed structures and floating structures. Fixed structures that extend to the seabed are as such:

Jacket Platforms

- Space framed structure with tubular members supported on pile foundation
- Piles are contained inside the jacket legs which are driven into the seabed
- Moderate water depths up to 400 meters

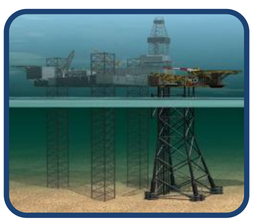
Gravity Based Structure (GBS)

- Remains in place on seabed because of selfweight
- Moderate water depths up to 300 meters
- Mostly made up of concrete
- Construction starts in a dry dock. Structure floats when dock is flooded



Compliant Tower

- Narrow flexible framed structure supported by piled foundation
- Water depths up to 800 meters
- No oil storage capacity



Jack Up

- Mobile platform of three-legged structures of tubular truss
- Have deck supports on each leg (typically buoyant)
- Can only be placed in relatively shallow waters (less than 120 meters)
- Move from one site to another for drilling operation

Figure 2: Fixed structures of offshore platforms

The examples of floating structures that float near the water surface are:

Tension Leg Platform (TLP)

- Has excess buoyancy over weight which keeps the tethers in tension
- For water depths up to about 1500 meters
- No integral storage facility
- Mini TLP is also know as SEA STAR

Semi-submersible

- Multi-legged floating structure with a large deck
- Legs are inter-connected at the bottom with horizontal pontoons
- Can be moved from place to place
- Water depths of range 200 to 1800 meters
- Weight sensitive and has flood warning systems

Spar

- Large diameter deep draught cylidrical floating calsson anchored to seafloor by mooring lines to the decks
- Ultra-deep water depths
- Good stability - centre of buoyancy is considerably above centre of gravity

Floating, Production, Storage and Offloading (FPSO)

- This facility is of ship-shaped structures with several different mooring systems
- Uses single point mooring (SPM) to hold FPSO in place
- Used in deepwater
- Integral oil storage capability

Figure 3: Floating structures of offshore platforms

Since most of the platforms in Malaysian waters consist of fixed jacket platform, then the author’s study will be focusing more on fixed jacket type of platforms.

2.2 Decommissioning Offshore Installations

Decommissioning is a unique yet costly, hazardous and time-consuming process. It is mandatory that the oil and gas installations and/or pipelines to be dismantled in a properly-organised detail process when the installations reach the end of their economic production life and the expiry of service design life of the installations ("Thailand Decommissioning Guidelines for Upstream Installations," 2009). The detailed process includes three key phases:

Table 1: Categorisation of phases in decommissioning process

Activities	Descriptions
Pre-decommissioning	• Detailed planning on the selection of decommissioning options in every possible aspects • The operator or concessionaire needs to compare and assess possible options and procedures before submitting the plan for approval
Decommissioning Execution	• Decommissioning activities for oil and gas installations and facilities based on options proposed and approved • Waste management, safety standards and, debris survey and clearance
Post-decommissioning	• Site survey and post-decommissioning monitoring are conducted for the assessment of environmental changes, recovery, or implications after production operations

Offshore decommissioning is already a common trend in the US and UK (Liew & Shawn, 2011). Malaysia's decommissioning market on the other hand is starting to scale up. There are approximately 300 offshore platforms off the coasts of Malaysia and 48% overall have exceeded their 25 years service design lives which so far, only a countable amount of platforms had been decommissioned (Zawawi et al., 2012).

Nevertheless, operators need to come up with a practical and sustainable framework in order to steer up the gear to a practical decommission plan, provided that it complies with the laws and regulations of decommissioning.

2.2.1 Decommissioning Legislations

2.2.1.1 International Regulations and Requirements

For over the last 50 years, global conventions and guidelines on decommissioning of oil and gas facilities that have reached economic production life and service design life have grown. According to Thungsuntonkhun (2012), there are five (5) global conventions and guidelines which uphold decommissioning of offshore installations, which are:

a) **1958 Geneva Convention on the Continental Shelf**

As stated by Hamzah (2003), 1958 Geneva Convention on the Continental Shelf was one of first important provisions having a special provision responsibility in completely removing all offshore installations to make sure that no intrusion during the exploration of the continental shelf on navigation, fishing, or the preservation and management of living resources. As mentioned in Article 5(5) of the convention, its function calls to secure any relation to maritime security interests.

b) **1982 Convention on the Law of the Sea (UNCLOS)**

UNCLOS consists of more broad and flexible provisions which permits partial removal on condition that IMO criteria are met as mentioned in Article 60(3). It is declared that to have a safe navigation and keeping the marine environment protected, any abandoned or disused installations or structures shall be removed, provided that the removal comply to competent international organization. Furthermore, any installations or structures which are not removed entirely shall be inclined with relevant attention (Gibson, 2002).

c) **1989 International Maritime Organization (IMO) Guidelines and Standards**

International Maritime Organization (1989) has come up with a guideline in the year 1989 for decommissioning offshore installations called “Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone”. The purpose of this guideline is to establish removal criteria for decommissioning. One of the standards to be followed is to completely remove all abandoned or disused installed facilities which weigh less than 4000 tonnes in air and are located standing in less than 75 meters of water, excluding the deck and superstructure. Besides that, this guideline requires all the abandoned or disused installations or structures standing less than 100 meters of water, weighing less than 4000 tonnes in air and being emplaced on the sea-bed to be completely removed except for the deck and superstructure. On the contrary, for partial removal, the installations or structures should be partially removed to an extent that an unobstructed water column exists to allow safe navigation, but to a depth of not less than 55 meters (International Maritime Organization, 1989).

d) **1972 London Convention (LC)**

1972 London Convention happens to be the first global convention to control and manage the deliberate dumping at sea of wastes and other matter (Molenaar, 1997).

e) **Protocol to the London Convention (1996)**

This protocol is a comprehensive revise of the 1972 London Convention which consists of 29 Articles and three Annexes, forming an integral part of the 1996 Protocol (Molenaar, 1997). This protocol has made changes to the concept of sea dumping. According to Hamzah (2003), areas of definitions, dumping provisions and environmental principles are the main changes done to the original convention. As an example, the 1972 LC does not define pollution yet the LC Protocol defines it on the point of anything that is dumped into the sea as a result of human activity which leads or may lead to deleterious impact on marine ecosystems and living resources.

Other than the international regimes mentioned beforehand, in 1993, the Convention of the Protection of the Marine Environment of the North East Atlantic (OSPAR Convention) was formed. OSPAR Convention is commonly used in the North Sea and is stricter compared to IMO Guidelines. As an example, deep sea dumping is not allowed in OSPAR Convention. Based on Hamzah (2003), he mentioned that OSPAR's Article 5 of Annex III describes the complete or partial non-removal of disused offshore installations or structures to disposal site can only be tolerated if the competent national authorities permit it. Apart from that, for complete removal of oil and gas installations made out of steel with a jacket that weigh less than 10000 tonnes shall be reused, recycled or disposed off while it is possible to remain the footings of a steel jacket that weigh more than 10000 tonnes in place (OSPAR Decision, 1998).

2.2.1.2 Malaysia Legislations

Apparently there is no governing legislation yet for decommissioning offshore installations in Malaysia. Decommissioning stipulations are still blooming in the domestic oil and gas without a doubt. However until then, platforms will be inspected, rendered and used to expand its lifespan to the maximum (Khalid, 2011). Also, Zawawi et al. (2012) mentioned that any decommissioning plans must comply with at least eight laws.

Apart from that following the international regulations and guidelines such as London Dumping Convention 1972/1996, United Nations Convention on the Law of Sea (UNCLOS) 1982 and the International Maritime Organization (IMO) Guidelines and Standards 1992, the local regulation Environmental Quality Act (EQA), developed in 1974 has also governed Malaysia's decommissioning of offshore oil and gas installations and structures. The national oil and gas company, PETRONAS has its own regulatory framework – 2008 PETRONAS Guidelines for Decommissioning of Upstream Installations where it is subjected to the major relevant international regulations mentioned above (Boothby, 2010).

2.2.2 Decommissioning Processes and Alternatives

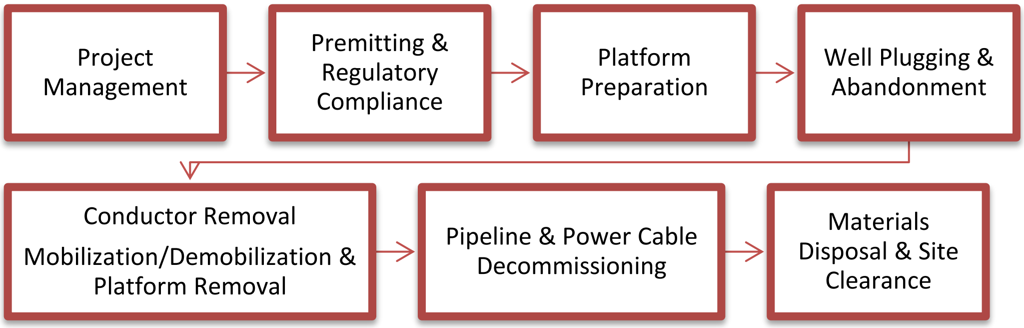


Figure 4: Steps to Decommissioning

The first common step to decommissioning offshore installations is to conduct engineering and planning. This process involves review of contractual duty, engineering analysis, operational planning as well as contracting. To obtain the federal and state permit, engaging to a consulting firm is the next step. The following step is platform preparation ("How Does Decommissioning Work?,"). Examples of processes in this step involve equipments and piping are cleaning as well as pipe and cable cutting removal. Wells are then plugged and conductors are to be removed. Next, topside and substructures are transported onshore, which is followed by cutting and removal of deck. Jacket normally has removal options which are either to be cut, lifted and transported onshore for refurbishment, reuse, or to be left-in-situ for reefing. Pipelines on the other hand are more likely to be left-in-situ but before that, they must be flushed with water, filled with seawater, plugged and be buried with the ends 1 meters below the mudline. The site can then be cleared as soon as the structure is removed with the aid of divers and remotely operated vehicles (ROVs). This is to avoid any future potential obstructions.

There are mainly three decommissioning alternatives in order to meet authoritarian requirements, which are to either remove a platform completely, partially or just leave it in place (Zawawi et al., 2012). The overview on decommissioning alternatives is as shown in Figure 5.

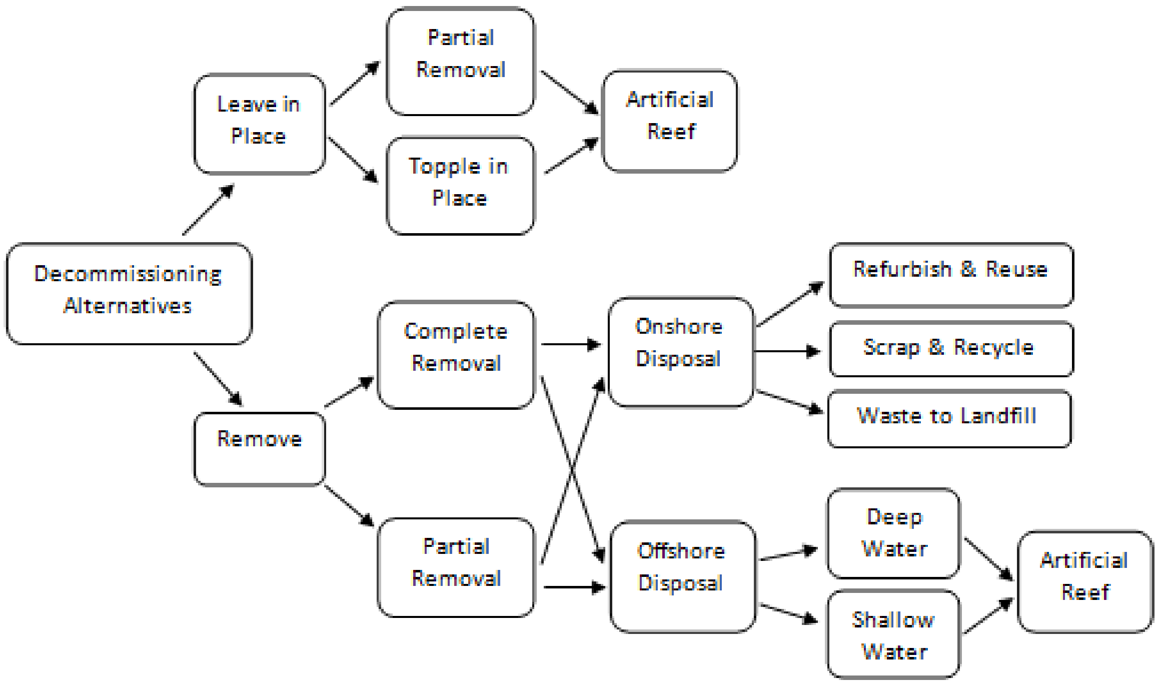


Figure 5: Overview of decommissioning alternatives

Take note that these alternatives seize wells have been decommissioned and plugged while topsides should be cleaned and removed or made safe for toppling with the jacket.

For complete removal and partial removal, bits and pieces of a structure both can possibly be disposed onshore and offshore. Take note that the structure to be removed completely by lifting it can either be lifted in pieces/sections or in one piece, depending on the jacket size and the capacity of the lift vessel (Kurian & Ganapathy, 2009). Furthermore, it is advisable for drill cuttings on the structure to be done in pieces so that it will be easier for transportation to shore. These removed structures will either be refurbished and reused, recycled, sold for scrap or to be a waste to landfill. It was affirmed that the first ever platform to be reused was in the Gulf of Mexico, in the year 1967 (Kurian & Ganapathy, 2009). In Malaysia, the first platform decommissioned was Ketam Platform, off the coasts of Sabah, which was totally removed in 2003 and brought onshore for disposal after the production was stopped in 1997 (Kurian & Ganapathy, 2009). When it comes to offshore disposal, the structure remains can be dumped in a deep water site or into a seabed nearby the original site which will later on become artificial reefs.

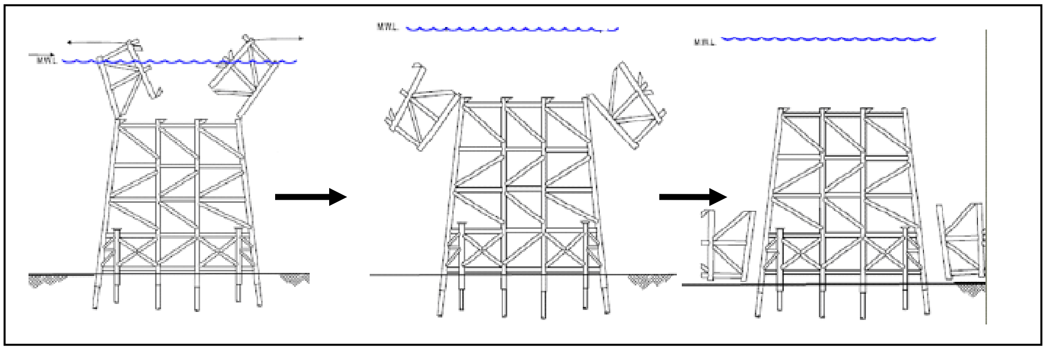


Figure 6: Sections cut by partial removal disposed nearby the original site

Additionally, leaving the structure in place option has two types of method; partial removal and topple in place. As mentioned by Kurian and Ganapathy (2009), partial removal is allowed under IMO Guidelines for large structures. It is stated in the guidelines that the structure to be removed must be partially removed such that an unobstructed water column exists in order to allow safe navigation, whereby the jacket top part is cut to a required depth of not less than 55 meters meanwhile the bottom part will be left on the seabed. The detached top part can be transported ashore for recycling or onshore disposal, or can be disposed offshore. Besides that, a platform's current position plays a role in toppling a platform structure in place whereby the entire jacket or the upper portion of the jacket in-situ is pulled over to collapse the structure so that the water column will be unobstructed as well as to create a reef site

Rigs-to-Reefs means to non-productive offshore platforms' installations as permanent artificial reefs on the seabed to support marine habitat (Enforcement, 2014b). Artificial reefs in the Gulf of Mexico are the most wide-ranging decommissioned jacket in the world where about 200 platforms have already been laid out. Meanwhile for Malaysia, the first artificial reef was of Baram-8's tripod jacket. Baram-8 platform was installed in 1968 and got hit by a storm and collapsed on the sea bed in 1975 until all production had to be impeded (Twomey, 2010). The platform was partially removed in 2004 and this project cost about 8 million USD. It is currently a tourist attraction for diving in Miri.

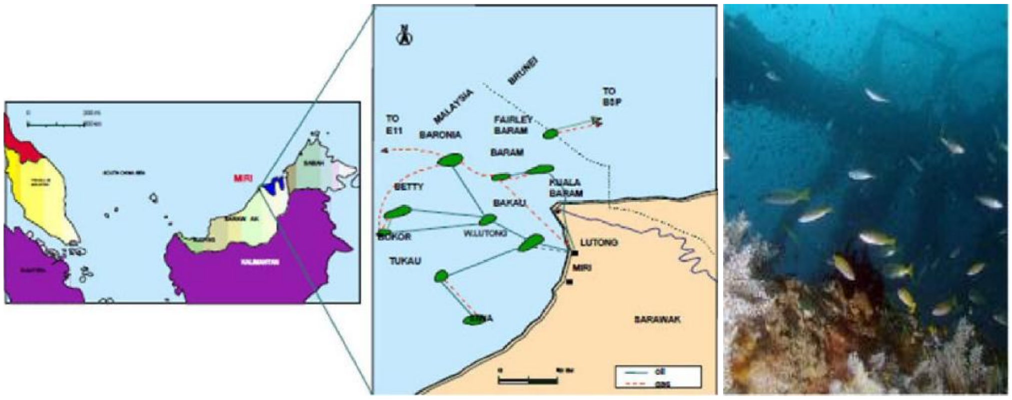


Figure 7: Baram-8's jacket location and transformation into an artificial reef since 2004

2.3 Best Practicable Environmental Option (BPEO)

There are a few criteria to be considered in managing and selecting the most suitable decommissioning option. Based on PETRONAS Research & Scientific Services Sdn. Bhd. (2006), PETRONAS is opting for Best Practicable Environmental Option (BPEO) as of now, which helps to comparatively assess the integrity and use of platforms to be decommissioned as it offers a systematic approach to decision-making in which the practicality of all reasonable options is examined. BPEO consists of four performance criteria; technical feasibility, environmental concerns, health and safety, and cost. Hence, there is no doubt that environmental impact assessment is one of the priorities that stakeholders should consider in decommissioning plan management.

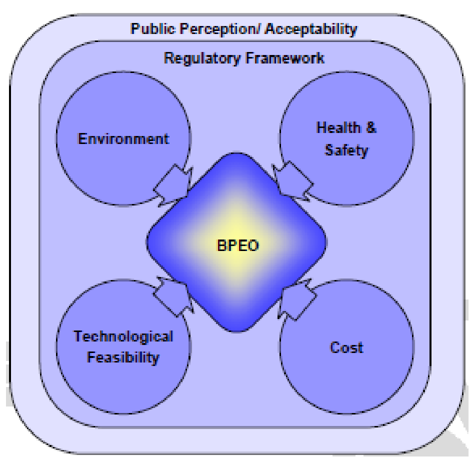


Figure 8: Best Practicable Environmental Option (BPEO) Concept

2.4 Life-Cycle Analysis (LCA)

Any environmental-related topics should be considered and assessed by the society and any industries or for marketing businesses as the impacts may cause greater harm in terms of health and safety, cost as well as public or politics. Hence, this is where LCA plays its role.

The basic idea of LCA is to help measure and compare the environmental impacts for the terms of processes, products or services, with the need of methods and tools (Rebitzer *et al.*, 2004). According to Rebitzer et al. (2004) as well, LCA uses "cradle-to-grave" approach which starts with raw data extractions to ideal disposal, materials production, manufacturing, et-cetera.

International Standardization Organization Standards (ISO) 14040 consists of framework and principles for LCA, which gives a summary of consecutive steps to supervising processes of multiple outputs. The typical standardizing activities of ISO are goal and scope definition, inventory analysis, impact assessment and interpretation as shown in Figure 9.

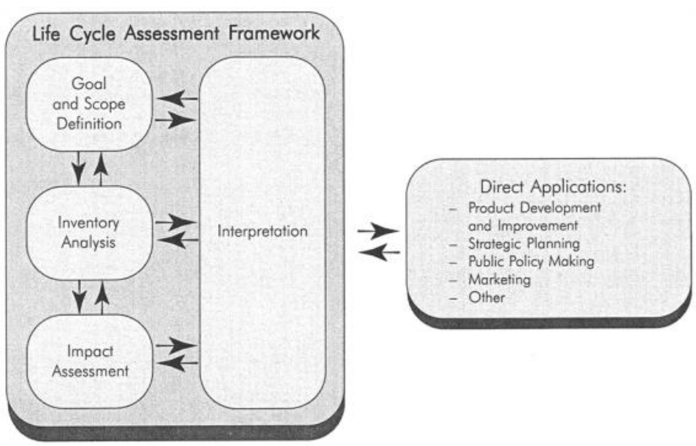


Figure 9: LCA Framework (Klöpffer, 1997)

The first step to LCA is the goal and scope definition that gives the aim of study in order to determine system boundaries, functional unit, rules and assumptions, the group to deal with (e.g. internal, marketing, etc) and the kind of impact evaluation ought to have (Klöpffer, 1997). Then the second step of LCA known as life cycle inventory (LCI), which is a vital step because it acts as the central of LCA that defines methodology in the estimation of resource conservation, energy saving and the quantities of waste flows and emissions rooted out by a product's life cycle. The third step of LCA, life cycle impact assessment (LCIA**)**, is where the environmental importance can be analysed through the potential quantified data or contributions. It is also where several impact categories can be integrated as the result of LCIA, such as effects of carcinogenic effects and climate change to years of human life (Rebitzer et al., 2004). The final step is the life cycle interpretation. This last step focuses at a critical evaluation, discussion and recommendations of the whole LCA that include results from LCI and LCIA.

2.4.1 Comparison between Process-based Method and EIO Method

Even though LCA is a holistic approach that analyses an entire system around a particular product, each LCA method has its own strengths and weaknesses. Process-based method is a simple and straightforward analysis of material and data of inputs (energy resources) and outputs (emissions and wastes released to the environment) for each step of life cycle stages. Process-based LCA tend to give outcomes based on a very specific process, by setting a chosen boundary that contributes most in being part of the system. Meanwhile, EIO method estimates energy resources required and the environment emissions resulting from the whole process and link it with money (Jia, 2013).

Table 2: Comparison of EIO-LCA and Process-Based Models (Hendrickson, C. T., Lave, L. B., Matthews, H. S. (2006))

	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
	• identifies areas for process improvements, weak point analysis	• uses publicly available, reproducible results
	• provides for future product development assessments	• provides for future product development assessment
		• provides information on every commodity in the economy

Disadvantages	• setting system boundary is subjective	• product assessments contain aggregate data
	• tend to be time intensive and costly	• difficult process assessments
	• 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	• difficult to apply to open economy (with substantial non-comparable imports)
		• data uncertainty

Referring to Table 2, it can be concluded that EIO-LCA method has more advantages in comparing results with less effort in data gathering and updating compared to process-based method. However, to authenticate the results and benchmark, it is essential to compare different LCA tools to each other (Hendrickson et al., 1997).

2.5 Researched Offshore Platforms in Malaysia

2.5.1 Case Study: Ledang Anoa Tarpon Drilling Platform (LDP-A)

In order for the author to pursue the environmental impacts of decommissioning fixed offshore platform installations, the author will choose a case study as a research strategy before conducting process-based LCA method. The quantitative results will then be compared to another platform known as SM-4 that has been decommissioned as being reported in the dissertation by Carolin Gorges (2014).

Hence, the platform chosen as a case study by the author is Ledang Anoa Drilling Platform (LDP-A) because of its specification properties is 40.9% similar to that of SM-4's based on the properties outlined in Tables 3 and 4. This helps to achieve precise and accurate quantitative outcomes when conducting the comparative assessment.

LDP-A, a tarpon monopod drilling platform located in the Ledang-Anoa field of approximately 200 km off east coast of Peninsular Malaysia, is chosen as the author's case study for this research project. This platform is known for its designed base on Light Weight Structure (LWS)/ minimum facilities platform (Tarpon), with up to 3 conductor's slots and host tie-in to Pulai-A Platform via 10.75 inch diameter pipeline of about 15 km in length (P. R. W. S. Bhd., 2005).

The basic structural components of a tarpon monopod platform are as shown in Figure 10 and each component's function has been briefly summarised below (Samsudin, 2012).

- Anchor Piles: To anchor/fix the guy wires to the mudline/seabed
- Caisson: A steel caisson with a diameter typically larger than the conductors which acts as the platform's leg, bracing points for the conductors via clamps, and in some cases, can be used to house several internal wells
- Conductor: A steel caisson or riser used to protect the well and production tubing
- Conductor Clamp: To vertically fix the conductor casings to the caisson
- Guy Cables: To provide lateral resistance and stability for the platform
- Topside: The superstructure placed above the reach of waves, equipped with facilities such as production equipment, jib crane, boat landing, helideck and a flare boom

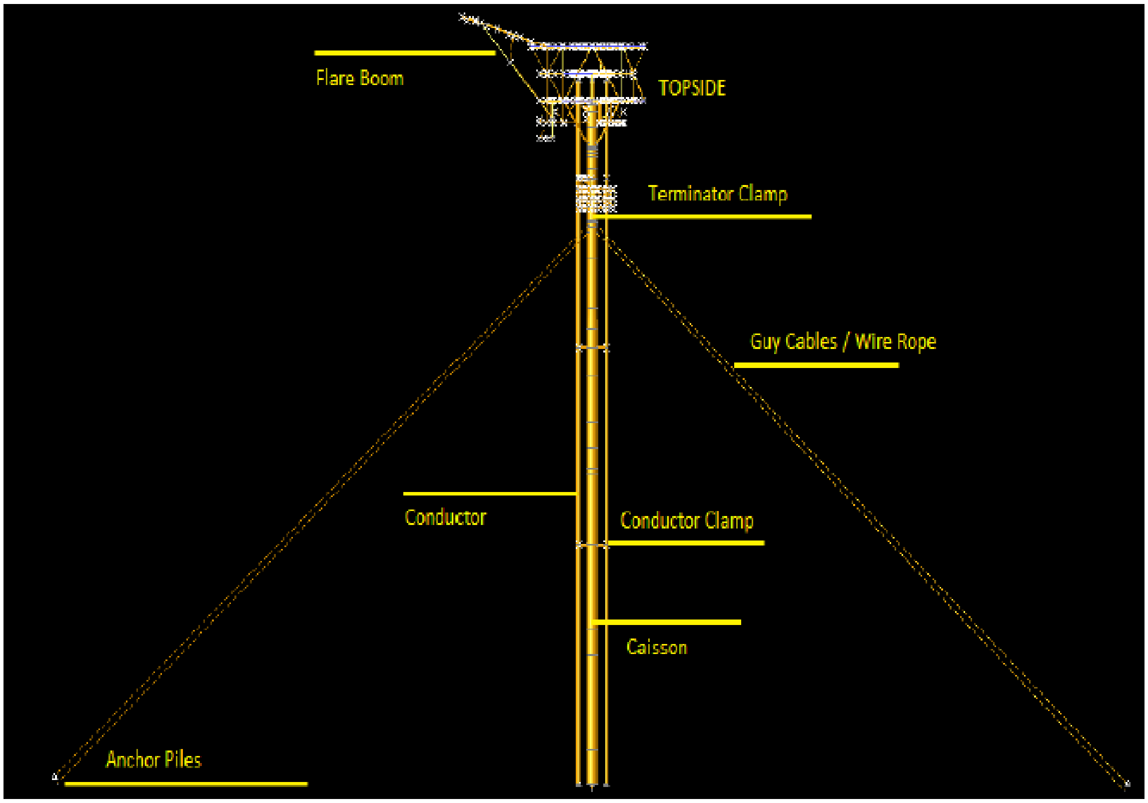


Figure 10: Basic structural components of LDP-A tarpon monopod platform as modeled in SACS 5.3 (Eik, 2013)

2.5.2 Samarang Jacket Platform (SM-4/SMJT-4)

SM-4, also known as SMJT-4 was a single leg platform (monopod), located at a water depth of about 10.5m in Samarang Field, approximately 50 km Northwest of Labuan. The platform was installed in March 1975 and had not been operated since 1986. It used to be a part of Sabah Operations' (SBO) under the Production Sharing Contract (PSC). After running through a few inspections and assessments, PETRONAS Carigali Sdn. Bhd. (PCSB) decided to decommission the platform because SM-4 was not suitable for the current operational requirements (PETRONAS Research & Scientific Services Sdn. Bhd., 2006).

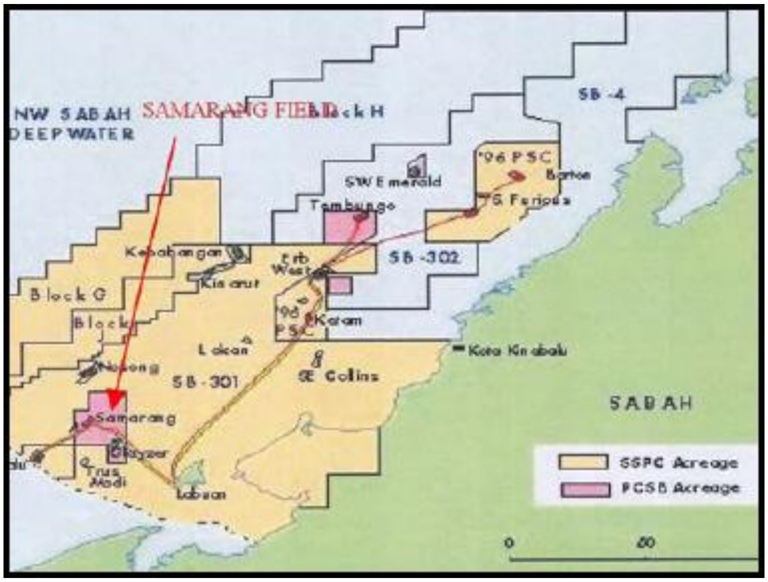


Figure 11: Location of Samarang Field at Offshore Sabah

Figure 12: View of SM-4 from different angles

As mentioned in PETRONAS Research & Scientific Services Sdn. Bhd. (2006), the installations of SM-4 are of the following:

- 42" x 1.25/1.00" WT Main pile from EL (+) 34' to 5' below mudline;
- 30" x 1.25/1.00" WT Main pile from EL (+) 35' to 5' below mudline;
- 32" x 0.75" WT Conductor Casing with Xmas Tree;
- Platform Main Deck / Wire line Deck;
- Cellar Deck/Wellhead Service Platform
- Boat Landing and Access Stairwell;
- One 6" Production Riser and Conductor;
- Topside Well/Valve Assembly; and
- 244 m of 6" pipeline to Samarang production platform SMP-A

On top of that, in April 2012, SM-4 was successfully decommissioned by part-by-part cutting removal, with a total actual lift weight of 80.5 tonnes.

2.5.3 Comparison between LDP-A Platform and SM-4 Platform (With Detailed Specifications)

Table 3: Detailed Differences between LDP-A Platform and SM-4 Platform

Platform	**SM-4/SMJT-4 (SBO)**	**LDP-A (PMO)**
Age	37 years upon decommissioning	8 years (finished installation in 2006)
Type of Platform	Single pile wellhead platform	Tarpon monopod with 3 guyed-wires
Location	South China Sea or within the range of Malaysian waters	South China Sea or within the range of Malaysian waters
Water Depth	10.5 m	76.3 m
Total weight (MT)	80.5	1000
Topside weight (MT)	28	200
Jacket weight (MT)	32.5	800
Service	Oil Production	Drilling Platform & Pipeline

Average Oil Production Capacity	1700 to 3500 barrel oil per day (Samarang Field)	n.a.
Gas Production Capacity	16 to 20 million cubic feet per day (Samarang Field)	n.a.
Miscellaneous materials of construction	1 tonne	a) Boatlanding clamps: 24.4 tonnes b) Boatlanding: 9.1 tonnes c) Wire Drums: 50 tonnes (assumed weight) d) Anode/Riser Clamps 1: 4.1 tonnes e) Anode/Riser Clamps 2 & 3: 4.3 tonnes f) Termination Clamp: 3 tonnes
Type of installations	a) Topside - Supported by one single leg, welded to the single pile driven into the seabed - Topside facilities: →Top Deck/Cellar Deck of 14” height: 16.2 tonnes → Jib crane → 4” Flowline → Topside Well/ Valve Assembly b) Jacket - 1 single support leg, welded to the main pile - Jacket and piles’ components: → Single 22.1 m of 6” Production Riser and Conductor: 0.9 tonnes → Boat Landing and Access	a) Topside: 200 tonnes - Topside facilities (4 levels): → Main deck → Wellhead Service Platform Deck → Wire line deck → Sump Deck b) Jacket: 800 tonnes - Jacket facilities: → Conductors: 244.18 tonnes → Caisson: 290.19 tonnes → Boat Landing: 35 tonnes → Guyed Wire + Piles: 150.34 tonnes c) Pipelines: 10.75 inch diameter pipe insulated with 50 mm and 75 mm thick of concrete at about 15km

	Stairwell: 15.8 tonnes → Conductor Casing (32" x 0.75"): 27.9 tonnes - Sacrificial Anodes (Aluminium alloy) - Mudmats (Wood) c) Piles - 1 single main pile (42", 16.8 tonnes) with 1 internal 30" diameter insert pile driven 16.764 m into the seabed (12.08 tonnes) - Combined weight of piles (assuming main pile + insert pile + annulus grout): 43.8 tonnes d) X'Mas Tree - 1 no. - 2.7 tonnes e) Pipelines (Oil export pipelines) - 6" diameter of 130.8 m long welded pipe sections with 0.375" wall thickness: 4.81 tonnes - Weight coating: 5 tonnes - Pipe coating: 0.4 tonnes - Side tap valve and manifold: 1tonnes	
Helideck	-	-
Accommodation	Unmanned	Unmanned

2.5.3 Comparison between LDP-A Platform and SM-4 Platform (Simplified)

Table 4: Simplified Differences between LDP-A Platform and SM-4 Platform

Platform	**SM-4/SMJT-4 (SBO)**	**LDP-A (PMO)**
Age	37 years upon decommissioning (2012)	8 years (finished installation in 2006)
Type of Platform	Single pile wellhead platform	Tarpon monopod with 3 guyed-wires
Location	South China Sea or within the range of Malaysian waters	South China Sea or within the range of Malaysian waters
Water Depth	10.5 m	76.3 m
Total weight (MT)	80.5	1000
Topside weight (MT)	48.0	200
Jacket/pile weight (MT)	32.5	800
Service	Oil Production	Drilling Platform & Pipeline
Average Oil Production Capacity	1700 to 3500 barrel oil per day	Yes (n.a.)
Gas Production Capacity	16 to 20 million cubic feet per day	n.a.
Helideck	No	No
Accommodation	Unmanned	Unmanned
Boatlanding	Yes	Yes
Jib Crane	Yes	No
Wellhead	Yes	Yes
Pipelines	Yes	Yes
Conductors	Yes	Yes
Mudmats	Yes	No
Flare/Vent Boom	No	Yes
Riser	Yes	Yes
Guyed Wire	No	Yes
Grouted Piles	Yes	No

Table 3 shows the comparison in basic information on platform profile, tonnage, structural specifications, and capacity between LDP-A platform and SM-4 platform, whereas Table 4 shows a metric version on similarities and differences regarding information and specification for both LDP-A and SM-4 platforms.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

Extensive research was done to obtain a feasible project plan. Journals and research papers were reviewed to have a general understanding of LCA tools as well as decommissioning offshore installations and its effects towards the environment. In order to make a comparative analysis for this project, verification of data collection from respective experts on platforms that have been decommissioned of the similar platform profile and region must be available. Subsequent to reviewing related literature, a project plan was developed to accomplish the project objectives as shown in the figure below:

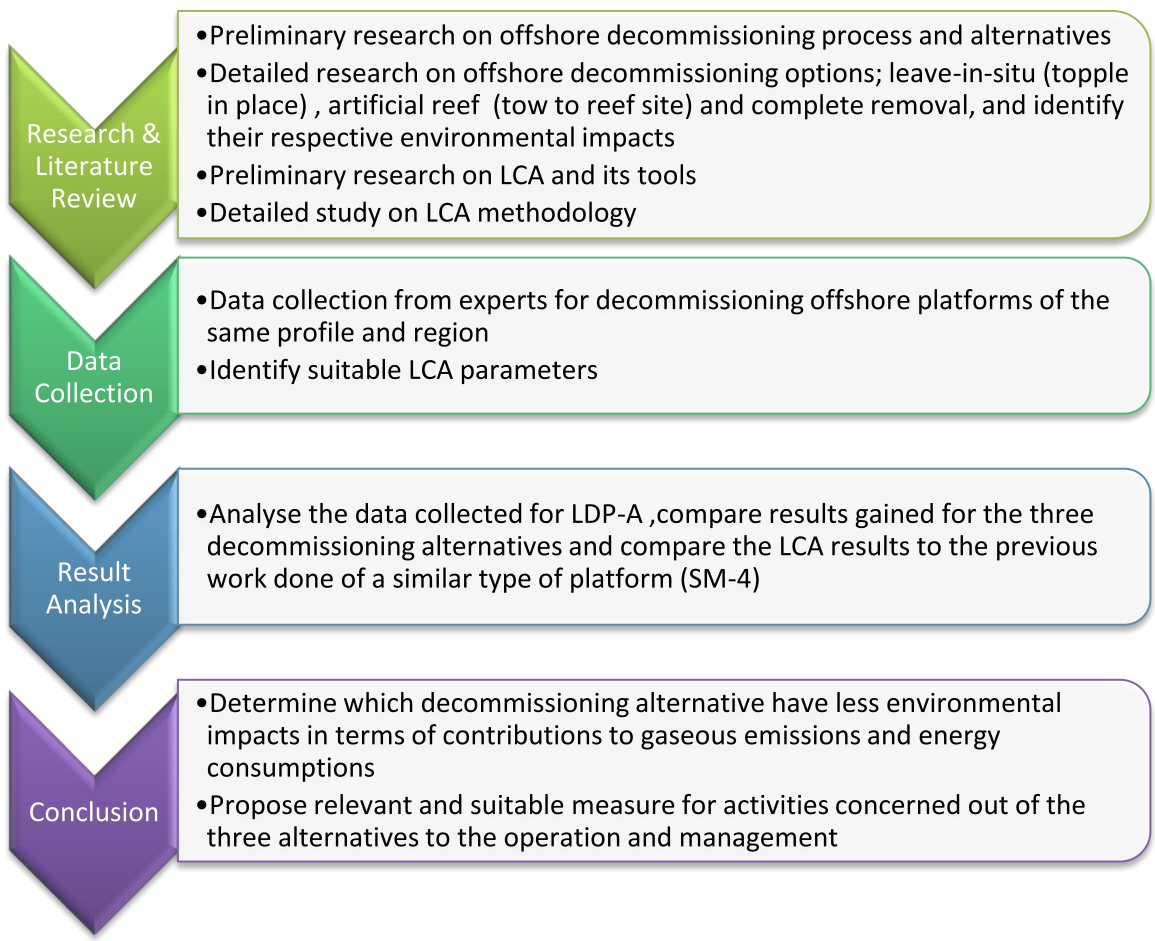


Figure 13: Project Flow Chart

3.2 Gantt Chart and Key Milestone

The Gantt chart is as shown in the figure below along with the important milestones for this project:

	FYP 1														FYP 2														
Project Related Activities	Week														Week														
	Jan-14			Feb-14				Mar-14				Apr-14			May-14		June-14				July-14				Aug-14				Sep-14
	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
Title Selection and Allocation																													
· Select title and attend first meeting with coordinator	■	■																											
· First meeting with assigned supervisor		■	■																										
Preliminary Research Work																													
· Understand offshore decommissioning process and alternatives		■	■	■	■																								
· Understand LCA and its tools		■	■	■	■																								
Extended Proposal																													
· Submit extended proposal draft to supervisor						■																							
· Submit extended proposal to supervisor							■																						
· Proposal defense (exact date to be announced)								■																					
Detailed Research Work																													
· Identify the environmental impacts and waste materials produced				■	■	■	■	■	■																				
· Study LCA methodology				■	■	■	■	■	■																				
Data Gathering and Analysis																													
· Case study and obtain data from experts for offshore platforms of the same profile and location for LCA								■	■	■	■	■																	
Interim Report																													
· Submit interim draft report to supervisor													■																
· Submit final interim report														■															

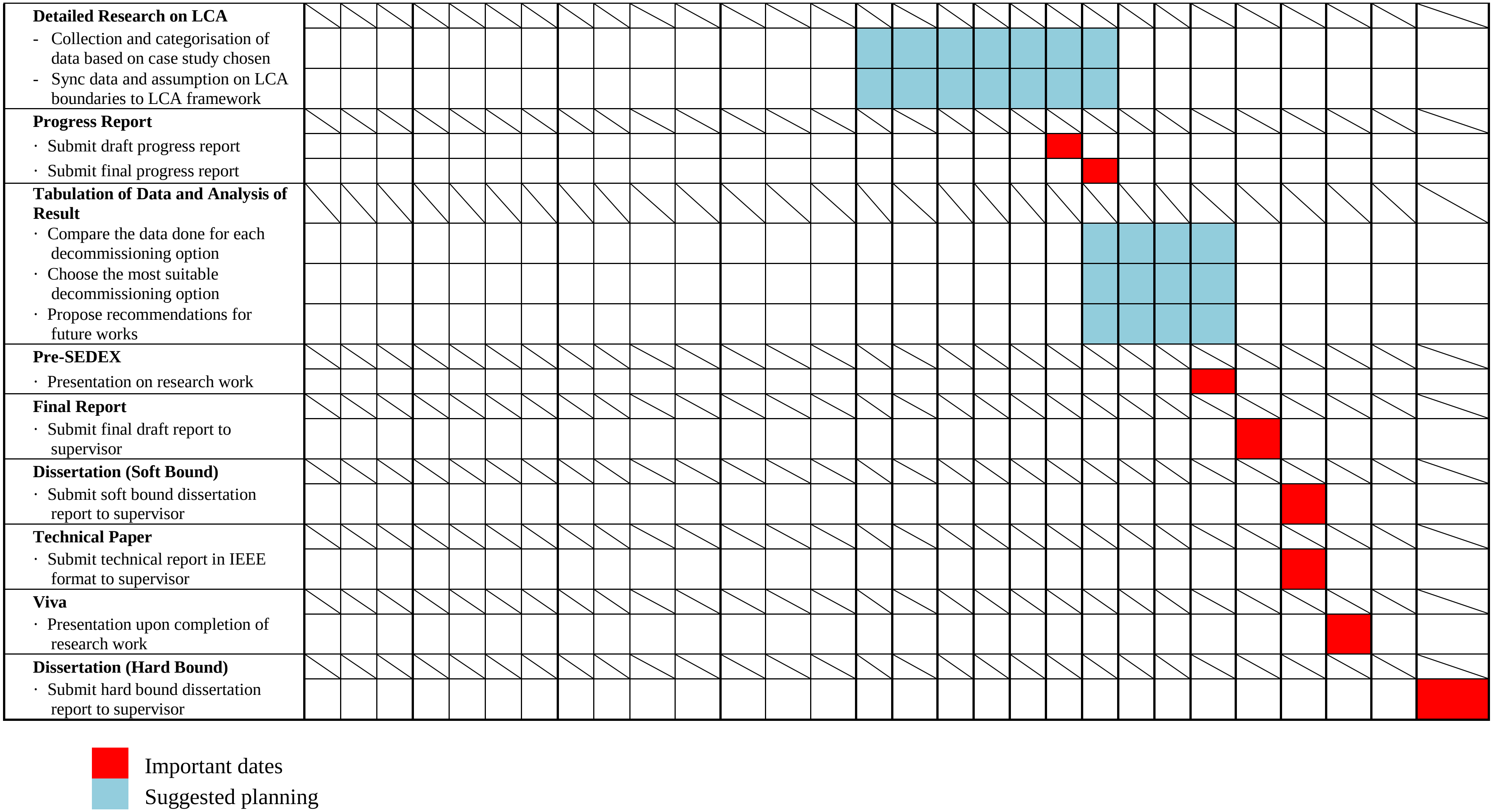


Figure 14: Project Gantt Chart

3.3 LCA Methodology

As mentioned before, there are four stages to an LCA framework based on the ISO standard (Figure 9); goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation.

3.3.1 Assumptions Set for LCA Methods

3.3.1.1 Assumptions Set for Process-based LCA Method

Due to limited available data regarding environmental impacts of decommissioning activities, it is to be taken into consideration that the author has to set a few boundaries and assumptions for this research project. Therefore, the author has to utilize any informative, reliable and relevant resources related to decommissioning and its effects towards the environment. The data retrieved by the author to proceed with process based LCA are from hook-up and commissioning documentations of LDP-A, BPEO Study for SM-4 as well as other relevant documentations on decommissioning offshore installations.

When it comes to lack of data for total energy consumptions and gaseous emissions in decommissioning offshore installations, the unit conversion factors used are attained by the paper published by Side, Kerr and Gamblin (1997), which has been checked with the recent published rate of the Department of Energy & Climate Change (2013), that the differences can be neglected as they are insignificant. For instance, there is only 5% difference in carbon dioxide emission conversion factor due to the use of aviation fuel when compared with the recent emission factor based on Annual European Union greenhouse gas inventory 1990 – 2011 and inventory report 2013. It is also stated by Side et.all (1997) that the quantification of energy consumptions associated with the dismantling of platform facilities based on unit fuel consumptions per tonne dismantled from the demolition contractors are gathered based on the contractors' experience.

With respect to that, it can be assumed that the data in the published paper can be referred to. The unit conversion factors and constants for energy consumption and gaseous emissions related to steel scrap and production for dismantling, recycling and leaving materials at sea, as well as the haulage constants and factors related to the fuel consumption of an on- and offshore transportation trip distance during decommissioning alongside with their respective references are as per attached in the Appendices. These constant factor values applicable are entered in linked spreadsheets whereby they are imported automatically into each decommissioning aspect spreadsheet. The purpose to using linked spreadsheet is to enable revision of the evaluation process in case of any changes to the input constants or relevant data.

3.3.1.2 Assumptions Set for EIO-LCA Method

All data integrated into EIO-LCA model is extracted out of the compilation from various surveys and forms submitted by industries to governments for national statistical purposes, which creates uncertainties in sampling and incomplete data or estimates. It has to be taken into account that the changes in data may vary extensively over time in using the model to replicate recent terms. Since the EIO model is based on the year 2002, it is verified that the model has been revised by the Green Design Institute with the latest economic input-output coefficients in 2009. Thus, the validity of results is ensured.

Hence, by applying the EIO model, the total energy consumption and gaseous emissions associated with the decommissioning of LDP-A platform can be verified.

3.3.2 Step 1: Goal and Scope Definition

The goal of this analysis is to follow the objectives of this study which entail the contribution of total energy consumption and gaseous emissions to the environment correlating on different options of decommissioning fixed offshore platforms in Malaysia, as well as to propose recommendations which concern the environment for future purposes.

The case study chosen for this research project is LDP-A platform which has similar properties as of SM-4's specifications within the South China Sea region as classified in Tables 3 and 4. Moreover, the means of this study is limited to three decommissioning options; complete removal and artificial reef conversion by towing to reef site and artificial reef conversion by toppling in place.

As referred in the paper published by Side, Kerr & Gablin (1997) on the assessment of the total energy consumption and gaseous emissions for the decommissioning of Heather Platform in the North Sea, it is noted that a few setbacks have been drawn to ease the consistency in data evaluation and to prevent any sort of energy to be counted twice. The same setbacks are drawn for the estimation environmental impacts for SM-4 decommissioning process and installations. Hence, the same boundaries will be taken into account for the chosen case study to obtain comparable accuracy and precision in the results.

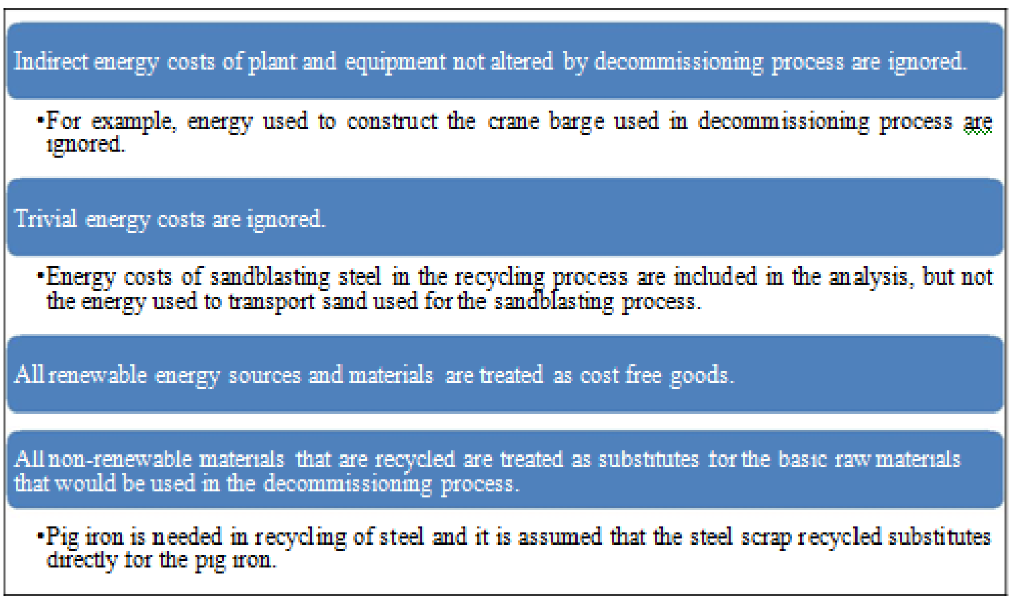


Figure 15: Defined boundaries for consistency in data evaluation (Amy Ngu Pei Jia, 2013)

3.3.3 Step 2: Life Cycle Inventory (LCI)

The LCI plays a vital role as it means to collect data and calculate on the estimation of relevant inputs and outputs by a product's life cycle (Rebitzer et al., 2004). For offshore decommissioning, the input would be the energy consumption meanwhile the output would best be gaseous emissions produced. The crucial gaseous scopes associated with decommissioning offshore installations are narrowed to the contribution towards greenhouse effects (CO_2, Equivalent CO_2 and overall CO_2 emissions), and acidification (SO_2 and NO_x emissions). The NO_x emissions consist of mono-nitrogen oxides; nitric oxide (NO) and nitrogen dioxide (NO_2).

3.3.3.1 Process-based Method

When it comes to process-based method, aspects that have been gathered which contributes to total energy consumptions and gaseous emissions for decommissioning are:

Table 5: Decommissioning aspects

Decommissioning Aspects	Related parameters
Transportation offshore of different types of marine utilization	• Fuel consumption • Travel distance • Period of usage
Transportation onshore	• Fuel consumption • Travel distance • Period of usage
Dismantling of platform facilities	• Cutting method • Removed platform materials (steels from topside/sub-structures or pipelines, miscellaneous materials) • Fuel consumption
Recycling of platform materials	• Steels from topside/sub-structures or pipelines • Miscellaneous materials
Platform materials left at sea	• Mudmat • Marine growth • Reefing purposes

These aspects will be defined to set the scope or boundaries for LCI process-based LCA. In terms of decommissioning the structural components, the major elements of LDP-A would be the topside, conductors, caisson, boat landing, and guyed wires with piles, by which each component will play major parts accordingly in every decommissioning aspect set. It should be noted that the well abandonment is not considered in this study. The assumptions done for these areas of aspects are described briefly under each section in the alongside with each decommissioning aspect calculation Appendices.

Else than that, for the decommissioning option of converting platform installations to artificial reef by towing to reef site, a reef site is said to meet the requirements implemented by Bureau Safety & Environmental Enforcement (BSEE) and The Outer Continental Shelf Lands Act (OCSLA). For decommissioned platform structures, they can either be partially removed near the surface, toppled in place, or towed to existing reef sites or reef planning areas. (Enforcement (2014a)) stated that in order to find areas best suited for artificial reef development, exclusion and inclusion mapping followed by public hearing should be undergone. Besides that, the required depth of the reef site should have sufficient sunlight and must have the “5-mile rule” which means new reef sites will not be established within 5 miles of existing reef locations. Thus, with reference to the these requirements, the author has assumed and suggested a new reef planning area, located not too far out from an island near to Redang Island with Lat 5°46’05.06” and Long 103°02’23.74”, approximately 230 km from platform site, provided that the public has agreed upon the artificial reef site planning area. One of the main reasons for the author to assume so is because the suggested reef site is nearer to the location of LDP-A platform compared to the existing reef site - Kenyalang Wreck, where the Baram-8 jacket legs decommissioned were converted to artificial reef and is currently one of the most visited diving site in Miri. This could reduce the travel distance when towing the decommissioned offshore installations to a reef site, which may indirectly reduce the cost of marine vessels’ mileage. Besides that, Redang Island is known as one of the top tourist attractions in Malaysia. So in a long run, more fisheries will be present for their new habitat, thus increasing the diving activities and contributes to Malaysia tourism.

The proposed reef area can be clarified in the following figures:

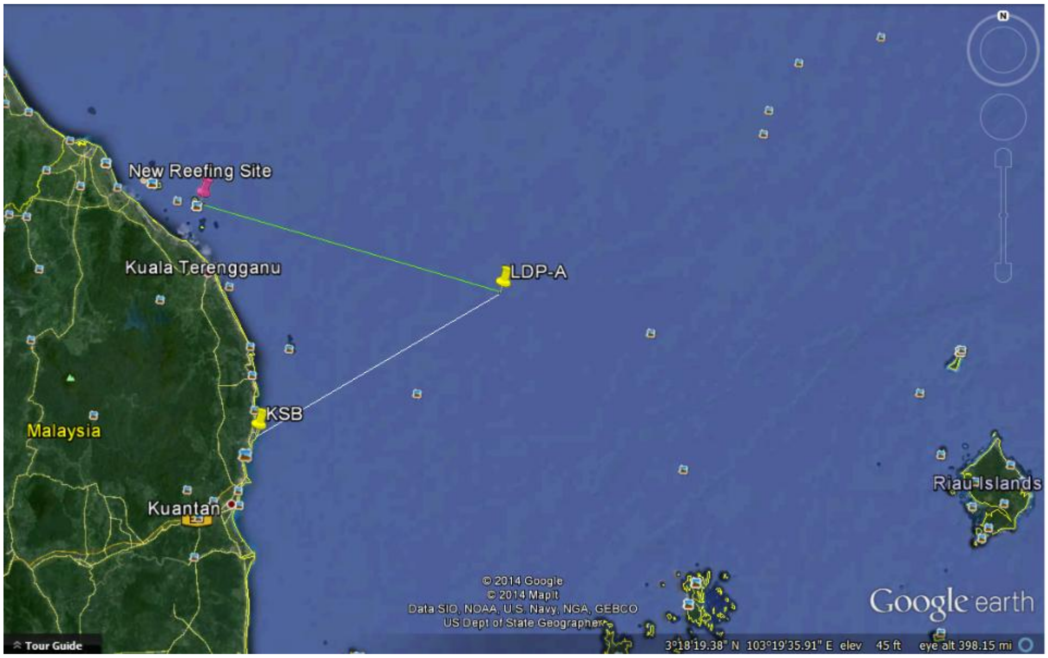


Figure 16: The location of the proposed reef site as mapped in Google Earth view

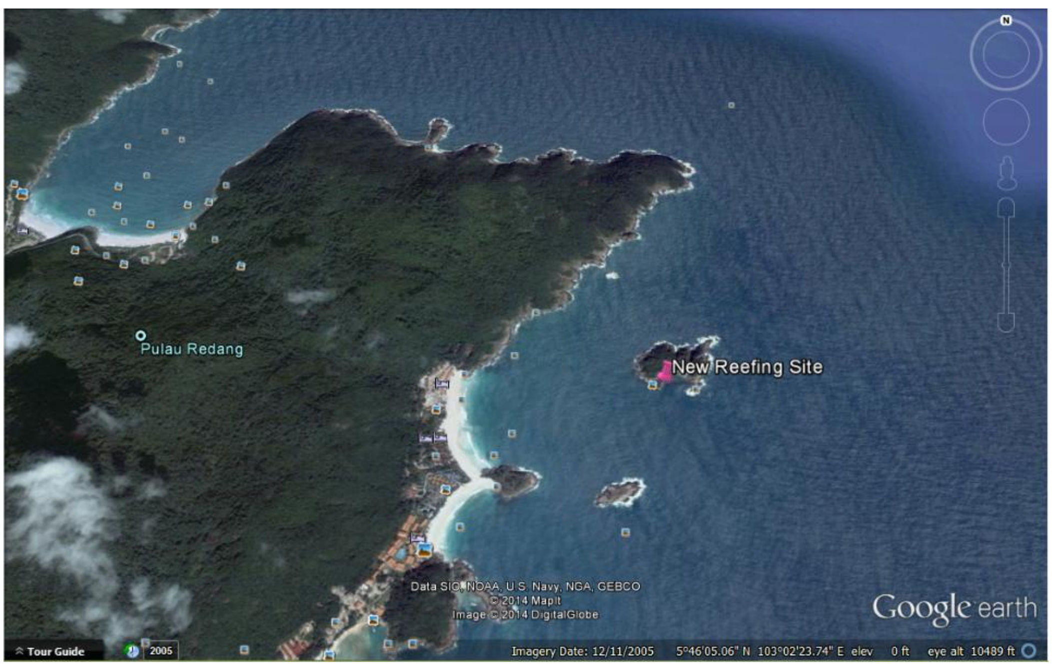


Figure 17: A nearer insight view of the proposed reef site

3.3.3.2 EIO Method

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.

However, LDP-A platform is yet to have decommissioning cost data. According to the BPEO study done for SM-4, SMV-A and EWV-A, the decommissioning cost for each of these platform is expected to be comparable as to KTV-A's because the sizing (tonnage) and functions are comparable slightly lighter in weight), except that the mobilization cost still varies depending on the location of the vessel embarkation point as well as the location of the fabrication yard nearby for removal activities. With that information, the author has decided to make an assumption for decommissioning cost data on LDP-A platform whereby the decommissioning cost is assumed to be comparable as KTMP-A's (decommissioned in 2003), in condition that the removal of facilities to be conducted is done in a similar or simpler manner; removal in sections. The sizing (tonnage) and components of KTMP-A platform are comparable to LDP-A platform's as well, although LDP-A platform is slightly lighter than KTMP-A platform. Even though LDP-A and KTMP-A are not of the similar type of platform, but the tonnage can be taken into account. Since the cost of KTMP-A's decommissioning cost by total removal is RM 46 million excluding well abandonment, therefore the assumed decommissioning cost for LDP-A is assumed to be of the same value; RM 46 million.

Table 6: Comparison between LDP-A and KTMP-A

Platform	**Water Depth [m]**	**Jacket Weight [t]**
KTMP-A	54	1062
LDP-A	76.3	800

For artificial reef conversion on the other hand, there seem to be no suitable cost information available. Only the platform removal scenario of conversion to artificial reef by towing to a reef site is applicable for this case study, whereby its decommissioning cost is assumed based on the comparison between the costs of complete removal and remote reefing calculated for three offshore platforms in the Gulf of Mexico. According to Gorges (2014), the comparison in decommissioning cost of Hidalgo, Gail and Harmony platforms from complete removal to remote reefing options differs approximately 35% based on a paper published by Twatchman Synder & Byrd, Inc. (2000). With that, the estimated cost for the option conversion to artificial reef by towing for LDP-A is assumed to be RM 16,100,000, hence US$ 5,247,015.87.

In order to be able to use the value in the EIO model, the author has converted the cost data obtained in Ringgit Malaysia (RM 46 million) to US Dollar (14 million USD). Even though the currency fluctuates every day, the outcomes may not have an effect much since the fluctuation rate is unimportant compared to the amount of decommissioning costs.

Then, as mentioned previously, the EIO online model and database from www.eiolca.net is run to assess the total energy consumption and gaseous emissions related to decommissioning offshore installations. When running the model, US 2002 Purchaser Price Model is chosen, with Mining and Utilities as Broad Sector Group, and Support activities for oil and gas operations on a contract or free basis for oil and gas operations for Detailed Sector (excluding site preparation and related construction activities). Other than that, services included in this sector are exploration (excluding 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, cleaning out, bailing and swabbing wells.

3.3.4 Step 3: Life Cycle Impact Assessment (LCIA)

The LCIA defines a better understanding by evaluating the significance of the potential environmental impacts obtained from the previous step. As the inventory data has been categorized to their respective impacts, the impacts will then be computed and weighted. The impact categories relevant for this LCA are global warming (CO_2 and Equivalent CO_2) as well as acidification (SO_2 and NO_x).

3.3.5 Step 4: Life Cycle Interpretation

The life cycle interpretation is the interpretation and analysis from the findings of the inventory analysis and impact assessment combined. The least decommissioning option in the contribution to total energy consumption and gaseous emission can be determined. Hence, the quantitative outcomes provided by process-based LCA method can be compared to the previous work done by Carolin (2014) on SM-4. Finally, relevant recommendations which concern the environmental impact due to decommissioning can be suggested.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results and Discussion

4.1.1 Process-based LCA Method

It has been stated previously in LCA's Methodology that for Process-based LCA, the data retrieved by the author to proceed with process based LCA are from hook-up and commissioning documentations of LDP-A, BPEO Study for SM-4, published paper worked by Side, Kerr & Gamblin (1997) on the estimation of energy consumption and gaseous emissions associated with the decommissioning of Heather Platform, as well as other relevant documentations on decommissioning offshore installations. The assumptions and calculations carried out on energy consumption and gaseous emissions for decommissioning alternative studied with respective decommissioning aspect are as attached in the Appendices.

The total energy consumption and gaseous emissions are assigned to several decommissioning aspects to obtain precise and accurate results in evaluation and for the ease of evaluation. Table 6 and Figure 18 show the quantitative results for total energy consumption and gaseous emissions for complete removal as well as conversion to artificial reef by reefing in place and towing to new reefing site by process-based LCA tool using Microsoft Excel.

Table 7: Results and percentage difference between complete removal, conversion to artificial reef (tow to reef site) and conversion to artificial reef (topple in place)

Variable	**Complete Removal (A)**	**Artificial Reef (I)-Tow to Reef Site (B)**	**Artificial Reef (II)-Topple in Place (C)**	**(A)-(B)**		**(A)-(C)**		**(B)-(C)**	
				Diff. [unit]	**Diff. [%]**	**Diff. [unit]**	**Diff. [%]**	**Diff. [unit]**	**Diff. [%]**
Energy Consumption [GJ]	93,593	97,233	95,002	3,640	3.74	1,410	1.51	2,230	2.29
SO_2 Emissions [kg]	89,501	93,418	91,032	3,918	4.19	1,532	1.71	2,386	2.55
NO_x Emissions [kg]	89,182	92,986	90,775	3,804	4.09	1,593	1.79	2,211	2.38
CO_2 Emissions [kg]	3,773,380	3,932,477	3,838,888	159,097	4.05	65,508	1.74	93,589	2.38
Equivalent CO_2 Emissions [kg]	6,405,076	6,652,079	6,499,782	247,003	3.71	94,706	1.48	152,298	2.29
Overall CO_2 Emissions [kg]	10,178,456	10,595,722	10,343,541	417,266	3.94	165,085	1.60	252,181	2.38

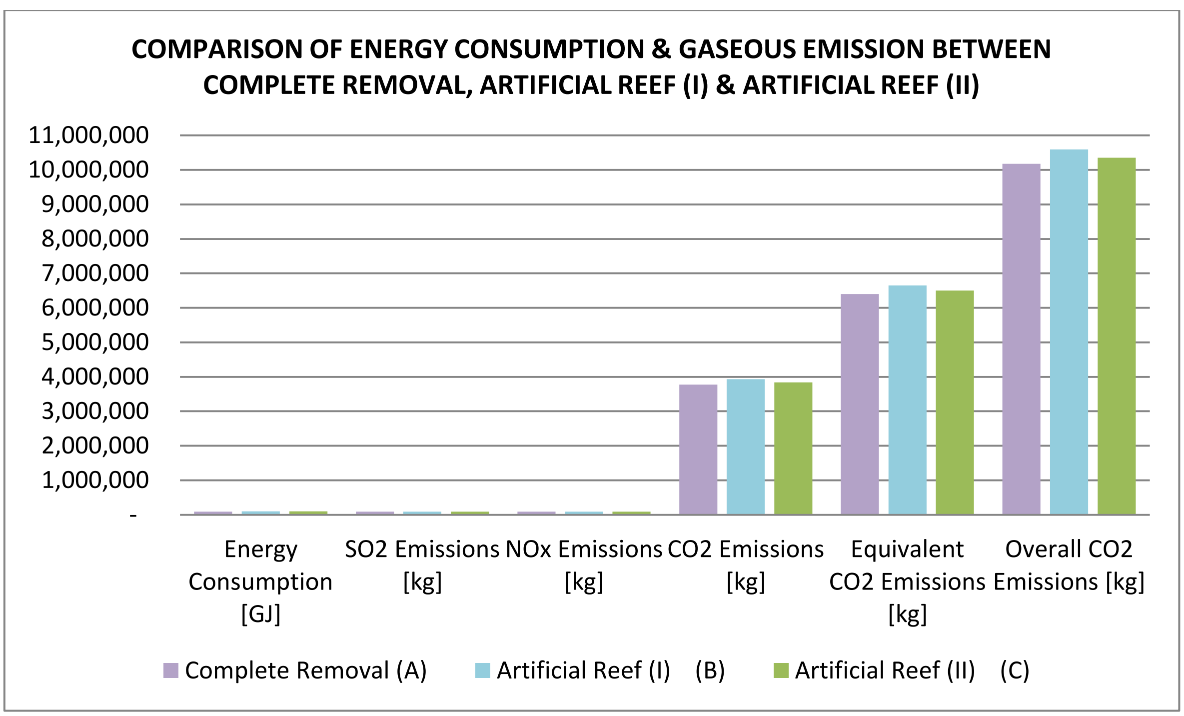
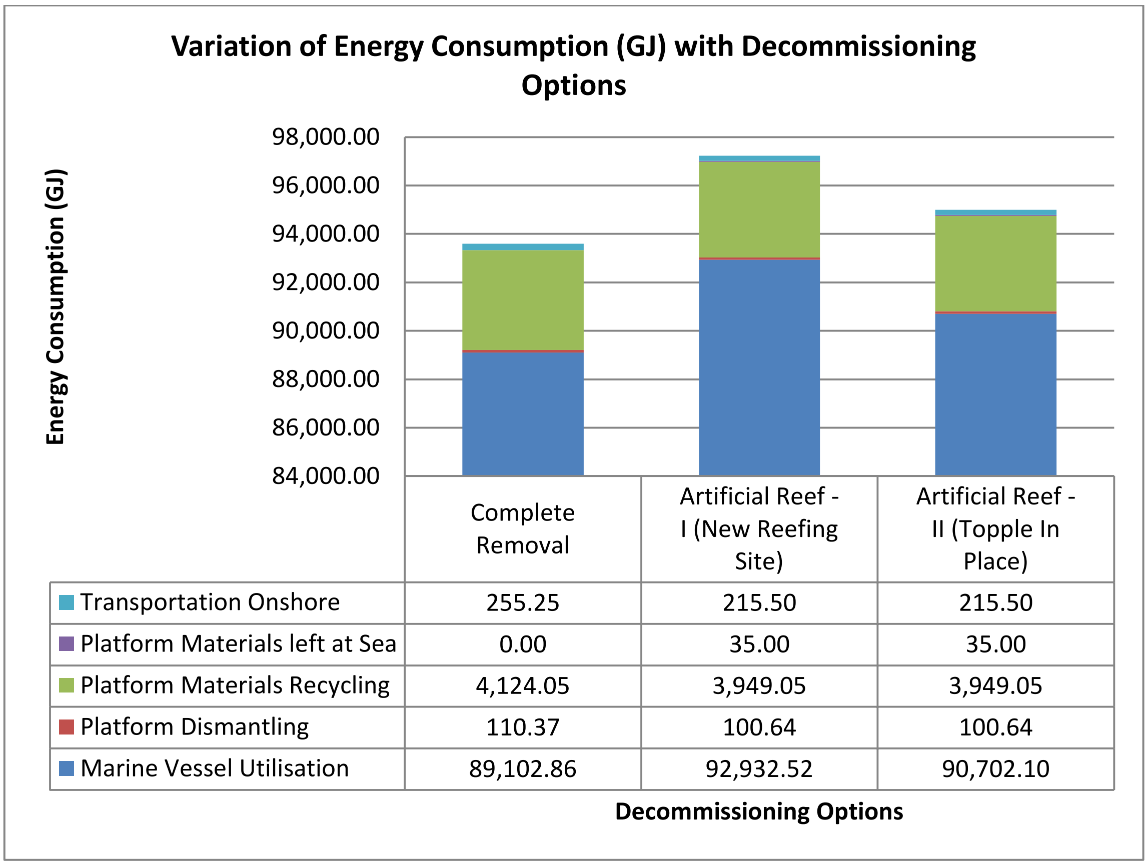


Figure 18: Comparison of total energy consumption and gaseous emissions between decommissioning options for LDP-A

Based on the table and figure from previous page, it can be concluded that the conversion of platform into artificial reef by towing to reef site consumes more energy and produces more gaseous emissions compared to complete removal and artificial reefing in place. The values of total energy consumption and gaseous emissions produced between cases complete removal and artificial reef by towing to reef site, complete removal and artificial reefing in place, as well as artificial reef by towing to reef site and artificial reefing slightly varies ranging between 3.71 to 4.19%, 1.48 to 1.79% and 2.29 to 2.55% respectively.



	Complete Removal	Artificial Reef - I (New Reefing Site)	Artificial Reef - II (Topple In Place)
Transportation Onshore	255.25	215.50	215.50
Platform Materials left at Sea	0.00	35.00	35.00
Platform Materials Recycling	4,124.05	3,949.05	3,949.05
Platform Dismantling	110.37	100.64	100.64
Marine Vessel Utilisation	89,102.86	92,932.52	90,702.10

Figure 19: Breakdown of energy consumption with respective decommissioning aspects/activities for complete removal, conversion to artificial reef (tow to reef site) and conversion to artificial reef (topple in place) of LDP-A

Besides that, Table 6 also shows that the highest total energy consumed is when it comes to comparing complete removal and reefing option by towing to reef site, with a difference of 3.74%. This could be due to the huge amount of energy contributed by steel being left at sea for artificial reefing is replaced by steel production from ore.

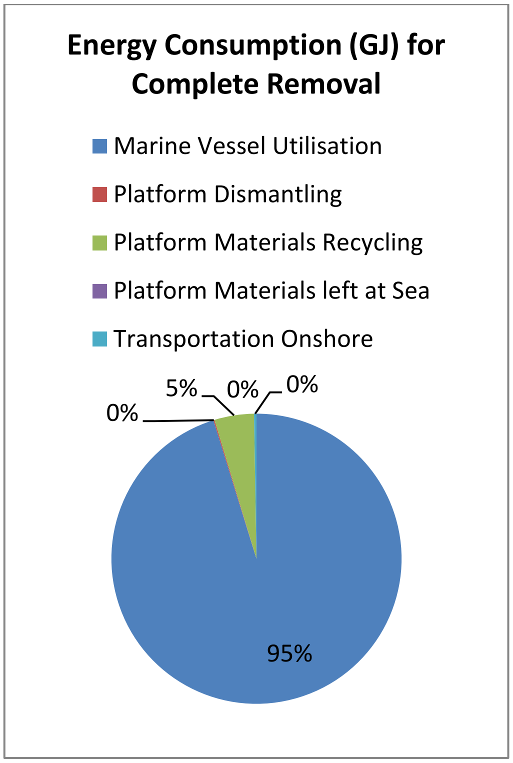


Figure 20: Energy consumption (GJ) of complete removal depending on decommissioning activities for LDP-A

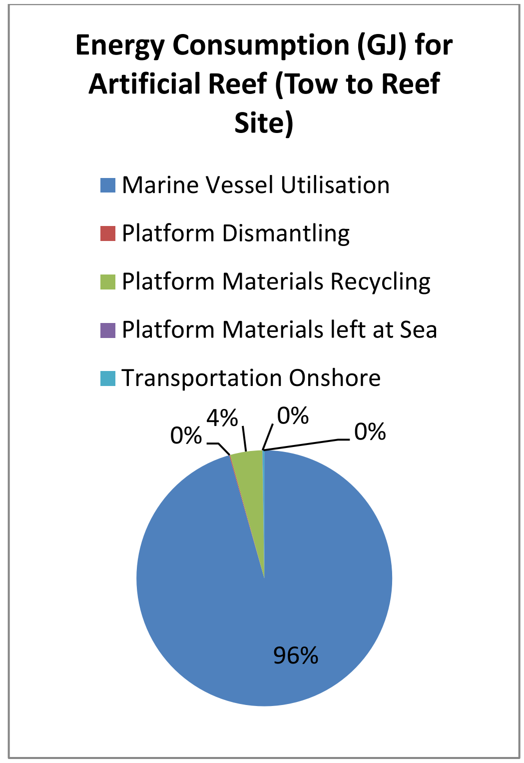


Figure 21: Energy consumption (GJ) of conversion to artificial reef by towing to reef site decommissioning activities for LDP-A

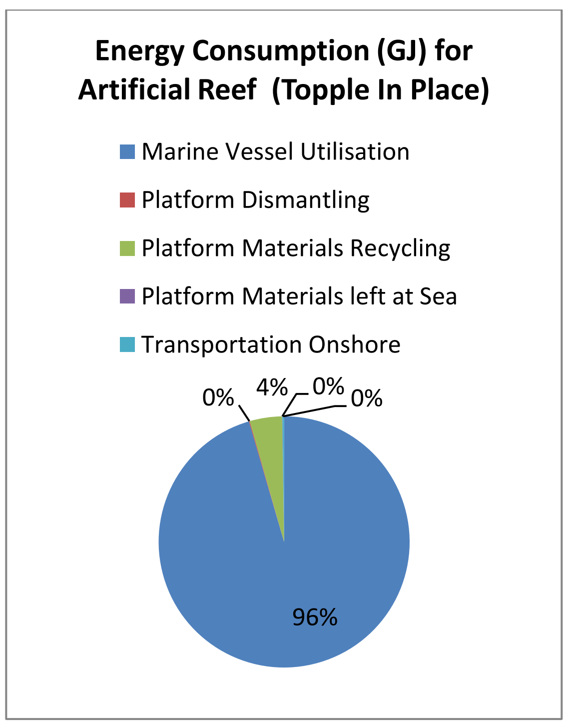
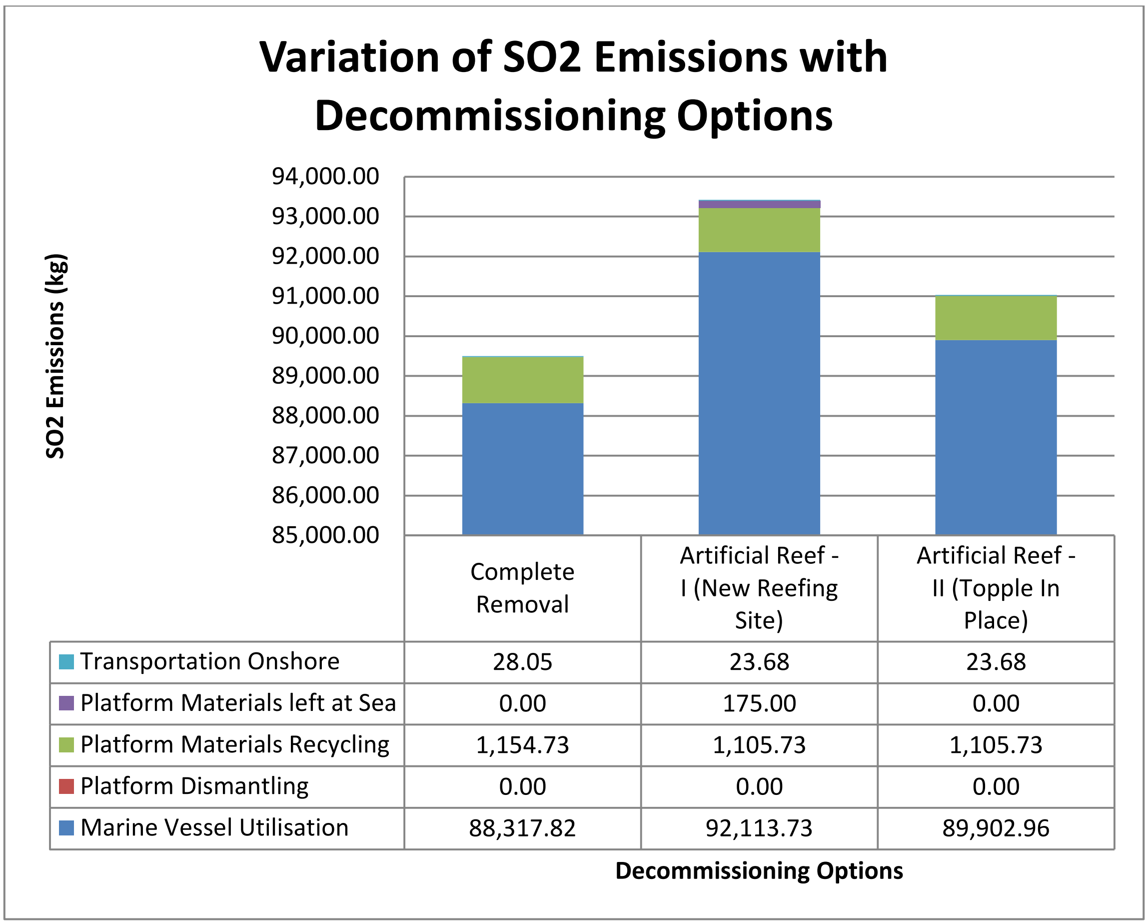


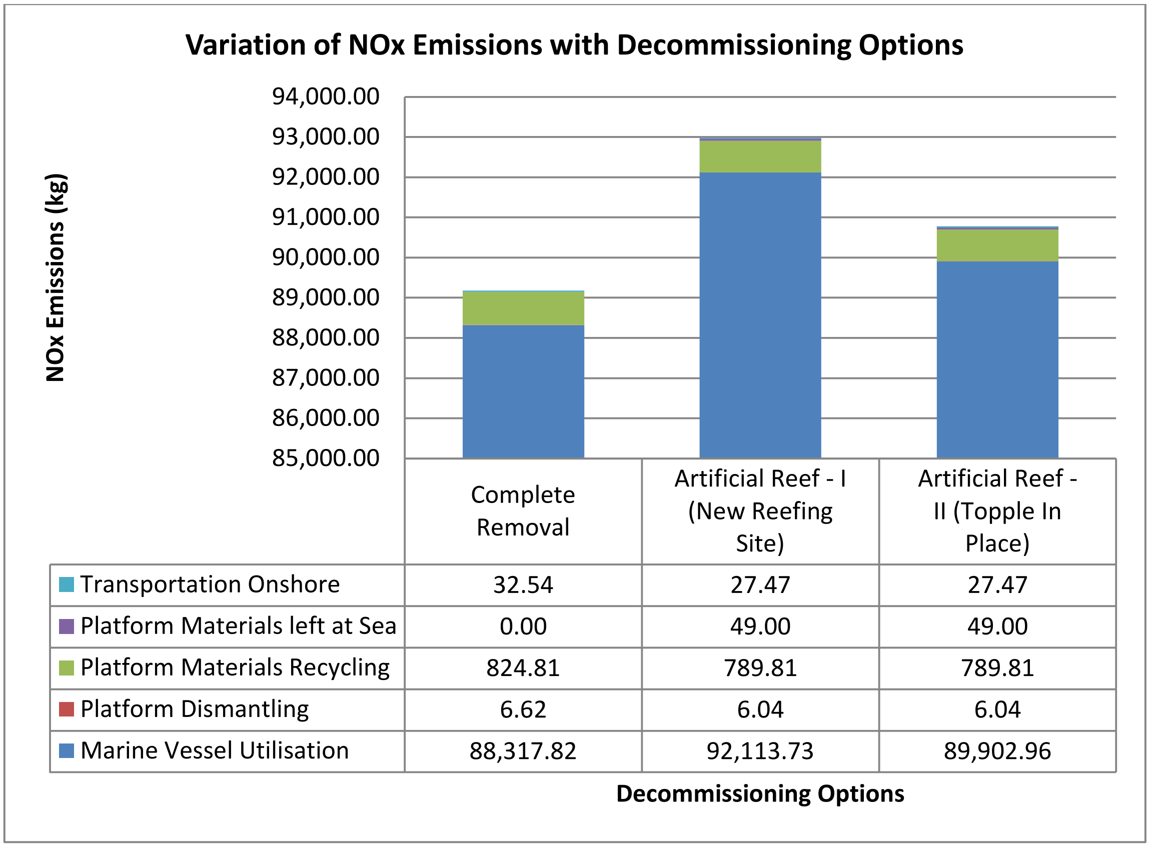
Figure 22: Energy consumption (GJ) of conversion to artificial reef by toppling in place depending on decommissioning activities for LDP-A

It is evident from the pie charts in the previous page that the decommissioning aspect on marine utilisation contributes the most total energy consumption from all three decommissioning options; complete removal (95%), artificial reef by towing to reef site (96%) and artificial reefing in place (96%). In addition, when the platform is to be opt for artificial reefing, unlike complete removal option, additional input may incur on fuel consumption for marine utilisation, scraping, dismantling and recycling activities as the topside is brought ashore.



	Complete Removal	Artificial Reef - I (New Reefing Site)	Artificial Reef - II (Topple In Place)
Transportation Onshore	28.05	23.68	23.68
Platform Materials left at Sea	0.00	175.00	0.00
Platform Materials Recycling	1,154.73	1,105.73	1,105.73
Platform Dismantling	0.00	0.00	0.00
Marine Vessel Utilisation	88,317.82	92,113.73	89,902.96

Figure 23: Breakdown of SO_2 emissions (kg) with respective decommissioning aspects/activities for complete removal, conversion to artificial reef (tow to reef site) and conversion to artificial reef (topple in place) of LDP-A



	Complete Removal	Artificial Reef - I (New Reefing Site)	Artificial Reef - II (Topple In Place)
Transportation Onshore	32.54	27.47	27.47
Platform Materials left at Sea	0.00	49.00	49.00
Platform Materials Recycling	824.81	789.81	789.81
Platform Dismantling	6.62	6.04	6.04
Marine Vessel Utilisation	88,317.82	92,113.73	89,902.96

Figure 24: Breakdown of NO_x emissions (kg) with respective decommissioning aspects/activities for complete removal, conversion to artificial reef (tow to reef site) and conversion to artificial reef (topple in place) of LDP-A

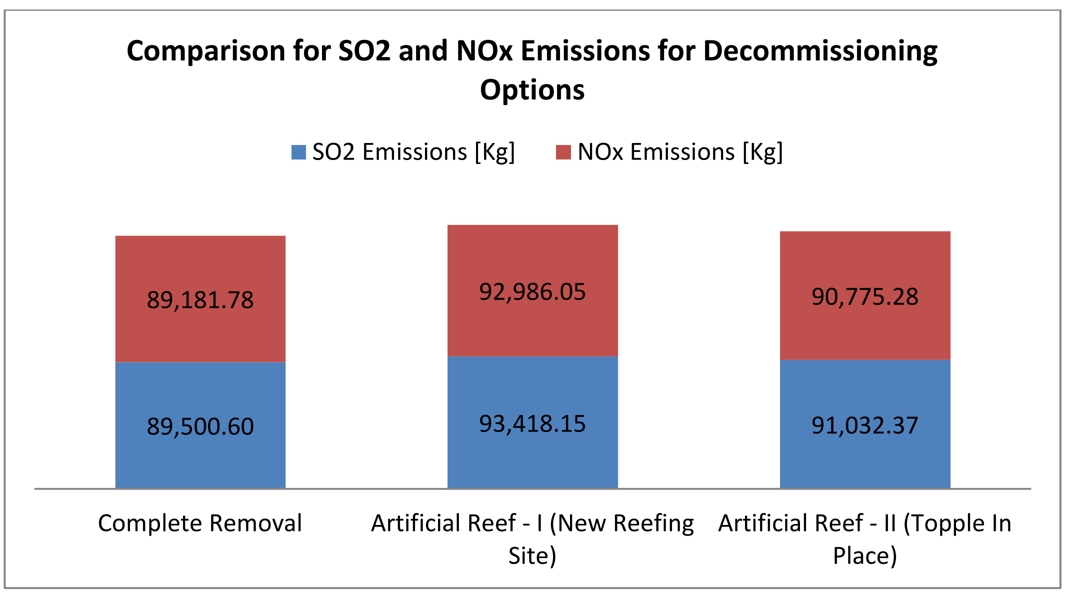


Figure 25: Comparison of SO_2 and NO_x emissions (kg) for complete removal, conversion to artificial reef (tow to reef site) and conversion to artificial reef (topple in place) of LDP-A

SO_2 and NO_x are acidic gases which are widely known as the main chemicals that generate acid rain once these substances rise high up in the air and react with water, oxygen and other chemicals. Acid rain brings harmful effects towards the ecosystem, disrupts building materials and human's health.

From the Figure 23, 24 and 25, towing platform to a reef site releases the most SO_2 and NOx gases overall with 93 418.15 kg, 4.19 % more than complete removal and 2.55 % more than reefing in-place, and 92 986.05 kg, 4.09 % more than complete removal and 2.38 % more than reefing in-place. The decommissioning aspect that contributes most to these emissions is marine vessel utilisation, followed by platform material recycling. The reason for marine vessel utilisation contribution to these gases is the greater usage of fuel for transportation offshore in transporting topside and other installations onshore for scrapping, removal and recycling purposes for complete removal and both artificial reef conversion options. On the other hand, the gaseous emissions produced for both artificial reef options are less than that of complete removal as the tonnage of structures brought ashore for scrapping and recycling are greater than that of both artificial reef options.

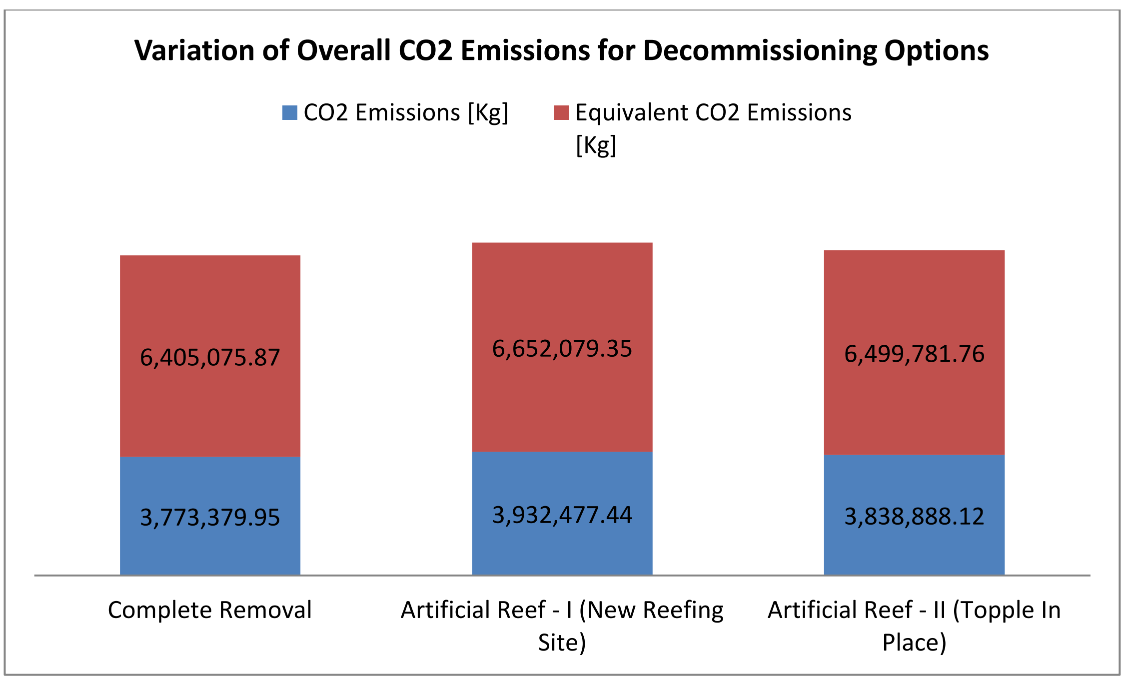
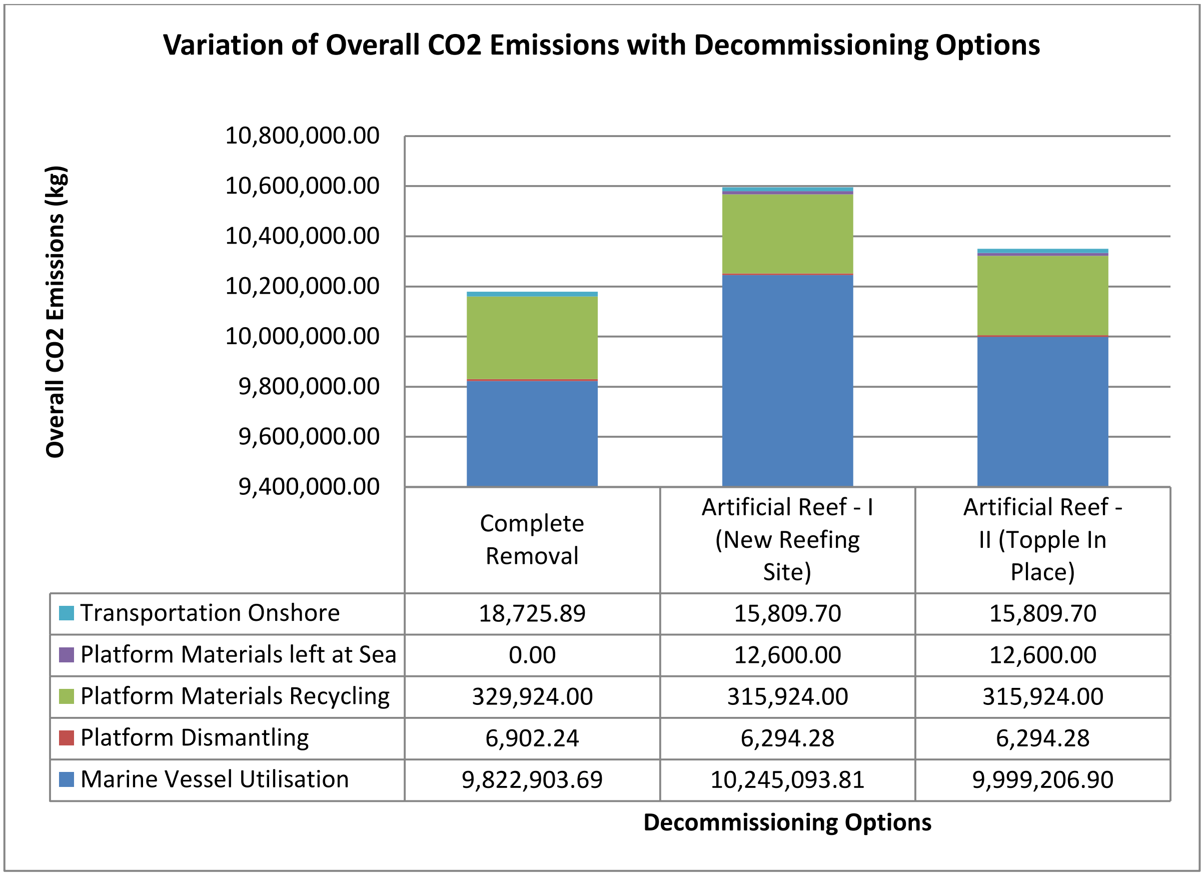


Figure 26: Comparison of overall CO_2 emissions (kg) for complete removal, conversion to artificial reef (tow to reef site) and conversion to artificial reef (topple in place) of LDP-A



	Complete Removal	Artificial Reef - I (New Reefing Site)	Artificial Reef - II (Topple In Place)
Transportation Onshore	18,725.89	15,809.70	15,809.70
Platform Materials left at Sea	0.00	12,600.00	12,600.00
Platform Materials Recycling	329,924.00	315,924.00	315,924.00
Platform Dismantling	6,902.24	6,294.28	6,294.28
Marine Vessel Utilisation	9,822,903.69	10,245,093.81	9,999,206.90

Figure 27: Breakdown of overall CO_2 emissions (kg) with respective decommissioning aspects/activities for complete removal, conversion to artificial reef (tow to reef site) and conversion to artificial reef (topple in place) of LDP-A

The CO_2 and Equivalent CO_2 are greenhouse gases that happen to be the main contributor towards global warming, causing rise in sea levels and climate change as a result of the dangerous heat waves. It is shown from Figure 26 and 27 that by converting the platform to artificial reef by towing it to a reef site, this option . The greater amount of the overall CO_2 emissions is due to the greater amount of fuel by the marine vessels used to transport sub-structure (boat landing) to reefing site and the topside and other offshore installations ashore for scrapping, dismantling and disposal.

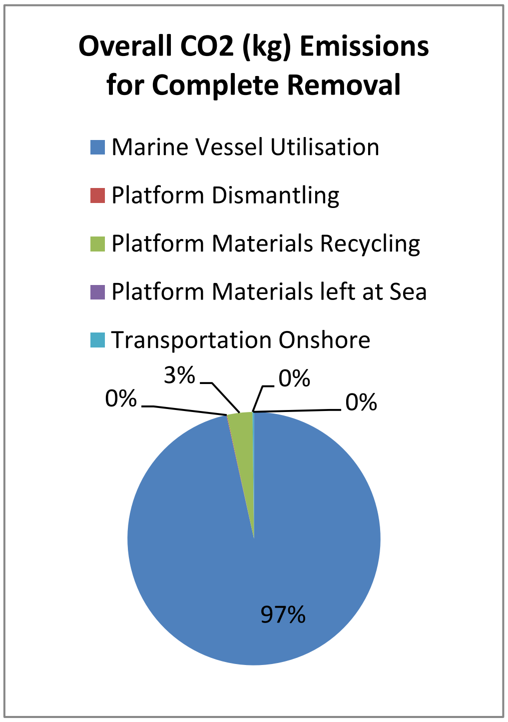


Figure 29: Overall CO_2 emissions (kg) of complete removal depending on decommissioning activities for LDP-A

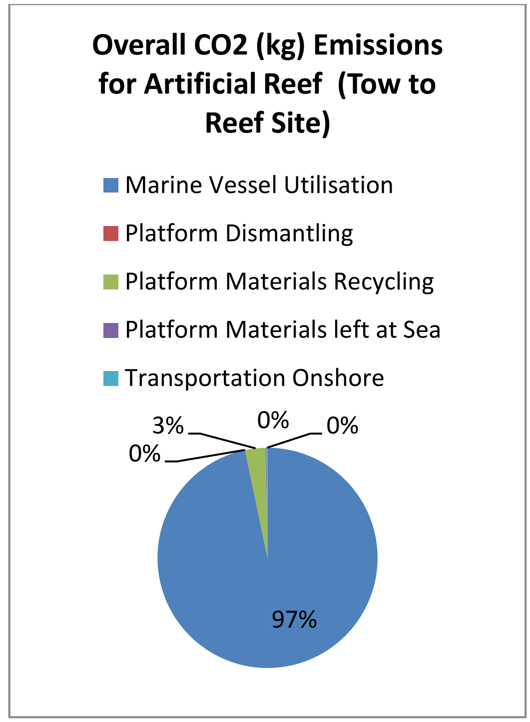


Figure 28: Overall of CO_2 emissions (kg) of conversion to artificial reef by towing to reef site depending on decommissioning activities for LDP-A

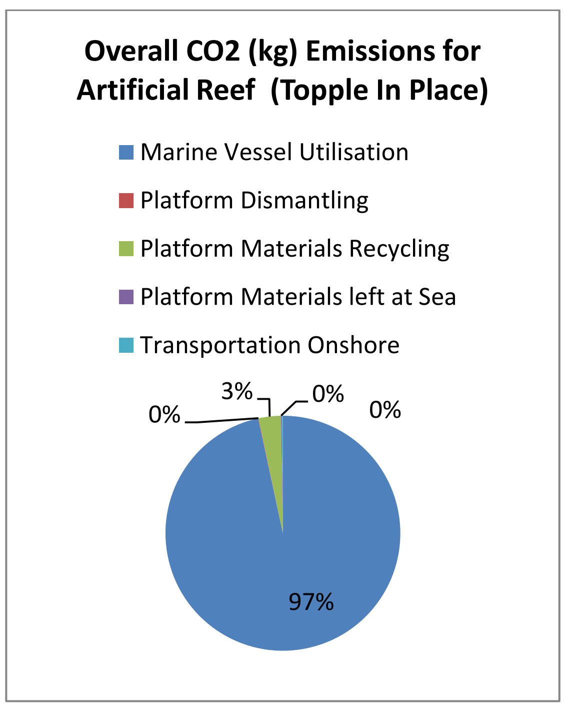


Figure 30: Overall CO_2 emissions (kg) of conversion to artificial reef by toppling in place depending on decommissioning activities for LDP-A

It is clear in Figure 28, 29 and 30 that the decommissioning aspect on marine vessel utilisation gives roughly the same amount of overall CO_2 emissions for all three decommissioning options with the percentage of 97% whereas the other 3% is released by platform materials recycling aspect for all three options as well. This may be caused by the scrapping, dismantling and disposal of steel activities including tonnage of steel, transportation onshore as well as offshore.

The results obtained from process-based LCA is clear that the decommissioning aspect of marine vessel utilisation contributes the most in consuming energy as well as releasing CO_2, NO_x and SO_2, followed by recycling of platform materials as well as the amount of steel production left at sea to convert to an artificial reef. Hence, it can be concluded at current that to plan a decommissioning beforehand, reducing the usage of marine vessels should be taken into account in order to minimise the environmental impacts of decommissioning offshore installations.

It can be seen as well that by converting the platform to an artificial reef by towing it to a reef site and reefing in place, more energy consumption and gaseous emissions will be produced as compared to removing it completely. Somehow this is unexpected because this option is acknowledged for its environmental friendly characteristics as it benefits the marine ecology. The contribution in higher energy consumption and gaseous emissions could be due to the great distance for certain type of vessels to move back and forth either to the platform site, artificial reef site, or to a port to be sent to a selected fabrication yard for onshore disposal purposes compared to complete removal. Surely the tonnage of steel for complete removal option is higher for materials recycling purposes; however it could not compensate the decommissioning aspects of the amount of steel being left at sea and marine vessel utilisation of artificial reefing.

In conclusion, the best decommissioning alternative for LDP-A platform is complete removal as it consumes less energy and releases less gaseous emissions.

4.1.2 EIO-LCA Method

By using the total removal cost of KTMP-A, the data applied for assumed complete removal of LDP-A is USD 14,991,473.91. Meanwhile for the conversion of artificial reef by towing to a reef site option cost is assumed as 35% of the estimated total removal cost of LDP-A as stated in LCA methodology. 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 8: Results of complete removal and artificial reefing by towing to reef site of LDP-A in terms of total energy consumption and gaseous emissions using EIO-LCA

Variable	**Standard Unit (1 million USD)**	**Complete Removal (14 million USD)**	**Conversion to Artificial Reef by Towing to Reef Site (5.25 million USD)**	**Difference [%]**
Total Energy Consumption [GJ]	7790	116,783.58	40,874.25	65
No_x Emmissions [kg]	6330	94,896.03	33,213.61	65
SO_2 Emissions [kg]	1890	28,333.89	9,916.86	65
Overall CO_2 Emissions [kg]	649000	9,729,466.57	3,405,313.30	65

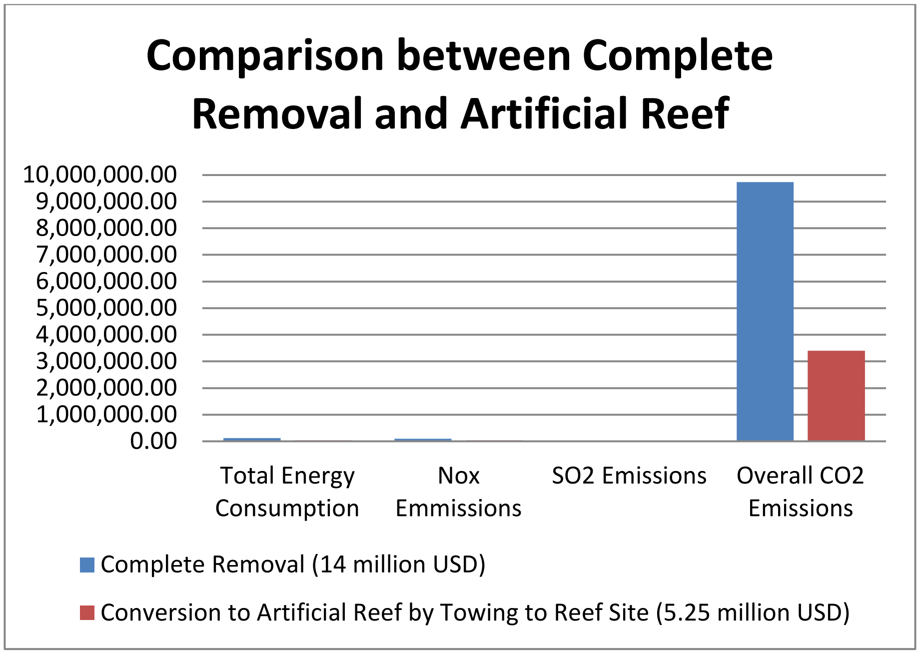


Figure 31: Comparison between total energy consumption and gaseous emissions with regards to LDP-A's decommissioning options

Based on the results obtained, complete removal produces 65% more for both energy consumption and gaseous release. In comparison to process-based LCA, EIO-LCA concludes that conversion to artificial reef option is more beneficial in terms of energy consumption and gaseous emission due to lower cost presumed based on the validated estimations which establish that artificial reefing is more cost-effective.

4.1.3 Comparison between Process-based LCA Method and EIO-LCA Method

Table 9: Percentage difference between the results of process-based LCA and EIO-LCA

Variable	Complete Removal (PB)	Complete Removal (EIO)	Artificial Reefing (PB)	Artificial Reefing (EIO)	Difference in Complete Removal for LDP-A [%]	Difference in Artificial Reefing for LDP-A [%]
Total Energy Consumption (GJ)	93,592.53	116,783.58	97,232.71	40,874.25	19.86	57.96
NOx Emissions (Kg)	89,181.78	94,896.03	92,986.05	33,213.61	6.02	64.28
SO2 Emissions (Kg)	89,500.60	28,333.89	93,418.15	9,916.86	68.34	89.38
Overall CO2 Emissions (Kg)	10,178,455.82	9,729,466.57	10,595,721.79	3,405,313.30	3.94	67.86

As shown in Table 11, the results to complete removal and artificial reefing vary with variance ranging between 3.94% to 68.34%, and 57.86% to 89.38% respectively. These variances are mostly due to each of the assumptions set for process-based- and EIO-LCA methods, as different input data is needed to perform both LCA methods. Estimated cost based on economic values of experiences retrieved by industrial surveys and published papers is input in for EIO-LCA whereas for process-based LCA, conversion constant factors and other particulars associated with the factors are applied.

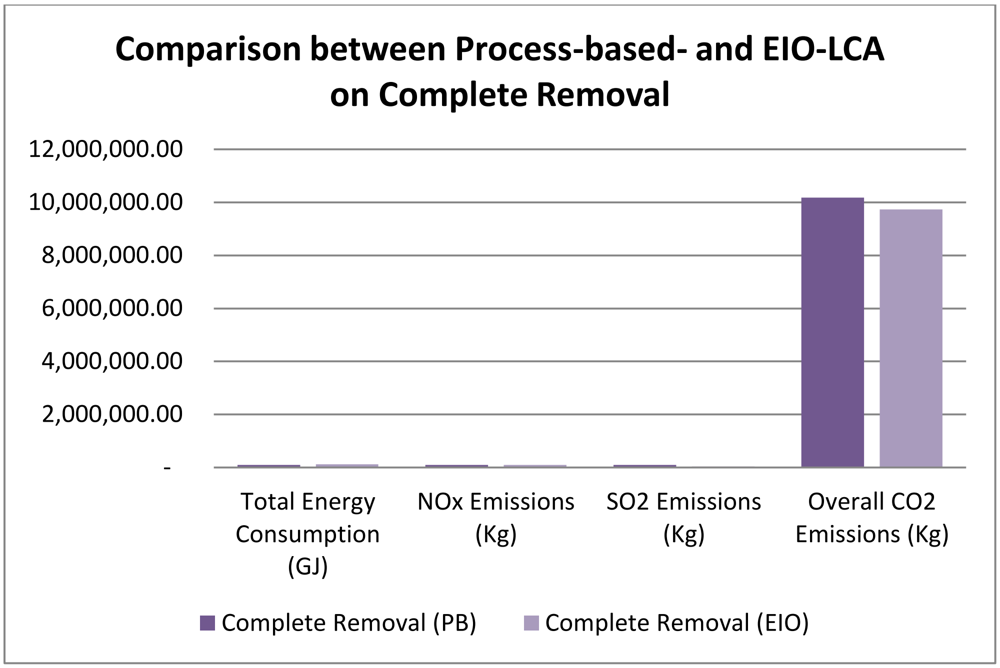


Figure 32: Comparison between process-based- and EIO-LCA methods on complete removal for LDP-A

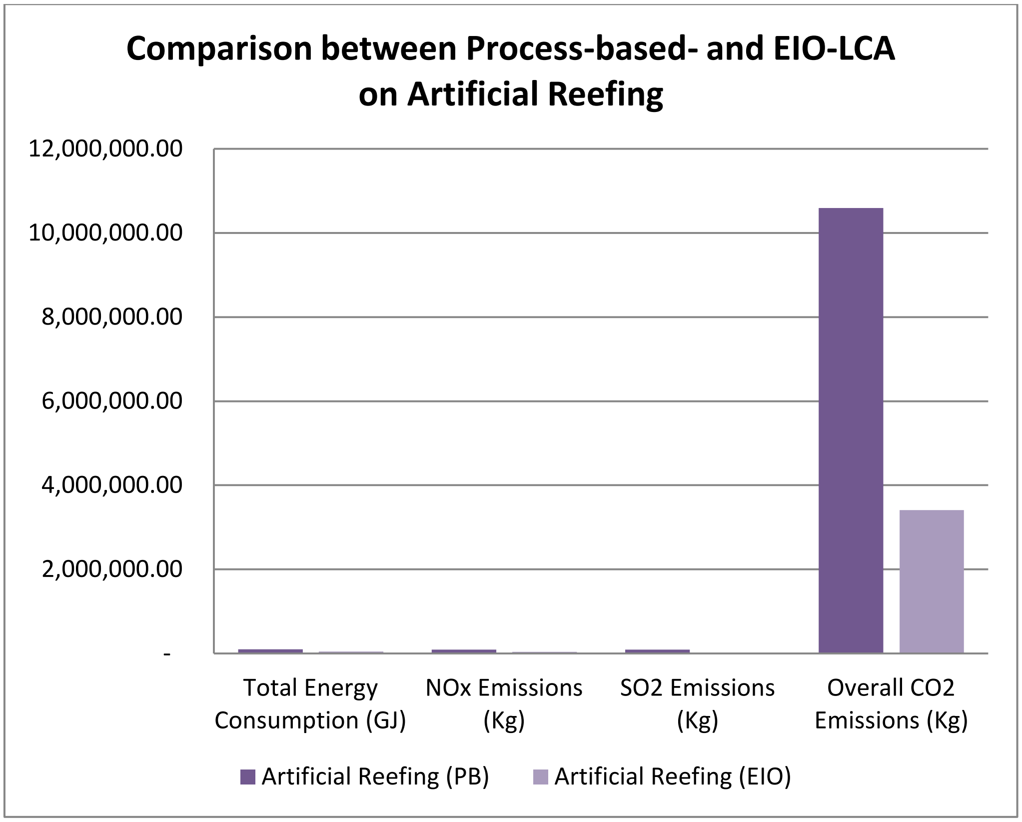


Figure 33: Comparison between process-based- and EIO-LCA methods on artificial reefing for LDP-A

Based on the illustration in Figures 34 and 35, it is apparent that the quantity of overall CO_2 emissions dominates the release of harmful gaseous compared to the other gaseous emissions for both decommissioning options despite the fact that there are huge gap of differences in the distribution for both LCA methods.

The detailed calculations on the percentage differences are attached in the Appendices.

4.1.4 Comparison between LDP-A Platform and SM-4 Platform

4.1.4.1 Comparison in Process-based Method between LDP-A and SM-4

Table 10: Results and percentage difference between complete removal option for LDP-A and SM-4

Variable	Complete Removal LDP-A	Complete Removal SM-4	Difference [unit]	Difference [%]
Energy Consumption [GJ]	97,380.00	37,105.26	60,274.74	61.90
SO_2 Emissions [kg]	90,506.68	36,408.59	54,098.09	59.77
NO_x Emissions [kg]	89,914.10	36,372.19	53,541.90	59.55
CO_2 Emissions [kg]	3,802,693.89	2,535,263.20	1,267,430.68	33.33
Equivalent CO_2 Emissions [kg]	6,676,009.38	1,539,530.83	5,136,478.55	76.94
Overall CO_2 Emissions [kg]	10,478,703.27	4,074,794.03	6,403,909.24	61.11

Table 11: Results and percentage difference between artificial reef option for LDP-A and SM-4

Variable	Artificial Reef LDP-A	Artificial Reef SM-4	Difference [unit]	Difference [%]
Energy Consumption [GJ]	97,232.71	37,542.79	59,689.93	61.39
SO2 Emissions [kg]	93,418.15	36,738.03	56,680.11	60.67
NOx Emissions [kg]	92,986.05	36,711.14	56,274.91	60.52
CO2 Emissions [kg]	3,932,477.44	2,578,800.81	1,353,676.64	34.42
Equivalent CO2 Emissions [kg]	6,652,079.35	1,553,928.56	5,098,150.79	76.64
Overall CO2 Emissions [kg]	10,595,721.79	4,132,729.36	6,462,992.43	61.00

Based on the compilation of results of total energy consumption and gaseous emissions on complete removal and artificial reef conversion for both LDP-A and SM-4 platforms presented in Table 10 as well as Table 1, 58.8% and 59.1% are the average percentage differences for the overall total for complete removal and artificial reefing options respectively. Both the average differences reach half of the overall percentage total energy consumption and gaseous emissions due to the massive structural differences in terms of sizing, tonnage of installation, water depth and location from shore even though both platforms are within the Malaysian waters. Moreover, it should be taken into account that the quantity and types of vessels and cranes with difference in capacity, the types and quantity of necessary equipments, the amount of personnel handling decommissioning activities depending on the size of platform, and the planned method to decommission differs.

In addition, LDP-A is of tarpon monopod platform, whereby it has an addition of 3-guyed wire caissons compared to SM-4 platform which is of a single pile leg platform. For more similarities in properties, please refer to Table 3 and 4. Even though the water depth, type of structural installations, distance of platforms to reef sites and vessel embarkation point as well as the location of the fabrication yard nearby for removal activities, requirements and challenges of each decommissioning option, and assumptions to conduct calculation for process-based LCA varies, the trend of the energy consumed and gases emitted are still comparable mainly because of the similarities in specifications for both platforms and the cutting method assumed as well.

4.1.4.2 Comparison in EIO-LCA Method between LDP-A and SM-4

Table 12: Results and percentage difference between complete removal option for LDP-A and SM-4

Variable	Complete Removal LDP-A	Complete Removal SM-4	Difference [unit]	Difference [%]
Energy Consumption [GJ]	116,783.58	69,022.41	47,761.17	40.90
SO_2 Emissions [kg]	94,896.03	56,086.24	38,809.79	40.90
NO_x Emissions [kg]	28,333.89	16,746.13	11,587.76	40.90
CO_2 Emissions [kg]	9,729,466.57	5,759,250.99	3,970,215.58	40.81

Table 13: Results and percentage difference between artificial reef option for LDP-A and SM-4

Variable	Artificial Reefing LDP-A	Artificial Reefing SM-4	Difference [unit]	Difference [%]
Energy Consumption [GJ]	40,874.25	24,157.84	16,716.41	40.90
SO_2 Emissions [kg]	33,213.61	19,630.19	13,583.42	40.90
NO_x Emissions [kg]	9,916.86	5,861.15	4,055.71	40.90
CO_2 Emissions [kg]	3,405,313.30	2,015,737.85	1,389,575.45	40.81

The outcome of the results gained from Table 14 and 15 shows that the percentage differences for both options for both platforms are similar for each decommissioning variable contributing to environmental impacts. This could be due to the similarities in assumptions done on artificial reefing to be 35% of complete removal cost for both platforms.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research paper addresses the pressing issue of environmental impacts of decommissioning offshore installations of different options; complete removal, artificial reef conversion by towing to reef site, and artificial reef conversion by toppling in place, with the aid of LCA tools; process-based method and EIO method.

A platform, LDP-A has been opted as case study to perform comparative analysis with another previous case study on SM-4 by using LCA, in order to differentiate the parameters to total energy consumed and harmful gases (CO_2, SO_2 and NO_x) released to the environment during decommissioning works with regards to the decommissioning aspects studied upon, in order to choose the best decommissioning option. LDP-A is chosen mainly due to its similarities in specifications although there is an inherent big gap in tonnage difference.

Based on the results gained for process-based LCA method, it is found that the decommissioning marine vessel utilisation is the main culprit in all the parameters concerned. Therefore, mitigation measures to this issue have been suggested such as reducing the fuel consumption, travel distances such as finding alternative routes to an aimed location (e.g. artificial reef site, port, and fabrication yard), reduce the number of vessels and narrow down to only the sufficient ones and make sure they are in ideal condition. The results also show that complete removal option gives out less harmful gases and consumes less energy.

In contrast with the results gained for process-based LCA, the outcome to using EIO-LCA method has shown that complete removal results in a greater environmental impact in terms of energy consumption and harmful gaseous emissions. This is because of the validated estimations which establish that artificial reefing is more cost-effective.

Else than that, the results tabulated and illustrated from both LCA methods show a similar pattern for both platforms compared despite the fact that the data input and function of tools differ. Even though the LCA tools are able to evaluate environmental impacts, but each method relies on the availability of data to proceed with respective analysis. Thus, due to the limitations of data accessibility plus lack of examples and experiences of decommissioning offshore installations in Malaysia, it is not possible to sum up a strong conclusion despite the similarities found applicable to estimate environmental impacts for future decommissioning offshore platform projects by simple use of local unit rate.

In conclusion, this study is vital as the results from the life-cycle analysis will narrow down which decommissioning option that contributes less harm to the environment. It offers stakeholders the opportunity to prepare and manage decommissioning plan well for the environment criteria in the long run.

5.2 Recommendations

5.2.1 Recommendations on Decommissioning Offshore Installations

One of the ways to reduce environmental impacts caused by decommissioning offshore installations would be the planning and managing a decommissioning project stages especially during the critical early stage of planning. Every aspect of the planning stage should be done in detail and in a proper manner and should abide by the rules and regulations of decommissioning offshore platform, which not only comprise to reducing the environmental impacts but to reducing the cost, safety risks and future liabilities as well. Should there be any alternatives raised in planning stage regarding any relevant issues (e.g. technical, health and safety, environment, society, cost), do not ignore in order to adapt to lateral thinking, current legislations and existing technology. For instance, based on the results obtained by process-based LCA it is apparent that marine vessel utilisation is the major role to increasing environmental impacts in decommissioning offshore platforms, the operators and management team should manage and plan the necessary amount, types, capacity, alongside with the usage of marine vessels properly beforehand. Besides that, they should be aware of the weather forecast reports either before planning the operation duration or during the operation activities are being conducted and it must be ensured that the personnel are experienced, efficient and well-equipped in handling restraining activities during decommissioning as well. It is also advised that the marine vessels to be used in decommissioning projects to be in tip-top condition and well-maintained for vessel performance efficiency.

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. It is suggested that a project specific risk assessment be undertaken for a preferred option to make sure that all potential risks are identified and preventive measures can be put in place. The operation team may study and refer to the projects that have been decommissioned not only throughout Malaysia but throughout the whole world too to obtain relevant ideas and data necessary.

During post-decommissioning stage for rigs-to-reef, it is advised that inspections shall be done continuously once in a while to study on the after-effects of reefing for the aquatic lives and their surroundings, for future analysis and references of artificial reefing option.

5.2.2 Recommendations for Life Cycle Analysis

In order for the results to be verified impeccably, there must be adequate data to proceed in accomplishing LCA. Insufficient data and information of either one of the platforms for the study will meddle with the number of parameters that can be assessed for comparison. Even though there will be difficulties in obtaining complete set of data, it is still advisable to attain as much data inputs as possible to increase the precision, accuracy and the feasibility to conduct LCA.

Besides that, it is recommended to obtain platforms data of the same region, water depth and profile. For example, obtaining data of any fixed offshore platforms which seat roughly at similar depths of water (e.g. shallow water) in South China Sea. It also helps in the accuracy and reliability for LCA.

Furthermore, be sure to be consistent and apparent in setting assumptions as this may cause carry-forward error because process-based LCA method is a lengthy and linked process. Once a slight mistake or error is made in any aspects of calculations, the whole results will be invalid.

5.2.3 Recommendations for Future Research

The results of this research paper could be set as a benchmark for future environmental impacts linked with offshore decommissioning in Malaysia by using LCA. It is said so because the paper done focuses on comparative analysis of three decommissioning options between two platforms with regards to their similarities in structural properties and specifications, parameters and location. Hence, this can be beneficial for projects of the similar situations in choosing a better option in terms of environmental. Moreover, the findings for this research paper could be a starting point into finding more capable and adequate methods as new technologies and decommissioning methods arises in time.

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APPENDICES

(PROCESS-BASED LCA METHOD)

APPENDIX A: UNIT CONVERSION FACTORS AND 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

Aspects	Related Parameters
Transportation Offshore of Different Types of Marine Utilisation	Travel Distance (km or miles)
	Period of Usage (days)
	Fuel Consumption (litre/day)
Transportation Onshore	Travel Distance (km or miles)
	Period of Usage (days)
	Fuel Consumption (litre/day)
Dismantling of Platform Installations:	
a) Topside Dismantling Offshore [tonnes]	Structural Steel
	Timber
	Miscellaneous Materials
b) Topside Dismantling Onshore [tonnes]	Structural Steel
	Timber
	Miscellaneous Materials
c) Jacket Dismantling Offshore [tonnes]	Structural Steel
	Marine Growth
d) Jacket Dismantling Onshore [tonnes]	Structural Steel
	Marine Growth
e) Boat Landing Dismantling Offshore [tonnes]	Structural Steel
	Marine Growth
f) Boat Landing Dismantling Onshore [tonnes]	Structural Steel
	Marine Growth
g) Conductors, Caissons and Pile Dismantling Offshore [tonnes]	Steel
h) Conductors, Caissons and Pile Dismantling Onshore [tonnes]	Steel
Total Dismantling [tonnes]	Total Steel
	Timber
	Marine Growth
	Miscellanous Materials
Platform Materials left at Sea [tonnes]	Jacket
	Boat Landing
	Marine Growth
	Mudmat
Onshore Disposal of Platform Materials [tonnes]	Timber
	Marine Growth
	Miscellaneous materials
Recycling of Platform Materials Onshore [tonnes]	Steel

Cutting Method	Oxy-Acetylene Cutting
	Abrasive Water Jet Cutting
	Diamond Wire Cutting

APPENDIX C: HAULAGE CONSTANTS AND FACTORS

Haulage Constants and Factors	Values
Onshore Haulage Roundtrip Distance	
Pasir Gudang Port (Johor) to Fabrication Yard (Dismantling Site) [miles]	6.2758471
Fabrication Yard (Dismantling Site) to Scrap Dealer [miles]	23.9227835
Fabrication Yard (Dismantling Site) to Landfill for Disposal (Johor Bahru) [miles]	33.554034
Onshore Haulage Factors	
Average truck load [tonne]	20
Average truck fuel consumption [litre/mile]	1.8
Average truck fuel weight [tonne/litre]	0.00085
Additional percentage fuel consumption allowance for loading and offloading [%]	10
Offshore Roundtrip Distance	
Terengganu Port to Platform Site [miles]	124.2742
Platform Site to Artificial Reef Site [miles]	142.91533
Platform Site to Pasir Gudang Port (Johor) [miles]	267.18953
Pasir Gudang Port (Johor) to Terengganu Port [miles]	279.61695
Artificial Reef Site to Terengganu Port [miles]	130.48791
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
Empoline Corporation Sdn. Bhd.
No. 11 Jln Bukit Kempas 4/1,
Taman Bukit Kempas,

81200 Johor Bahru, Malaysia.

Landfill
Seelong Sanitary Landfill
Jalan Seelong,

81300 Johor Bahru,
Johor, Malaysia

Terengganu Port
Kemaman Supply Base (KSB) Sdn. Bhd.
Pangkalan Bekalan Kemaman Sdn. Bhd.,
24007 Kampong Kemaman,
Terengganu, Malaysia.

1 km =	0.62137	miles

	Route (km)
Distance between Pasir Gudang Port (Johor) to Sime Sembcorp Engineering	10.1
Distance between Sime Sembcorp Engineering to Scrap Dealer	38.5
Distance between Sime Sembcorp Engineering to Seelong Landfill	54
Distance between Terengganu Port to Platform Site	200
Distance between Platform Site to Artificial Reef Site	230
Distance between Platform Site to Pasir Gudang Port (Johor)	430
Distance between Pasir Gudang Port (Johor) to Terengganu Port	450
Distance between Artificial Reef Site to Terengganu Port	210

*Note: Option 1 for dismantling site/fabrication yard is chosen - Sime Sembcorp Engineering Sdn. Bhd.

APPENDIX D: UNIT CONVERSION FACTORS (DISMANTLING)

Unit Conversion Factors (Dismantling)	Propane Consumption [kg/tonne]	Diesel Consumption [litre/tonne]
Topsides Piecesmall Dismantling Offshore		
Structural steel	2.4	14.5
Timber	0	14.5
Pipework	2.4	14.5
Equipment	0.6	14.5
Miscellanceous materials	0	14.5
Topsides Modular Dismantling Onshore		
Structural steel	2.4	11
Timber	0	11
Pipework	2.4	11
Equipment	0.6	11
Miscellanceous materials	0	11
Jacket Dismantling Offshore		
Steel	2.4	11
Marine Growth	0	11
Boat Landing Dismantling Offshore		
Steel	2.4	11
Conductor Dismantling Offshore		
Steel	2.4	11
Cement Grout	0	11
Caisson Dismantling		
Steel	2.4	11
Pile Dismantling		
Steel	2.4	11
Removal of Marine Growth Onshore	0	11

APPENDIX E: AVERAGE DAILY FUEL CONSUMPTION OF MARINE VESSELS [tonne marine diesel oil/day]

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

APPENDIX F: CALCULATION ON MARINE VESSEL UTILISATION

Fuel Consumption [tonnes marine diesel]

15 Days Decommissioning Process
3.5 Days to Port Johor

			in Port			in Transit			Working			Waiting on Weather (W.O.W)			
Type of Vessel	**No.**	**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 (WB)	1	20	0	2	0	2	10	20	15	10	150	0	10	0	170
Anchor Handling Tug (WB)	2	17	13.5	2	27	3.5	10	35	3.5	10	35	0	10	0	194
Dumb Barge (DB)	1	23.5	1	2	2	7.5	15	112.5	15	15	225	0	15	0	339.5
Anchor Handling Tug (DB)	2	23.5	13.5	2	27	9	10	90	9	10	90	0	10	0	414
Support Vessel	1	16.5	0	2	0	1.5	20	30	15	25	375	0	25	0	405
Supply Boat	1	15	0	2	0	15	10	150	0	5	0	0	5	0	150
													Total Fuel Consumption [t]		**1672.5**

Type of Vessel	**No.**	**Average vessel Fuel Consumption [t/mile]**	**Kemaman Supply Base (Terengganu) to Platform Site (A) [miles]**	**Platform Site to Pasir Gudang Port Johor (B) [miles]**	**Port Johor to Port Kemaman Supply Base (C) [miles]**	**Number of Trips for A**	**Number of Trips for B**	**Number of Trips for C**	**Travel Distance [miles]**	**Fuel Consumption [t]**
Workbarge (WB)	1	0.035	124.2742	267.18953	279.61695	2	0	0	248.5484	8.699194
Anchor Handling Tug (WB)	2	0.035	124.2742	267.18953	279.61695	4	0	1	776.7137 5	54.3699625
Dumb Barge (DB)	1	0.035	124.2742	267.18953	279.61695	1	1	1	671.0806 8	23.4878238
Anchor Handling Tug (DB)	2	0.035	124.2742	267.18953	279.61695	3	1	1	919.6290 8	64.3740356
Support Vessel	1	0.035	124.2742	267.18953	279.61695	2	0	0	248.5484	8.699194
Supply Boat	1	0.035	124.2742	267.18953	279.61695	30	0	0	3728.226	130.48791
								Total Fuel Consumption [t]		**290.12**

ARTIFICIAL REEF (NEW REEF SITE) - (I)

Fuel Consumtion [tonnes marine diesel]

3.5 days from Platform Site to Artificial Reef Site (Near Redang Island)

			in Port			in Transit			Working			Waiting on Weather (W.O.W)			
Type of Vessel	**No.**	**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 (WB)	1	22	0	2	0	3	10	30	16	10	160	0	10	0	190
Anchor Handling Tug (WB)	2	19	13.5	2	27	4.5	10	45	4.5	10	45	0	10	0	234
Dumb Barge (DB)	1	23.5	1	2	2	7.5	15	112.5	15	15	225	0	15	0	339.5
Anchor Handling Tug (DB)	2	23.5	13.5	2	27	9	10	90	9	10	90	0	10	0	414
Support Vessel	1	16.5	0	2	0	1.5	20	30	15	25	375	0	25	0	405
Supply Boat	1	17	0	2	0	16	10	160	0	5	0	0	5	0	160
													Total Fuel Consumption [t]		**1742.5**

Type of Vessel	**No.**	**Average Vessel Fuel Consumption [t/mile]**	**Kemaman Supply Base (Terengganu) to Platform Site (A) [miles]**	**Platform Site to Pasir Gudang Port Johor (B) [miles]**	**Port Johor to Port Kemaman Supply Base (C) [miles]**	**Platform Site to Artificial Reef Site (D) [miles]**	**Artificial Reef Site to Kemaman Supply Base (E) [miles]**	**Number of Trips for A**	**Number of Trips for B**	**Number of Trips for C**	**Number of Trips for D**	**Number of Trips for E**	**Travel Distance [miles]**	**Fuel Consumption [t]**
Workbarge (WB)	1	0.035	124.2742	267.18953	279.61695	142.91533	130.48791	1	0	0	1	1	397.68	13.92
Anchor Handling Tug (WB)	2	0.035	124.2742	267.18953	279.61695	142.91533	130.48791	3	0	0	1	1	646.23	45.24
Dumb Barge (DB)	1	0.035	124.2742	267.18953	279.61695	142.91533	130.48791	1	1	1	0	0	671.08	23.49
Anchor Handling Tug (DB)	2	0.035	124.2742	267.18953	279.61695	142.91533	130.48791	3	1	1	0	0	919.63	64.37
Support Vessel	1	0.035	124.2742	267.18953	279.61695	142.91533	130.48791	2	0	0	0	0	248.55	8.70
Supply Boat	1	0.035	124.2742	267.18953	279.61695	142.91533	130.48791	32	0	0	1	1	4250.18	148.76
												Total Fuel Consumption [t]		**304.47**

ARTIFICIAL REEF (TOPPLE IN-PLACE) - (II)

Fuel Consumption [tonnes marine diesel]

Platform Site = Artificial Reef Site

			in Port			in Transit			Working			Waiting on Weather (W.O.W)			
Type of Vessel	**No.**	**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 (WB)	1	21	0	2	0	2	10	20	16	10	160	0	10	0	180
Anchor Handling Tug (WB)	2	18	13.5	2	27	3.5	10	35	3.5	10	35	0	10	0	194
Dumb Barge (DB)	1	23.5	1	2	2	7.5	15	112.5	15	15	225	0	15	0	339.5
Anchor Handling Tug (DB)	2	23.5	13.5	2	27	9	10	90	9	10	90	0	10	0	414
Support Vessel	1	16.5	0	2	0	1.5	20	30	15	25	375	0	25	0	405
Supply Boat	1	17	0	2	0	16	10	160	0	5	0	0	5	0	160
													Total Fuel Consumption [t]		**1692.5**

Type of Vessel	**Number**	**Average Vessel Fuel Consumption [t/mile]**	**Kemaman Supply Base (Terengganu) to Platform Site (A) [miles]**	**Platform Site to Pasir Gudang Port Johor (B) [miles]**	**Port Johor to Port Kemaman Supply Base (C) [miles]**	**Platform Site = Artificial Reef Site (D) [miles]**	**Artificial Reef Site to Kemaman Supply Base (E) [miles]**	**Number of Trips for A**	**Number of Trips for B**	**Number of Trips for C**	**Number of Trips for D**	**Number of Trips for E**	**Travel Distance [miles]**	**Fuel Consumption [t]**
Workbarge (WB)	1	0.035	124.2742	267.18953	279.61695	0	279.63	1	0	0	1	1	403.90	14.14
Anchor Handling Tug (WB)	2	0.035	124.2742	267.18953	279.61695	0	279.63	3	0	0	1	1	652.45	45.67
Dumb Barge (DB)	1	0.035	124.2742	267.18953	279.61695	0	279.63	1	1	1	0	0	671.08	23.49
Anchor Handling Tug (DB)	2	0.035	124.2742	267.18953	279.61695	0	279.63	3	1	1	0	0	919.63	64.37
Support Vessel	1	0.035	124.2742	267.18953	279.61695	0	279.63	2	0	0	0	0	248.55	8.70
Supply Boat	1	0.035	124.2742	267.18953	279.61695	0	279.63	32	0	0	1	1	4256.40	148.97
												Total Fuel Consumption [t]		**305.34**

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]	Decommissioning Option
1962.62	89,102.86	88,317.82	88,317.82	3,738,787.52	6,084,116.17	9,822,903.69	**Complete Removal**
2046.97	92,932.52	92,113.73	92,113.73	3,899,481.26	6,345,612.55	10,245,093.81	**Artificial Reef (I)**
1997.84	90,702.10	89,902.96	89,902.96	3,805,891.94	6,193,314.96	9,999,206.90	**Artificial Reef (II)**

Difference between CR & AR (I):							
84.35	3,829.66	3,795.92	3,795.92	160,693.74	261,496.38	422,190.12	**Difference [unit]**
4.12	4.12	4.12	4.12	4.12	4.12	4.12	**Difference[%]**
Difference between CR & AR (II):							
35.23	1,599.23	1,585.14	1,585.14	67,104.42	109,198.79	176,303.21	**Difference [unit]**
1.76	1.76	1.76	1.76	1.76	1.76	1.76	**Difference[%]**
Difference between AR (I) & AR (II):							
49.13	2,230.42	2,210.77	2,210.77	93,589.32	152,297.59	245,886.91	**Difference [unit]**
2.40	2.40	2.40	2.40	2.40	2.40	2.40	**Difference[%]**

COMPARISON LDP-A & SM-4 (COMPLETE REMOVAL)

Decommissioning Option	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]
Complete Removal LEDP-A	89,102.86	88,317.82	88,317.82	3,738,787.52	6,084,116.17	9,822,903.69
Complete Removal SM-4	53,720.96	53,247.65	53,247.65	3,668,171.26	2,254,150.40	5,922,321.66
Difference [unit]	35,381.90	35,070.17	35,070.17	70,616.26	3,829,965.77	3,900,582.03
Difference[%]	39.71	39.71	39.71	1.89	62.95	39.71

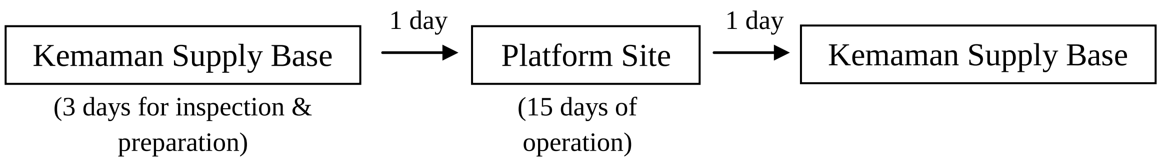
COMPARISON LDP-A & SM-4 (ARTIFICIAL REEF - I)

Decommissioning Option	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]
Artificial Reef LEDP-A	92,932.52	92,113.73	92,113.73	3,899,481.26	6,345,612.55	10,245,093.81
Artificial Reef SM-4	57,256.98	56,752.51	56,752.51	3,909,617.39	2,402,522.94	6,312,140.33
Difference [unit]	35,675.54	35,361.22	35,361.22	-10,136.13	3,943,089.60	3,932,953.47
Difference[%]	38.39	38.39	38.39	-0.26	62.14	38.39

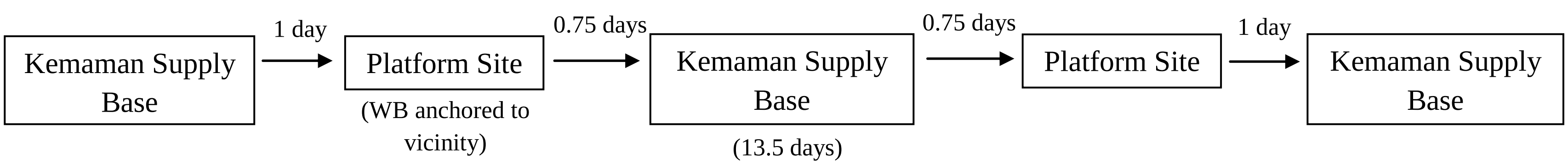
APPENDIX G: TYPES OF VESSELS - PERIOD OF USAGE, ACTIVITIES AND LOCATIONS WITH RESPECT TO THE USAGE

A. COMPLETE REMOVAL

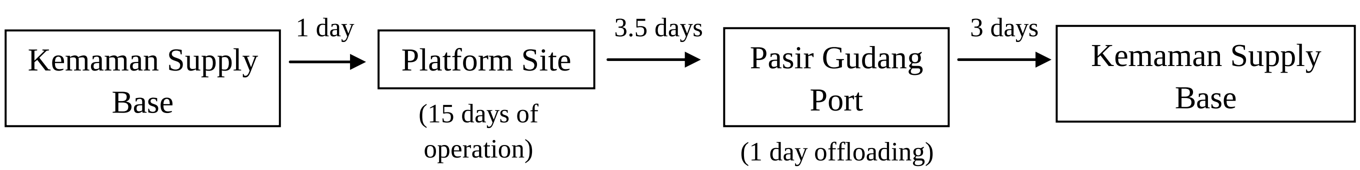
1. Workbarge (WB)



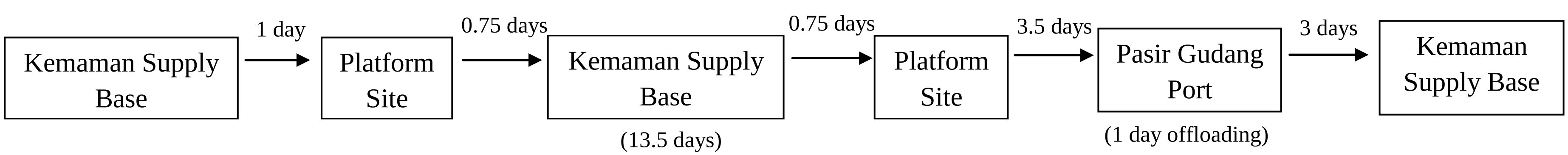
2. 2 AHTs to assist Workbarge



3. Dumb Barge (DB)



4. 2 AHTs to assist Dumb Barge

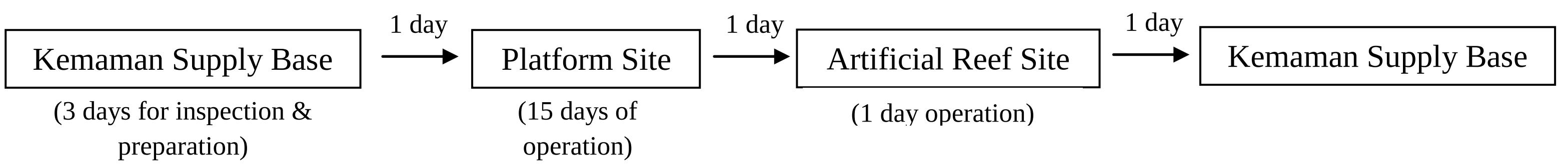


5. Supply Boat

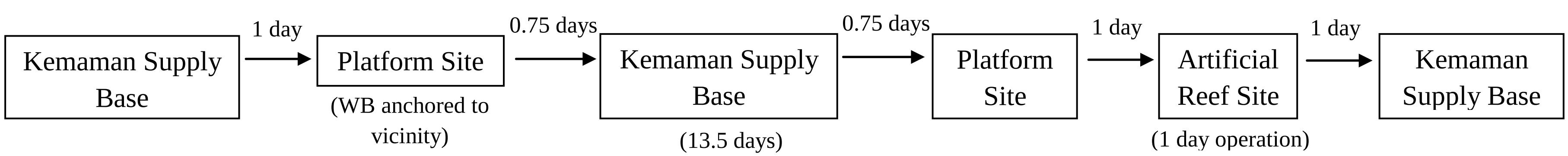
6. Support Vessel

B. ARTIFICIAL REEF (TO NEW REEFING SITE NEAR REDANG ISLAND)

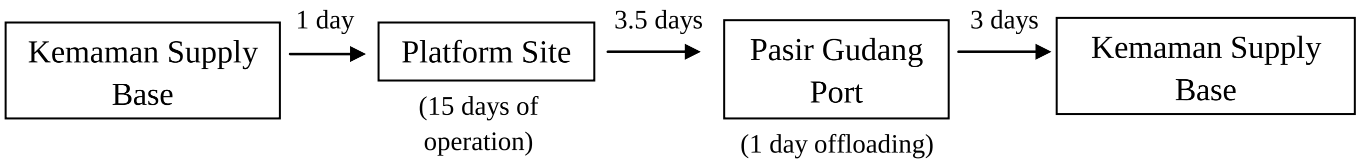
1. Workbarge (WB)



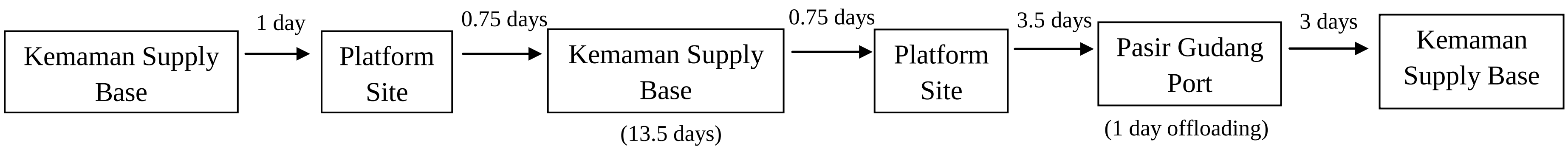
2. 2 AHTs to assist Workbarge



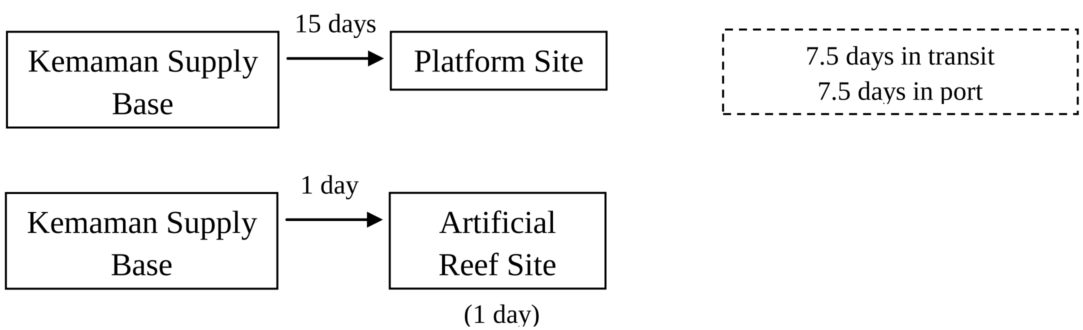
3. Dumb Barge (DB)



4. 2 AHTs to assist Dumb Barge



5. Supply Boat



6. Support Vessel

C. ARTIFICIAL REEF (TOPPLE IN PLACE)

1. Workbarge (WB)

Kemaman Supply Base (3 days for inspection & preparation) → 1 day → Platform Site (15 days of operation) → = → Artificial Reef Site (Topple at site - 1 day operation) → 1 day → Kemaman Supply Base

2. 2 AHTs to assist Workbarge

Kemaman Supply Base → 1 day → Platform Site (WB anchored to vicinity) → 0.75 days → Kemaman Supply Base (13.5 days) → 0.75 days → Platform Site → = → Artificial Reef Site (1 day operation) → 1 day → Kemaman Supply Base

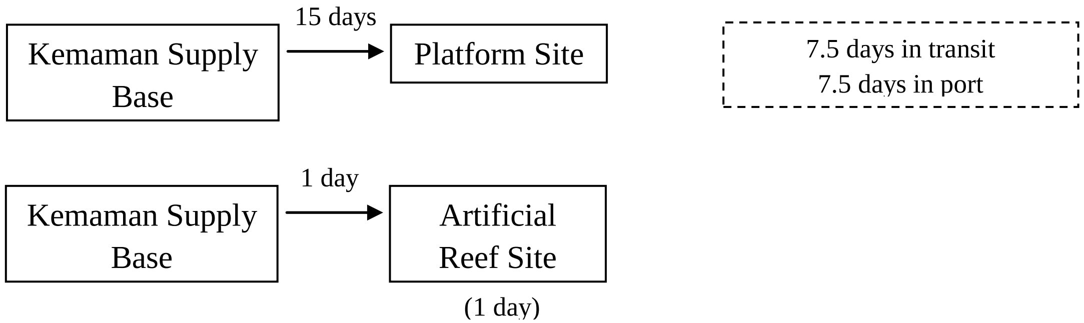
3. Dumb Barge (DB)

Kemaman Supply Base → 1 day → Platform Site (15 days of operation) → 3.5 days → Pasir Gudang Port (1 day offloading) → 3 days → Kemaman Supply Base

4. 2 AHTs to assist Dumb Barge

Kemaman Supply Base → 1 day → Platform Site → 0.75 days → Kemaman Supply Base (13.5 days) → 0.75 days → Platform Site → 3.5 days → Pasir Gudang Port (1 day offloading) → 3 days → Kemaman Supply Base

5. Supply Boat



6. Support Vessel

APPENDIX H: CALCULATION ON PLATFORM DISMANTLING

COMPLETE REMOVAL

A. Offshore

Component	Material	Weight [t]	Cutting Method	Propane Consumption [kg/t]	Propane Consumption [kg]
Topside	Steel	200.00	Abrasive Water Jet Cutting	2.40	480.00
	Miscellaneous	94.90	Others	0	0.00
Jacket	Steel	800.00	Diamond Wire Cutting	2.40	1920.00
Conductor	Steel	244.18	Diamond Wire Cutting	2.40	586.03
Caissons	Steel	290.19	Diamond Wire Cutting	2.40	696.46
Boat Landing	Steel	35.00	Oxy-Acetylene Cutting	2.40	84.00
Guyed Wire + Pile	Steel	150.34	Oxy-Acetylene Cutting	2.40	360.82

(Don't include jacket. If not results will be counted twice)

Marine Growth:

11.76 % of Jacket Weight

(according to Heather Platform)

Cutting Method:

Oxy-Acetylene Cutting
Abrasive Water Jet Cutting
Diamond Wire Cutting

Assumptions:

- Cutting into Sections not considered (insignificant)
- Propane Consumption is constant for each Cutting Method
- Energy Consumption of Dismantling Miscellaneous Materials not considered

B. Onshore

Component	Weight	Cutting Method	Propane Consumption [kg/t]	Propane Consumption [kg]
Marine Growth	94.08	Abrasive Water Jet Cutting	0.00	0.00

Total Propane Consumption [kg]	Total Propane Consumption [t]
2207.30	2.21

(Don't include jacket. If not results will be counted twice)

ARTIFICIAL REEF (I & II)

A. Offshore

Component	Material	Weight [t]	Cutting Method	Propane Consumption [kg/t]	Propane Consumption [kg]	
Topside	Steel	200.00	Abrasive Water Jet Cutting	2.40	480.00	
Jacket	Miscellaneous	94.90	Others	0	0.00	
	Steel	800.00	Diamond Wire Cutting			
Conductor	Steel	244.18	Diamond Wire Cutting	2.40		586.03
Caissons	Steel	244.18	Diamond Wire Cutting	2.40	586.03	
Boat Landing	Steel	35.00	Oxy-Acetylene Cutting	Towed to Artificial Reef Site		
Guyed Wire + Pile	Steel	150.34	Oxy-Acetylene Cutting	2.40		360.82

B. Onshore

Component	Weight	Cutting Method	Propane Consumption [kg/t]	Propane Consumption [kg]
Marine Growth	94.08	No Removal	--	--

Total Propane Consumption [kg]	Total Propane Consumption [t]
2012.88	2.01

Decommissioning Opt.	Total Propane Consumption	Total Energy Consumption	SO_2 Emissions [kg]	No_x Emissions	CO_2 Emissions	Equivalent CO_2 Emissions	Overall CO_2 Emissions

	[t]	[GJ]		[kg]	[kg]	[kg]	[kg]
Complete Removal	2.21	110.37	0.00	6.62	264.88	6,637.36	6,902.24
Artificial Reef (I & II)	2.01	100.64	0.00	6.04	241.55	6,052.73	6,294.28
Difference [unit]	0.19	9.72	0.00	0.58	23.33	584.63	607.96
Difference [%]	8.81	8.81	0.00	8.81	8.81	8.81	8.81

COMPARISON LDP-A & SM-4 (COMPLETE REMOVAL)

Decommissioning Opt.	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]
Complete Removal LDP-A	110.37	0.00	6.62	264.88	6,637.36	6,902.24
Complete Removal SM-4	12.19	0.00	0.73	733.39	29.27	762.65
Difference [unit]	98.17	0.00	5.89	-468.51	6,608.10	6,139.59
Difference [%]	88.95	0.00	88.95	-176.88	99.56	88.95

COMPARISON LDP-A & SM-4 (ARTIFICIAL REEF - I & II)

Decommissioning Opt.	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]
Artificial Reef LDP-A	100.64	0.00	6.04	241.55	6,052.73	6,294.28
Artificial Reef SM-4	5.92	0.00	0.35	355.79	14.20	369.99
Difference [unit]	94.73	0.00	5.68	-114.24	6,038.53	5,924.29
Difference [%]	94.12	0.00	94.12	-47.30	99.77	94.12

APPENDIX: I: CALCULATION ON RECYCLING PLATFORM MATERIALS

COMPLETE REMOVAL

Component	Weight [t]
Topside (including misc.)	200
Jacket (including MG)	800
Conductor	244.18
Caissons	290.19
Boat Landing	35
Guyed Wire + Piles	150.34
Marine Growth (MG)	94.08
Miscellaneous	94.9

Tonnage of steel to be recycled [t]	824.81

ARTIFICIAL REEF (I&II)

Component	Weight [t]
Topside (including misc.)	200
Jacket	--
Conductor	244.18
Caissons	290.19
Boat Landing	--
Guyed Wire + Piles	150.34
Marine Growth	94.08
Miscellaneous	94.9

(Don't include jacket. If not results will be counted twice)

Tonnage of steel to be recycled [t]	789.81

Decommissioning Option	Total Steel Recycling [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]
Complete Removal	824.81	4,124.05	1,154.73	824.81	32,992.40	296,931.60	329,924.00
Artificial Reef (I&II)	789.81	3,949.05	1,105.73	789.81	31,592.40	284,331.60	315,924.00

Difference [unit]	35.00	175.00	49.00	35.00	1,400.00	12,600.00	14,000.00
Difference [%]	4.24	4.24	4.24	4.24	4.24	4.24	4.24

COMPARISON LDP-A & SM-4 (COMPLETE REMOVAL)

Decommissioning Opt.	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]
Complete Removal LDP-A	4,124.05	1,154.73	824.81	32,992.40	296,931.60	329,924.00
Complete Removal SM-4	469.90	131.57	93.98	33,832.80	3,759.20	37,592.00

Difference [unit]	3,654.15	1,023.16	730.83	840.40	293,172.40	292,332.00
Difference [%]	88.61	88.61	88.61	2.55	98.73	88.61

COMPARISON LDP-A & SM-4 (ARTIFICIAL REEF - I & II)

Decommissioning Opt.	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]
Artificial Reef LDP-A	3,949.05	1,105.73	789.81	31,592.40	284,331.60	315,924.00
Artificial Reef SM-4	246.50	69.02	49.30	17,748.00	1,972.00	19,720.00
Difference [unit]	3,702.55	1,036.71	740.51	13,844.40	282,359.60	296,204.00
Difference[%]	93.76	93.76	93.76	43.82	99.31	93.76

APPENDIX J: CALCULATION ON PLATFORM MATERIALS LEFT AT SEA

PLATFORM MATERIALS LEFT AT SEA

COMPLETE REMOVAL

Assumptions:

- No mudmat (timber) present to be left at the sea

- 100% total removal

PLATFORM MATERIALS LEFT AT SEA

ARTIFICIAL REEF (I)

Assumptions:

- Marine growth is not to be removed and left at sea (to be neglected in calculation)

- Jacket and boat landing is to be towed to the artificial reef site and to be left at sea

- "Steel Plate and Schape from Ore" conversion factors are to be used in the calculations

PLATFORM MATERIALS LEFT AT SEA

ARTIFICIAL REEF (II)

Assumptions:

- Marine growth is not to be removed and left at sea (to be neglected in calculation)

- Jacket and boat landing are to be toppled in-place as a new artificial reefing site and to be left at sea

- "Steel Plate and Scrape from Ore" conversion factors are to be used in the calculations

Component	Weight [t]
Topside (including misc.)	200
Jacket (including MG)	800
Conductor	244.18
Caissons	290.19
Boat Landing	35
Guyed Wire + Piles	150.34
Marine Growth (MG)	94.08
Miscellaneous	94.9

Tonnage of steel to be recycled [t]	35

(Don't include 'jacket'. If not results will be counted twice)

Decommissioning Option	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]
Complete Removal	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Artificial Reef (I&II)	35.00	175.00	49.00	35.00	1,400.00	12,600.00	14,000.00
Difference [unit]	35.00	175.00	49.00	35.00	1,400.00	12,600.00	14,000.00
Difference[%]	100.00	100.00	100.00	100.00	100.00	100.00	100.00

<u>COMPARISON LDP-A & SM-4 (COMPLETE REMOVAL)</u>

Decommissioning Opt.	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]
Complete Removal LDP-A	0.00	0.00	0.00	0.00	0.00	0.00
Complete Removal SM-4	0.00	0.00	0.00	0.00	0.00	0.00
Difference [unit]	0.00	0.00	0.00	0.00	0.00	0.00
Difference[%]	0.00	0.00	0.00	0.00	0.00	0.00

<u>COMPARISON LDP-A & SM-4 (ARTIFICIAL REEF - I & II)</u>

Decommissioning Opt.	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]
Artificial Reef LDP-A	175.00	49.00	35.00	1,400.00	12,600.00	14,000.00
Artificial Reef SM-4	304.00	32.00	24.00	35,200.00	960.00	36,160.00
Difference [unit]	129.00	17.00	11.00	-33,800.00	11,640.00	22,160.00
Difference[%]	73.71	34.69	31.43	-96.02	92.38	158.29

APPENDIX K: CALCULATION ON TRANSPORTATION ONSHORE

COMPLETE REMOVAL

Marine Growth:
11.76 % of Jacket Weight
(according to Heather Platform)

Truck Load:
20 tonnes

Component	Weight [t]
Topside (including misc.)	200
Jacket (including MG)	800
Conductor	244.18
Caissons	290.19
Boat Landing	35
Guyed Wire + Piles	150.34
Marine Growth (MG)	94.08
Miscellaneous	94.9

Steel Recycling [t]	Disposal [t]	Number of Trucks Recycling	Number of Trucks Disposal	Distance Port Pasir Gudang to Fabrication Yard [miles]	Distance Fabrication Yard to Scrap Dealer [miles]	Distance Fabrication Yard to Landfill for Disposal [miles]	Total Distance for Recycling [miles]	Total Distance for Disposal [miles]
824.81	188.98	42	10	6.28	23.92	33.55	2536.68497	796.60

(Don't include 'jacket'. If not results will be counted twice)

Average Truck Diesel Consumption [litre/mile]	Average Weight Engine Diesel [t/litre]	Additional Percentage [%]	Total Distance for Recycling [miles]	Total Distance for Disposal [miles]	Total Fuel Consumption for Recycling [tonnes]	Total Fuel Consumption for Disposal [tonnes]	Total Fuel Consumption [tonnes]
1.8	0.00085	10	2536.68497	796.60	4.27	1.34	5.61

ARTIFICIAL REEF (I&II)

Component	Weight [t]
Topside (including misc.)	200
Jacket (including MG)	Towed to AR-Site
Conductor	244.18
Caissons	290.19
Boat Landing	Towed to AR-Site
Guyed Wire + Piles	150.34
Marine Growth (MG)	No Removal
Miscellaneous	94.9

Steel Recycling [t]	Disposal [t]	Number of Trucks Recycling	Number of Trucks Disposal	Distance Port Pasir Gudang 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]
789.81	94.90	40	5	6.28	23.92	33.55	2415.890448	398.30

Average Truck Diesel Consumption [litre/mile]	Average Weight Engine Diesel [t/litre]	Additional Percentage [%]	Total Distance for Recycling [miles]	Total Distance for Disposal [miles]	Total Fuel Consumption for Recycling [tonnes]	Total Fuel Consumption for Disposal [tonnes]	Total Fuel Consumption [tonnes]
1.8	0.00085	10	2415.890448	398.30	4.07	0.67	4.74

(Don't include 'jacket'. If not results will be counted twice)

Decommissioning Option	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]
Complete Removal	5.61	255.25	28.05	32.54	1,335.16	17,390.74	18,725.89
Artificial Reef (I&II)	4.74	215.50	23.68	27.47	1,127.23	14,682.47	15,809.70
Difference [unit]	0.87	39.75	4.37	5.07	207.92	2,708.27	2,916.19
Difference[%]	15.57	15.57	15.57	15.57	15.57	15.57	15.57

COMPARISON LDP-A & SM-4 (COMPLETE REMOVAL)

Decommissioning Opt.	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]
Complete Removal LDP-A	255.25	28.05	32.54	1,335.16	17,390.74	18,725.89
Complete Removal SM-4	26.65	2.93	3.40	1,815.54	139.39	1,954.92
Difference [unit]	228.60	25.12	29.14	-480.38	17,251.35	16,770.97
Difference[%]	89.56	89.56	89.56	-35.98	99.20	89.56

COMPARISON LDP-A & SM-4 (ARTIFICIAL REEF - I & II)

Decommissioning Opt.	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]
Artificial Reef LDP-A	215.50	23.68	27.47	1,127.23	14,682.47	15,809.70
Artificial Reef SM-4	26.65	2.93	3.40	1,815.54	139.39	1,954.92
Difference [unit]	188.85	20.75	24.07	-688.30	14,543.08	13,854.78
Difference[%]	87.63	87.63	87.63	-61.06	99.05	87.63

APPENDIX L: VARIATION OF TOTAL ENERGY CONSUMPTION AND GASEOUS EMISSIONS WITH REGARDS TO DECOMMISSIONING ASPECTS AND OPTIONS

Variable	Decommissioning Aspect	Complete Removal	Artificial Reef - I (New Reefing Site)	Artificial Reef - II (Topple In Place)
Energy Consumption [GJ]	Marine Vessel Utilisation	89,102.86	92,932.52	90,702.10
	Platform Dismantling	110.37	100.64	100.64
	Platform Materials Recycling	4,124.05	3,949.05	3,949.05
	Platform Materials left at Sea	0.00	35.00	35.00
	Transportation Onshore	255.25	215.50	215.50
	All Decommissioning Aspects	**93,592.53**	**97,232.71**	**95,002.29**
SO_2 Emissions [Kg]	Marine Vessel Utilisation	88,317.82	92,113.73	89,902.96
	Platform Dismantling	0.00	0.00	0.00
	Platform Materials Recycling	1,154.73	1,105.73	1,105.73
	Platform Materials left at Sea	0.00	175.00	0.00
	Transportation Onshore	28.05	23.68	23.68
	All Decommissioning Aspects	**89,500.60**	**93,418.15**	**91,032.37**
NO_x Emissions [Kg]	Marine Vessel Utilisation	88,317.82	92,113.73	89,902.96
	Platform Dismantling	6.62	6.04	6.04
	Platform Materials Recycling	824.81	789.81	789.81
	Platform Materials left at Sea	0.00	49.00	49.00
	Transportation Onshore	32.54	27.47	27.47
	All Decommissioning Aspects	**89,181.78**	**92,986.05**	**90,775.28**
CO_2 Emissions [Kg]	Marine Vessel Utilisation	3,738,787.52	3,899,481.26	3,805,891.94
	Platform Dismantling	264.88	241.55	241.55
	Platform Materials Recycling	32,992.40	31,592.40	31,592.40
	Platform Materials left at Sea	0.00	35.00	35.00
	Transportation Onshore	1,335.16	1,127.23	1,127.23
	All Decommissioning Aspects	**3,773,379.95**	**3,932,477.44**	**3,838,888.12**
Equivalent CO_2 Emissions [Kg]	Marine Vessel Utilisation	6,084,116.17	6,345,612.55	6,193,314.96
	Platform Dismantling	6,637.36	6,052.73	6,052.73
	Platform Materials Recycling	296,931.60	284,331.60	284,331.60
	Platform Materials left at Sea	0.00	1,400.00	1,400.00
	Transportation Onshore	17,390.74	14,682.47	14,682.47
	All Decommissioning Aspects	**6,405,075.87**	**6,652,079.35**	**6,499,781.76**
Overall CO_2 Emissions [Kg]	Marine Vessel Utilisation	9,822,903.69	10,245,093.81	9,999,206.90
	Platform Dismantling	6,902.24	6,294.28	6,294.28
	Platform Materials Recycling	329,924.00	315,924.00	315,924.00
	Platform Materials left at Sea	0.00	12,600.00	12,600.00
	Transportation Onshore	18,725.89	15,809.70	15,809.70
	All Decommissioning Aspects	**10,178,455.82**	**10,595,721.79**	**10,349,834.88**

APPENDICES

(EIO-LCA METHOD)

APPENDIX M: 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 N: OVERALL CO_2 EMISSIONS FOR EIO STANDARD UNIT MODEL

	Sector	Total t CO2e
	Total for all sectors	*649.*
213112	Support activities for oil and gas operations	139.0
221100	Power generation and supply	120
211000	Oil and gas extraction	82.3
327310	Cement manufacturing	71.2
331110	Iron and steel mills	67.7
484000	Truck transportation	15.5
324110	Petroleum refineries	15.5
212100	Coal mining	12.5
325120	Industrial gas manufacturing	10.4
486000	Pipeline transportation	9.41

APPENDIX O: SO_2 AND NO_X EMISSIONS FOR EIO STANDARD UNIT MODEL

	Sector	CO t	NH3 t	NOx t	PM10 t	PM2.5 t	SO2 t	VOC t
	Total for all sectors	*8.22*	*0.084*	*6.33*	*0.904*	*0.578*	*1.89*	*1.26*
213112	Support activities for oil and gas operations	6.15	0.007	5.03	0.444	0.420	0.886	0.792
331110	Iron and steel mills	0.337	0.001	0.050	0.014	0.011	0.038	0.011
532400	Commercial and industrial machinery and equipment rental and leasing	0.337	0.000	0.005	0.001	0.001	0.002	0.027
211000	Oil and gas extraction	0.209	0.000	0.152	0.001	0.001	0.010	0.212
327310	Cement manufacturing	0.134	0.000	0.196	0.033	0.015	0.144	0.008
221200	Natural gas distribution	0.131	0.000	0.006	0.000	0.000	0.002	0.006
484000	Truck transportation	0.129	0.000	0.136	0.039	0.007	0.003	0.015
331200	Iron, steel pipe and tube manufacturing from purchased steel	0.048	0.000	0.007	0.002	0.002	0.005	0.003
33131A	Alumina refining and primary aluminum production	0.046	0.000	0.002	0.001	0.001	0.015	0.000
333920	Material handling equipment manufacturing	0.045	0.000	0.011	0.000	0.000	0.000	0.004

APPENDIX P: COST INPUT DATA FOR ARTIFICIAL REEF

Twachtman Snyder & Byrd, Inc. (2000). *State of the Art of Removing Large Platforms Located in Deep Water (Final Report).* Houston, Texas.
Carolin Gorges (2014). *Comparative Assessment of Environmental Impacts Associated with the Decommissioning of Fixed Offshore Platforms.*

Platform	**Water Depth [ft]**	**Jacket Weight [t]**	**Cost Complete Removal [$]**	**Cost Remote Reef [$]**	**Percentage Cost Remote Reefing of Complete Removal [%]**	**Average Difference [%]**
Hidalgo	430	10,950	44,245,300	17,768,257	40.16	34.79
Gail	739	18,300	56,678,210	20,316,947	35.85	
Harmony	1198	42,900	123,295,033	34,976,168	28.37	

Cost estimation equivalent to KTMP-A's by SSB: RM 46,000,000.00

35 % of Complete Removal Cost **RM 16,100,000.00**

APPENDIX Q: COMPARISON BETWEEN PROCESS-BASED LCA METHOD AND EIO-LCA METHOD

PROCESS-BASED METHOD

COMPARISON BETWEEN COMPLETE REMOVAL OF LDP-A & SM-4

Variable	Complete Removal LDP-A	Complete Removal SM-4	Difference [unit]	Difference [%]
Energy Consumption [GJ]	97,380.00	37,105.26	60,274.74	61.90
SO_2 Emissions [kg]	90,506.68	36,408.59	54,098.09	59.77
NO_x Emissions [kg]	89,914.10	36,372.19	53,541.90	59.55
CO_2 Emissions [kg]	3,802,693.89	2,535,263.20	1,267,430.68	33.33
Equivalent CO_2 Emissions [kg]	6,676,009.38	1,539,530.83	5,136,478.55	76.94
Overall CO_2 Emissions [kg]	10,478,703.27	4,074,794.03	6,403,909.24	61.11

COMPARISON BETWEEN ARTIFICIAL REEF OF LDP-A & SM-4

Variable	Artificial Reef LDP-A	Artificial Reef SM-4	Difference [unit]	Difference [%]
Energy Consumption [GJ]	97,232.71	37,542.79	59,689.93	61.39
SO2 Emissions [kg]	93,418.15	36,738.03	56,680.11	60.67
NOx Emissions [kg]	92,986.05	36,711.14	56,274.91	60.52
CO2 Emissions [kg]	3,932,477.44	2,578,800.81	1,353,676.64	34.42
Equivalent CO2 Emissions [kg]	6,652,079.35	1,553,928.56	5,098,150.79	76.64
Overall CO2 Emissions [kg]	10,595,721.79	4,132,729.36	6,462,992.43	61.00

EIO-LCA METHOD

COMPARISON OF COMPLETE REMOVAL BETWEEN LDP-A & SM-4

Variable	Artificial Reefing LDP-A	Artificial Reefing SM-4	Difference [unit]	Difference [%]
Total Energy Consumption (GJ)	40,874.25	24,157.84	16,716.41	40.90
NOx Emissions (Kg)	33,213.61	19,630.19	13,583.42	40.90
SO2 Emissions (Kg)	9,916.86	5,861.15	4,055.71	40.90
Overall CO2 Emissions (Kg)	3,405,313.30	2,015,737.85	1,389,575.45	40.81

COMPARISON OF ARTFICIAL REEF BETWEEN LDP-A & SM-4

Variable	Complete Removal LDP-A	Complete Removal SM-4	Difference [unit]	Difference [%]
Total Energy Consumption (GJ)	116,783.58	69,022.41	47,761.17	40.90
NOx Emissions (Kg)	94,896.03	56,086.24	38,809.79	40.90
SO2 Emissions (Kg)	28,333.89	16,746.13	11,587.76	40.90
Overall CO2 Emissions (Kg)	9,729,466.57	5,759,250.99	3,970,215.58	40.81