Decommissioning Options Assessment on Environmental Impact and Economic Impact for Fixed Offshore Platform

by

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CERTIFICATION OF APPROVAL

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Approved by,

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CERTIFICATION OF ORIGNINALTY

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.

YUSNIAH BINTI USOP

ABSTRACT

Decommissioning activity is undeniable has high potential on environment risk and also not economic in term of cost. The concern on these issues increasing as many parties realized the exploration of oil and gas is developing year by year. Thus, many platforms need to execute decommissioning once they reach their productive life. Life-Cycle Assessment (LCA) is designed as a tool to assess the impacts systemically, technically and analytically by quantifying the associated impacts. The assessment will be conducted using two LCA tools which are Process based Method and EIO-LCA Method. Both tools will be used to compare and evaluate the effects and differences between two decommissioning options (Complete Removal and Partial Removal) in term of energy consumption and greenhouse gaseous emissions and also economic impacts. The greenhouse gaseous will be focused on Carbon Dioxide (CO_2), Sulphur Dioxide (SO_2) and Nitrogen Oxides (NO_x). A platform located in the North Sea, Heather Platform will be used as research case study. Afterwards, the result from research case study will identify the contribution of each environmental burden quantitatively. Lastly, some mitigation measures that addressing the environmental risk will be proposed.

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ABBREVIATIONS AND NOMENCLATURES

CO_2	Carbon dioxide
EIA	Environmental Impact Assessment
EIO	Economic Input Output
EPA	US Environmental Protection Agency
GJ	Giga Joule
KG	Kilogram
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standardization Organization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NOx	Nitrogen oxides
OSPAR	Convention of the Protection of the Marine Environment of the North East Atlantic
SETAC	Society of Environmental Toxicology and Chemistry
SO_2	Sulphur dioxide
T	Metric Tonne

CHAPTER 1

1.0 BACKGROUND

Decommissioning activity is undeniable has high potential on environment risk and also not economic in term of cost. The concern on these issues increasing as many parties realized the exploration of oil and gas is developing year by year. Decommissioning activity usually will be a long-term process. From experience, most of operators concern that decommissioning activity involves a lot of expertise, require high technology, expose high risk to the safety of the workers, high operational cost and effect the environment. The awareness is to minimize the environmental impacts as well as to meet decommissioning as a marginal business. Many businesses have responded to the environment issues awareness by providing “greener” products and using “greener” processes. The environmental performance of products and processes has become a key issue, which is why some companies are investigating ways to minimize their effects on the environment. Many companies have found it advantageous to explore ways of moving beyond compliance using pollution prevention strategies and environmental management systems to improve their environmental performance as well as the cost. One such tool is LCA. This concept considers the entire life cycle of a product (Curran, 2006). To compile and evaluate the inputs and outputs, and the potential environmental implications, the product system consists of models of the technological activities used for the product’s various stages called as Life Cycle Assessment (LCA) is designed and introduced.

The broad scope of LCA can help decision makers avoid sub-optimization, which is the optimization or improvement in part of a system that negatively affects other parts of the system. An LCA’s broad scope reduces the risk that a decision aiming at reducing pollution simply shifts the environmental problem from one place to another or from one environmental issue to another. The life-cycle concept also helps shift the focus of pollution management from dealing with pollutants after they have formed, to preventing pollutants from being formed, so that environmental impacts can be avoided or mitigated at a lower cost through product development and purchasing decisions.

Until recently, towards the end of an oil and gas production, law required that "decommissioned" be removed, and the surrounding marine environment be maintained clean up and restored to a natural condition. These obligations were introduced to the oil and gas industry when the platforms were installed. However, for several years, the industry manipulated to change existing law to allow abandonment of offshore platforms in place after production ceases. Industry's motivation was to avoid the costs for this previously agreed-to remediation. As the numbers of offshore platforms is getting increase by years, the business of disposing, removing or dismantling offshore platforms become popular demanded. This had forced government and operators to remove and dispose their offshore platforms. Most of the operators nowadays aware and concern about the challenges associated with decommissioning activity. An efficient and effective decommissioning methodology must be considered to ensure no unnecessary cost liability is placed on operator. Most importantly, decommissioning activity created risk and Life Cycle Assessment is specially created to assess the environmental impacts that associated with decommissioning operation. An LCA presents information on the environmental performance of products, ecological processes, and systems. The LCA Tools applied in this study are Process Based Method and Economic Input-Output Method (EIO-LCA). The results evaluated will be compared and combined to get a more accurate outcome based on the limitation both methods. In this study, decommissioning for complete removal will be discussed. Finally, the relevant mitigation measures for environmental concerns arising in connection with the decommissioning of offshore.

1.2 PROBLEM STATEMENT

Decommissioning of offshore platform doubtlessly will give negative effects to the environment and costly. The waste substances delivered, gaseous emissions, noise pollution and vibrations from the decommissioning works are great illustrations for the earth effects of seaward decommissioning (Gibson, 2002). With the expanded awareness on environmental issues, it is imperative to ensure that decommissioning activities would not bring extreme harms or damages to the nature's turf or to ensure whether gaseous outflows are within the limit set.

Nowadays, the decommissioning becomes more significant because of the Brent Spar impacts. The oil companies and government authorities are forced to re-assessed position on disposal. However, the published information on environmental impacts assessment associated with offshore installations decommissioning and framework to assess and to quantify the environmental impact are very minimal. Life Cycle Assessment (LCA) is a systematic approach between decommissioning options, for quantifying and addressing the environmental impact simultaneously.

Besides that, the decommissioning action that is the significant giver for total energy consumption and gaseous emission could be distinguished by utilizing LCA examination. Mitigation could be proposed to minimize the environmental impacts of that specific decommissioning action. For this study, the author expects to deliver a far reaching LCA examination to focus and to quantify the environmental impacts of decommissioning of an offshore platform in North Sea.

1.3 OBJECTIVES OF STUDY

i. To assess and compare the Environmental Impacts of Decommissioning Offshore Platform in North Sea quantitatively using LCA Tools; Process-Based Method and EIO Method
ii. To compare the Economic Impacts from two decommissioning options for fixed platform: complete and partial removal
iii. To recommend relevant Mitigation Measures which related to the environmental and economic concerns addressed from decommissioning process

1.4 SCOPE OF STUDY

The scope of this study is to quantify the Environmental Impacts of Decommissioning Offshore Installations in North Sea Fixed Offshore Platforms using LCA Tools EIO (EIO-LCA) Method and Process Based Method. The comparison of energy cost will be analyzed as well. Thereby, two options for Offshore Decommissioning, the Complete Removal and the Partial Removal, will be analyzed and compared, regarding their impacts on the marine environment as well as the energy cost. Heather Platform was selected as a case study in this project. Data for the estimation of the energy consumption and gaseous emissions associated with decommissioning of Heather Platform obtained from a published paper was used as input data for the LCA analysis. For EIO-LCA, cost data was obtained from a published report and a model was constructed based on the online EIO model (Green Design Institute).

Due to technical complexity and safety concerns, this study will not discuss the decommissioning of pipelines and power cable. The scope will cover the environmental impacts and energy cost resulted from steelwork, marine vessel utilization, platform running, helicopters, platform materials recycling, platform materials left at sea and platform facility dismantling that consists of topsides and jacket removal.

2.1 MANAGING DECOMMISSIONING

Oil and gas industry has been in operation for more than 30 years. As of the latest statistics, there are around 9,000 offshore oil and gas platforms being operated all across the globe. With the production well reaching its maturity and the drilling platform reaching the end of its useful life, decommissioning becomes an unavoidable part of an offshore platform lifecycle. Decommissioning is essentially a change of process from being operational to non-operational. When being applied in the oil and gas industry, decommissioning have the meaning of the procedures to remove an oil and gas offshore installation (structure) as it reaches the end of the its use. According to Ruivo and Morroka (2001), the procedures of decommissioning are dismantling, decontamination and removal of the process equipment and facilities. In recent years, oil and gas activities are being scrutinized with rising concern on its environmental friendliness and sustainability, hence providing significant challenge on the decommissioning of offshore structures. Life-Cycle Assessment is a popular and useful tool in planning decommissioning activities that allows the quantification of resource consumption in order to manage environmental impacts of the planned activities.

2.1.1 OFFSHORE PRODUCTION PLATFORM

To utilize the most suitable type of platform best suited to an oceanic region will ensure good economic returns in oil and gas exploration. Depending on the weather condition and landscape of the area, circumstances and general purpose of the facility, a production platform can be a permanent structure fixed to the ocean floor or it can be a floating structure. In general, oil and gas offshore facilities are categorized into fixed platform or floating structure serving exploration or production purposes. Fixed platforms are structures that are affixed to a permanent location where support structures are being extended from the body of the platform to be anchored to the seabed, different types of fixed platforms such as jacket platform, gravity platform, compliant tower and jack-up each have its suitability for different circumstances. The fixed platform installation is economically feasible to be use in water depth up to 1,500 feet and it usually includes living quarters, a drilling rig, and production facilities. On the other hand, semi-submersible platforms such as TLP, SPAR and FPSO offer better mobility without the need of being attached to the seabed and are suitable to be used in deep water. The floaters are designed to be anchored to a temporary location using only wire rope and chain, or remain in a dynamic position with the help of thrusters. Due to the design limitations of the floating platforms, production risers are needed to facilitate the platform motion when product are being transferred from subsea well to the surface deck. Figure 1 below summarizes the types of offshore structure according to the corresponding depth of the sea.

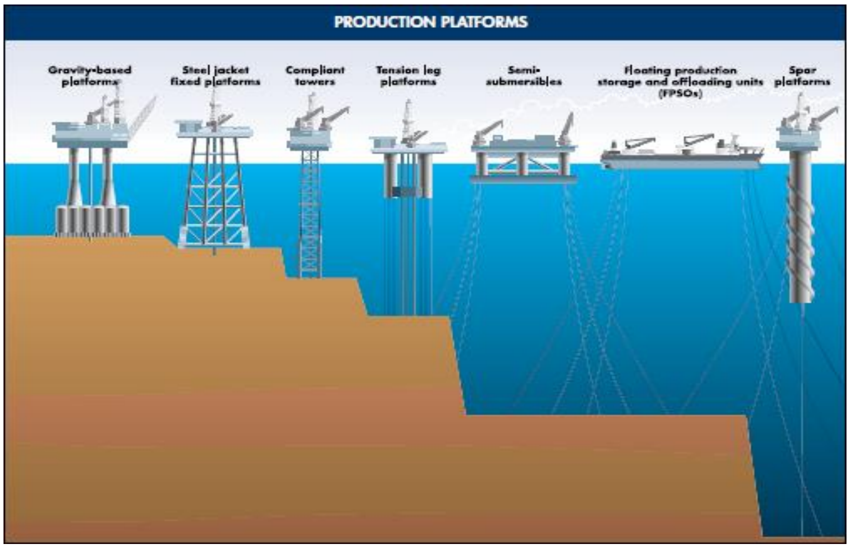

Figure 1: Types of Offshore Production Platform with depth (Twomey, 2012)

2.1.2 DECOMMISSIONING OPTIONS AND THE REGULATORY FRAMEWORK

Planning is always the most important phase of a project to analyze the options available and decide the best course of action for the success of the project. Equally, decommissioning is a huge and complex project on its own. Deciding on the best possible removal option will significantly affect the environmental impact of the decommissioning activities. Decommissioning activities in the oil and gas industry are being subjected to a structured and strict international, regional and national regulation depending on the location of the structure to be decommissioned as well as a tight industry standards and best practices. These are being put in place to oversee the two main components of decommissioning, which are removal and disposal. Removal is the complete (or partial) removal of the whole offshore structure whereas disposal is the leaving behind of the structure, there is also another use for a structure to be reused as an artificial reef (Bomel, 2001).

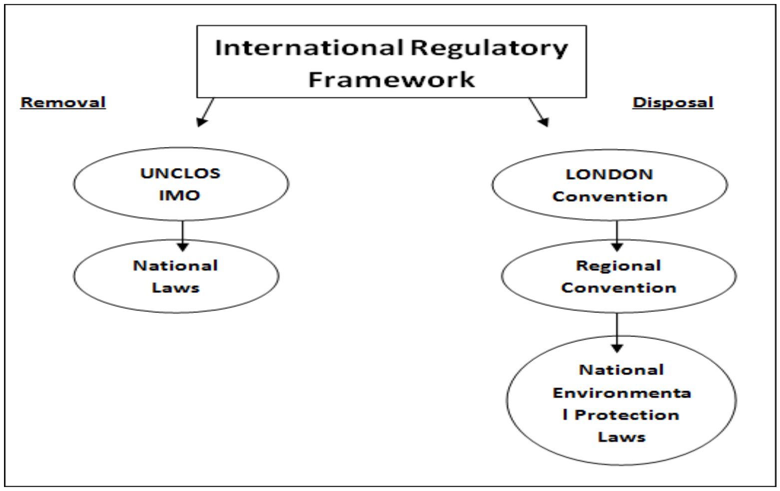

Figure 2: International Regulatory Framework of Decommissioning Options

Although the differences between removal and disposal of offshore installations may seem close, but it is important to identify the decommissioning practice into its correct component because they are under the jurisdiction of entirely different scope and framework. As an illustration, the legal requirements for removal are mainly focused on the safety of other users of the sea whilst disposal is focused on the prevention of pollution that may occur due to the decommissioning activity. There are myriads of issues that could be affecting the success of a decommissioning, to name a few such as potential environmental, safety, economic, political and technology issues. A feasibility study for the planning of a decommissioning should address the intricacies of each of the issues and how they intertwine with each other in order to highlight the best possible action to mitigate and reduce the impact these issues. (Ekins, Vanner and Firebrace, 2005).

Offshore decommissioning operations are actually of much higher complexities than the original installation itself. Many factors can affect the success of a decommissioning operation, such as the condition of the platform, the safety system, the residual strength of the installation and the actual weight of the structure. All these factors need to be taken into consideration when planning for the decommissioning options and/ or activities. Depending on the legislation and also the condition of the platform, the decommissioning of that platform can adapt different options and plans. This also highlights the fact that each decommissioning is unique and may vary for each platform. Examples of popular decommissioning methods are reuse for other non-oil and gas purpose, complete removal, partial removal, deep water disposal, abandonment and reuse as artificial reef. The topside (the structure visible above the sea water) of a platform contains all the operational machinery that are usually recycled and reused in another facility. The substructure (the parts between the water surface and the seabed, or mudline) are usually detached 15 feet below the mudline and removed to be sold as scrap for recycling or in cases of still in satisfactory condition, these substructure are refurbished to be used in other offshore installation.

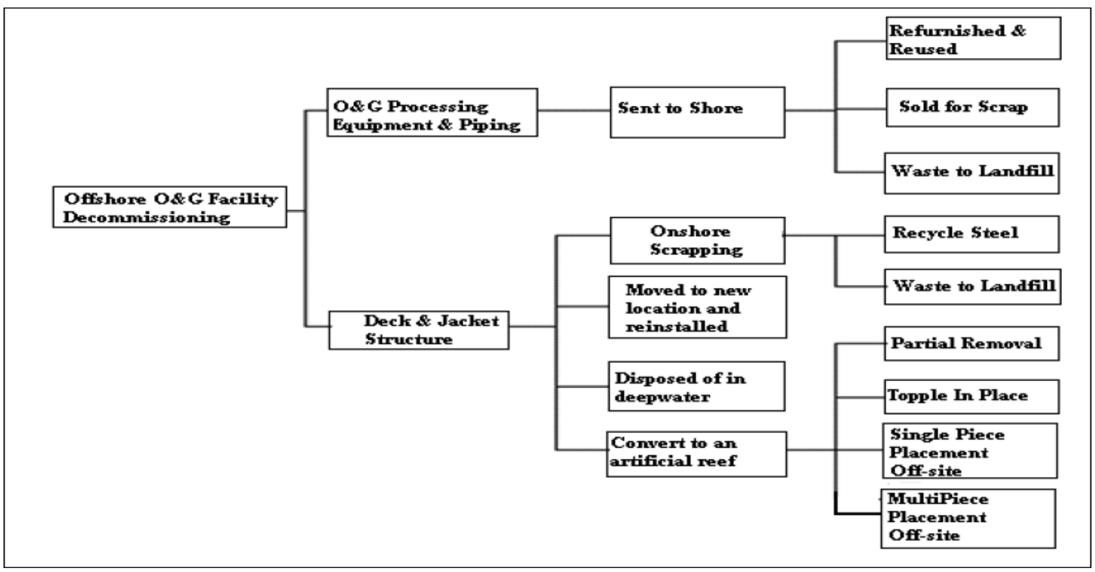

Figure 3: Decommissioning Options (Kurian and Ganaphathy, 2009)

OSPAR treaty is provisioning the regulatory framework that oversees the decommissioning of offshore installations in the North Sea. Under the OSPAR convention, all offshore structures are presumed to be decommissioned entirely onshore with limited possibilities for derogation. A summary of the requirement provisioned in the OSPAR Decision 98/3 (taken in 1998) is listed as below:

- All topsides of all structures are to be removed and brought to shore for reuse, recycling or disposal;

- All sub-structures or jackets weighing less than 10,000 tonnes must be totally removed and brought to shore for re-use, recycling or disposal;
- For sub-structures weighing over 10,000 tonnes, there is a presumption to remove totally but with the potential of a derogation being agreed on whether the footings might be left in place; and
- Derogation may be considered for the heavy concrete gravity based structures as well as for floating concrete installations and any concrete anchor-base.

The scope for decommissioning option of this dissertation is focused on complete removal and partial removal. Complete removal is defined as the total removal of every part of an offshore structure, inclusive of Christmas tree, tubing wellhead, casing, conductor and riser, leaving behind a clear seabed. The removed material needs to be disposed of properly onshore or in deep water with minimum water depth of 2,000m and 15 miles from shoreline. (Hustoft and Gambin, 1995). Onshore disposal of the removed material are usually done in fabrication yard and the scrap metal are sold to third party to be recycled while the reusable parts are refurbished for reuse. Unusable parts need to be disposed in accordance with applicable legal requirements as this is under heavy scrutiny from regulatory agencies. On the other hand, partial removal is defined as the removal of the offshore installation of up to 55m under sea level. In practice, partial removal is much simpler, safer and significantly cheaper than complete removal option. This is because in terms of coastal and deep water disposal options, partial removal allows the in-situ disposal of materials by placing them at the jacked stub on the seabed or through means of controlled toppling of the platform. However, these options are not really fishable because they leave behind obstructions on the seabed and requires changes to the navigation and fishing charts. (Hustoft and Gambin, 1995). Essentially, partial removal options require more follow-up steps than complete removal option.

2.2 ENVIRONMENTAL IMPACT OF DECOMMISSIONING

In recent years, environmental activism is getting a lot of attention. Undeniably decommissioning has a significant impact to the environment, and it is an important factor when making consideration for a decommissioning program. There are many environmental concerns to be taken into account throughout decommissioning process, from the planning and carrying out shut down operations on an oilfield or an offshore facility to waste disposal. Past track records has shown that many of the unplanned environmental issue happened during onshore demolition where the consideration was not taken account into during the planning phase. It is important to cater not just for offshore but also onshore decommissioning phases when making plans for the decommissioning program, for example the impact on marine ecosystem, gaseous emissions, impact on landfill, discharge impact on water quality, and energy consumption. OSPAR 98/3 mandates the following matters to be taken into account when assessing disposal options:-

- Impacts on the marine ecosystem including contaminant exposure, biological impacts caused by physical activities, conservation of species and their natural habitat;
- Impacts on other environmental areas such as atmospheric emissions, contamination of water sources contamination, and impact to the soil;
- Consumption of energy from re-use or recycling activities;
- Other consequences to the environment that might be caused by the activities;
- Impacts on comforts of the population and on future uses of the environment.

(International Association of Oil and Gas Producers, 2012)

This dissertation will discuss on the two major issues on the environmental impacts of decommissioning activities, namely the energy consumption and gaseous emission focusing on CO_2, SO_2, and NO_x. The energy consumption and gaseous emission will be quantified and compared using two different LCA evaluation approach, which are process-based method and EIO-LCA method. According to Gorges (2014), different data and perspective used in LCA tools, still give the similar trend of result. However, the tools can be used to evaluate the environmental impact depending on data availability.

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2.2.1 LCA TOOLS FOR ENVIRONMENTAL IMPACT ASSESSMENT

The data for both energy consumption and gaseous emissions will be quantified and evaluated using two different LCA Tools which are Process based Method and EIO-LCA Method to provide different perspective of evaluation. Life cycle assessment (LCA) is an approach to investigate, estimate, and assess the environmental impact of a process such as energy and material consumption as well as emission to the air and wastes generated by a product, material, service, or process throughout its life span. The assessment provide important insights of the environmental impact by translating data and information gathered from the overall operation of a process towards the end of its life span. Furthermore, the results can be significant for identifying areas with highest environmental impact, and for improving and evaluating design of a product. (Green Design Institute, a Primer on LCA).

This view is further strengthened by Rebitzer et.al (2003), who in their research found that quantification of environmental impact is necessary to help identify and achieve sustainable development to our societies. Products are created and used to fulfill a need, and every product has a "life", starting with the design/development of the product, followed by the production of the product, then the product being used or consumed, and finally reach the end of its useful life where its end-of-life activities (reuse, recycling, disposal) are to be carried out. All processes in a product's life will inevitably cause an environmental impact due to consumption of resources, emissions of substances into the environment, and other environmental exchanges. (Rebitzer and others, 2003).

As a scientific research tool, the life cycle assessment goes beyond the standardization which is divided into standards that cover the management of organizations and into standards that cover the life cycle of products. They include the following aspects of environmental management:

- ❖ Environmental Management Systems (EMS)
- ❖ Environmental Auditing & Related Investigations (EA&RI)
- ❖ Environmental Labels and Declarations (EL)
- ❖ Environmental Performance Evaluation (EPE)
- ❖ Life Cycle Assessment (LCA), and
- ❖ Terms and Definitions (T&D)

❖ Figure 4 shows the ISO 14000 family of standard that is used as the basis for practical application as well as for instruments with legal status.

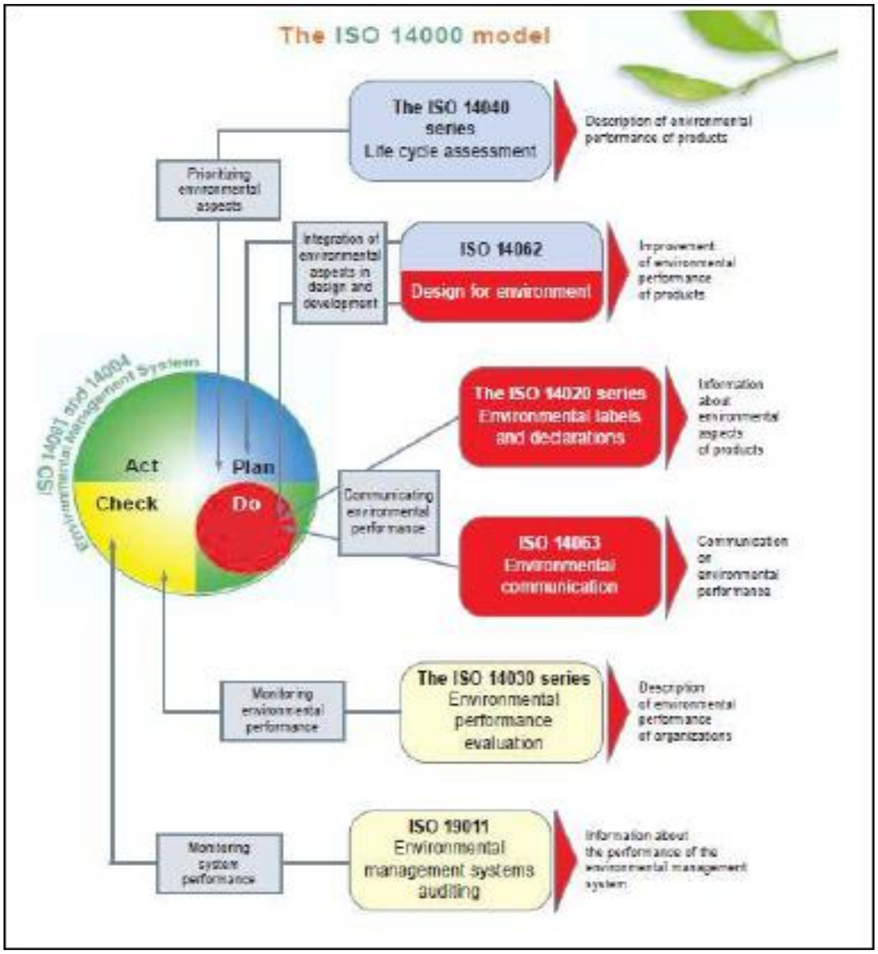

Figure 4: ISO 14000 Families of Standards (Liselotte, 2012)

Poremski (1998) in his researched stated that typical LCA framework shall include the four stages as shown in Figure 5.

1. The goal and scope of an LCA study shall be clearly defined and consistent with the intended application. In defining the scope of an LCA study, the following items shall be considered and clearly described : the functions of the product system, or, in the case of comparative studies, the systems ; the functional unit ; the product system to be studied ; the product system boundaries ; allocation procedures ; types of impact and methodology of impact assessment, and subsequent interpretation to be used ; data requirements ; assumptions ; limitations ; initial data quality requirements ; type of critical review, if any ; type and format of the report required for the study. The scope should be sufficiently well defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal. LCA is an iterative technique. Therefore, the scope of the study may need to be modified while the study is being conducted as additional information is collected.

2. Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. These inputs and outputs may include the use of resources and releases to air, water and land associated with the system. Interpretations may be drawn from these data, depending on the goals and scope of the LCA. These data also constitute the input to the life cycle impact assessment. The process of conducting an inventory analysis is iterative. As data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data collection procedures so that the goals of the study will still be met. Sometimes, issues may be identified that require revisions to the goal or scope of the study.

3. The impact assessment phase of LCA is aimed at evaluating the significance of potential environmental impacts using the results of the life cycle inventory analysis. In general, this process involves associating inventory data with specific environmental impacts and attempting to understand those impacts. The level of detail, choice of impacts evaluated and methodologies used depends on the goal and scope of the study. This assessment may include the iterative process of reviewing the goal and scope of the LCA study to determine when the objectives of the study have been met, or to modify the goal and scope if the assessment indicates that they cannot be achieved.

4. Interpretation is the phase of LCA in which the findings from the inventory analysis and the impact assessment are combined together, or, in the case of life cycle inventory studies, the findings of the inventory analysis only, consistent with the defined goal and scope in order to reach conclusions and recommendations. The findings of this interpretation may take the form of conclusions and recommendations to decision-makers, consistent with the goal and scope of the study. The interpretation phase may involve the iterative process of reviewing and revising the scope of the LCA, as well as the nature and quality of the data collected consistent with the defined goal.

Figure 5: LCA Framework according to ISO 14000

2.2.2 PROCESS-BASED METHOD AND EIO-LCA METHOD

Process-Based Method is the conventional method for environmental assessment. The core of process-based method is to systematically examining material and energy flows at each stage of the life-cycle to provide the precise consumption and emission values. This method has the flaws of being too time consuming, restrictive in scope that only allows for a limited number of products or processes, and lack in scalability to cater for more complex systems.

In contrast to Process-Based Method, EIO-LCA Method begins with a model of the national economy. A database of environmental impact per dollar is developed based on the EIO tables and industry-level environmental data. This method is perceived to be more comprehensive than Process-Based Method because the EIO tables are able to connect the interrelations of all economic sectors. However, input-output LCA has the issue of providing only total industry level data and is last updated from 2002 analysis economic data. (Simonen, 2014)
Further differences of both methods are presented as in Table 1 below:

Process-Based Method	EIO-LCA Method
• Specifies inputs (energy consumption) and outputs (gaseous emission and wastes) for each stage over entire life cycle.	• Estimate energy consumption and environmental emission and linked them with financial transaction for the whole process.
• Simple and straightforward analysis of material and data	• Uses economic wide interdependencies by using input-output matrices in order to find environmental impacts

Table 1: Differences between Process-Based Method to EIO-LCA Method
(Green Design Institute, EIO-LCA Method)

Process-Based Method has detailed and specific results whereas EIO-LCA results are economy-wide and comprehensive. In term of information analysis and comparison, Process-Based Method compares between specific products meanwhile EIO-LCA Method makes system-level comparison. Both methods after will eventually provide the necessary development assessment for future products upon the completion of data analysis phase. However, the data for both methods are ambiguous. The shortfalls of Process-Based Method will be that it is complicated to apply new process design in the evaluation, costly and time intensive. On the other hand, the shortfalls of EIO-LCA process assessment will be the tool is too complicated and dependant on the accuracy of the monetary values linked with physical unit in EIO-LCA. However, both tools need to take account on some assumptions and limitations before evaluation (Gorges, 2014). Table 2 summarizes the comparisons between Process-Based LCA and EIO-LCA assessment method.

	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 assessments
		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	process assessments difficult
	difficult to apply to new process design	must link monetary values with physical units
	use proprietary data	imports treated as products created within economic boundaries
	cannot be replicated if confidential data are used	availability of data for complete environmental effects
	uncertainty in data	difficult to apply to an open economy (with substantial non-comparable imports)
		uncertainty in data

Table 2: Advantages and Disadvantages of LCA Tools (Green Design Institute, EIO-LCA Method).

2.3 ECONOMIC IMPACT ASSESSMENT

The central issues of decommissioning activity are mainly on the cost and the question of who holds the liability. Decommissioning cost is found to be sensitive in term of removing platform. (Bemment, 2001). According to the OSPAR Convention the owner holds the ultimate responsibility for decommissioning once an installations approach its useful life. "The owner of an installation or pipeline at the time of its decommissioning will normally maintain as the person of any residues such as remaining abandoned facilities, pollutants or fluids. Any residual liability remains the owner's in perpetuity" (Royal Academy of Engineering, 2013).

In spite of the fact that weight and water depth are key parameters in determining the decommissioning costs for related activity, other factors such as type of the facility and location number of structures to be dismantled, water depth and weight related with the structure, the number and depth of wells and conductors, removal approaches, and transportation and disposal options may have important impact on the decommissioning cost. The unknowns and fluctuation such as estimated risks, market volatility, material change in condition, , industry experience, and supply chain inflation, loss of key personnel, , technical data and information management systems that invisibly exist in the cost making it notorious to calculate the exact amount of decommissioning cost. In this dissertation, the cost will be focusing on comparing the decommissioning options selected. The difference in cost between these two options will be further discussed in the next subtopic.

2.3.1 COST ELEMENTS

According to Byrd et al. (2014), there is common cost element in most decommissioning projects. There are as the following shown below and as in Figure 6:

- Planning
- Inspections and Permits (Regulatory Compliance)
- Well P&A
- Platform Preparation
- Pipeline Abandonment

❖ Conductor Removal
❖ Topsides Removal and Disposal
❖ Substructure Removal and Disposal
❖ Site Clearance and Remediation

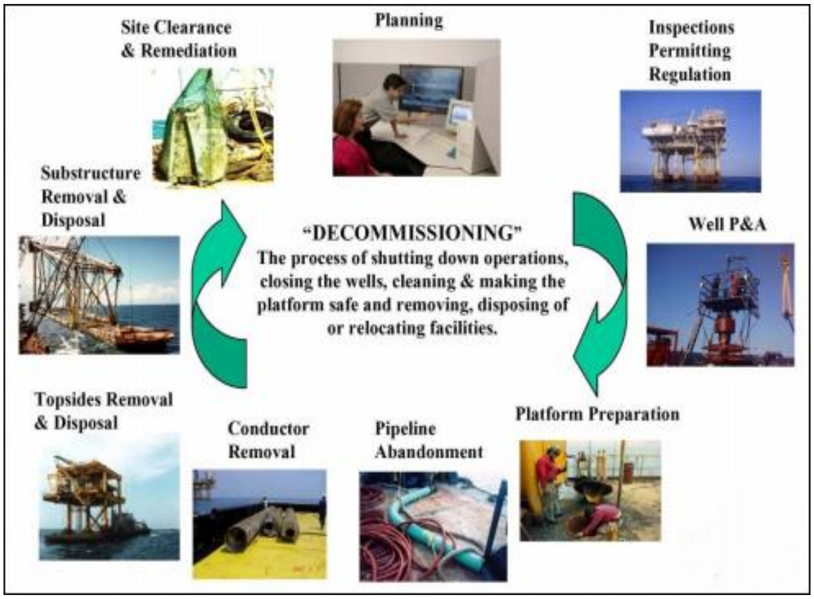

Figure 6: Common Cost Elements in Decommissioning

Due to the data limitation of researched platform, this dissertation will attempt to deal with the removal cost in detail focusing on two types of removal complete and partial removal.

Total removal usually applies to small and all large platform that will be totally removed onshore and recycled there. On the other hand, all topsides should be totally removed meanwhile disposal of in situ in deep water is only applicable for substructures of large platform which must parallel with IMO guidelines for partial removal. (Scheelhaase, 1998). Extension to this standpoint, Scheelhaase (1998) stated that in term of energy cases, total removal may be marginal compared to partial removal. However, when taking energy costs fully into consideration, total energy costs for partial removal appears to be more feasible.

The research study carried by Scheelhaase (1998) concluded that decommissioning costs cannot be clear cut taken on the amount of energy consumption and the standard cost only. The difference in total energy costs may be marginal for both partial and total removal but the overall cost for decommissioning activity is affected by other factors such as employment, fiscal effect and recycling process which cannot be overlooked. This is further strengthen by the Offshore Magazine (2001), concluded that when developing offshore platform decommissioning, the standard cost components such as platform dismantle preparation, conductor removal pipeline abandonment, site clearance, platform removal and verification, and onshore disposal as well as additional cost must be taken into account.

2.3.2 REMOVAL COST

Two types of removal will be highlighted in this dissertation which is the topside and substructures. The removal approach that adopted in a decommissioning activity will affect the total amount of works which in other meaning will represent the cost. Thus, it is important to understand the removal approach very detail in order to assess the cost involved throughout that process. According to Byrd et.al. (2014), in a decommissioning project, the fundamental is to remove the topside facilities, jacket, deck, piles and conductors. The topsides removal is almost the same as the reverse order of installation process. Modules are evacuated and put on a load scow and secured by welding ocean fastenings to the deck of the freight ship. After cutting the welded connections between deck leg and piles, the deck module support will be removed. The deck structure is then secured on the cargo barge after seated in load spreaders. In offshore platform removal, derrick barge services have the largest portion from the total removal cost.

In contrast to topside, Jacket is used as a structure supporting the topside and deck in a fixed offshore platform. The piling that carries the weight of the topsides also supported by the Jacket. The Jacket height is considered by water depth added with an additional approximately 5 meters above sea level. Multiple constraints such as weight op topsides, equipment, impact from wind, sea condition, current, fatigue and corrosion must be taken into consideration while designing jacket structure. Besides, jackets also designed to protect pipelines and conductors form touching with the seabed. The removal method of a jacket must be considered as most jacket differ in term of height, weight, number of legs and purpose. (Byrd and others, 2014).

The removal cost will decide the decommissioning activity that will involve. Below is the example of forecast expenditure provided by operators from a survey.

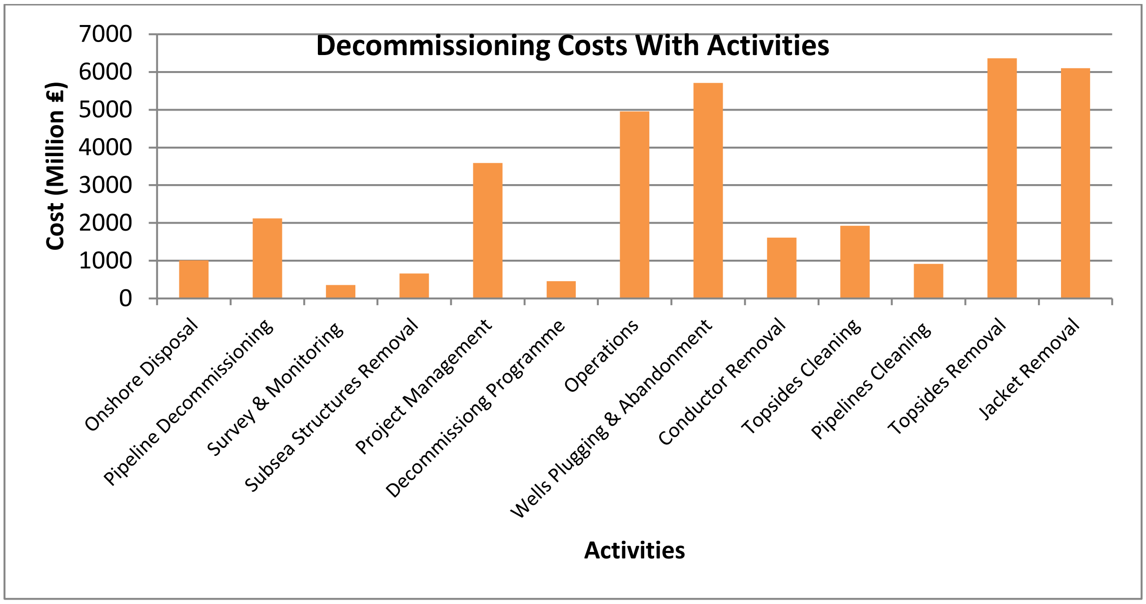

Figure 7: Decommissioning Cost with Activities

In the central and northern North Sea, it is estimated in the decommissioning survey that the topside module will costs around £4200 per tonne to remove, meanwhile, on average jackets cost £3100 per tonne to remove. The removal cost per tonne is determined by the location, previous experience, weather, installation age and will be different for each structure (Oil &Gas UK, 2012).

2.4 CASE RESEARCH PLATFORM-HEATHER PLATFORM

To make this research realistic and useful for future decommissioning, a case research is selected for the assessment. Subsequently, the quantitative results in regards to this Case Research can be contrasted and the Environmental Impacts of the Decommissioning of an alternate, entirely unexpected Offshore Platforms in the North Sea. Additionally, the result could be utilized to discover elective Options of Decommissioning for comparative tasks to alleviate the Environmental Concerns that emerges in Connection with Decommissioning of offshore platform.

The discovery of oil in Heather Field was in December 1973 and the exportation activity of its oil started on October 1978. Since 1978, more than 110 million barrels of have been extracted from the field, with a maximum average daily production of 36,000 barrels per day up to 1982. Heather field was developed with single production, drilling, production and quarter platform and has water depth of 143m. Heather Platform is situated in Block 2/5 in the U.K. Sector of the North Sea, 145km east of the Shetland Islands and was operated by Unocal Britain Limited. (Morel, 2002).

The topside has total dry weight estimated at 12,300 tonnes comprises of production, drilling, utility and quarter modules and 2 flares boom. Its jacket is designed with an 8 leg, tubular space frame and the steel structure supported by six piles which connected to each of the four legs. The jacket is approximately 17,000 tonnes in weight including piles and 41 well conductors located within pile sleeves to mudline. The growth for example living fauna on the jacket estimated to weigh about 2,000 tonnes. (Hustoft and Gamblin, 1995). Figure 8 shows Heather Platform presented in graphic.

The detailed descriptions of Heather Platform are as the following:

- Structure Type- Jacket
- Maximum height and water depth- 236 m, 143 m
- Service- Drilling production
- Topside- sitting on a deck support frame (DSF) supported by steel jacket substructure piled to seafloor
- Topside facility- lift units: drilling, production, utility and quarter modules, 2 flare booms (each 52m long), 1 drilling derrick, 2 diesel powered pedestal cranes
- Topside weight- 12,300 tonnes (including DSF)
- Jacket- 8 leg, tubular space frame steel structure
- Piles- 6 piles connected to each of the 4 corner legs

- ❖ Jacket weight- 17,300 tonnes (including the piles, grout within the pile sleeves to the mud line)
- ❖ Well conductor- 41
- ❖ Riser- 2(16 inches)
- ❖ Conductor and riser weight- 4,300 tonnes to mud line
- ❖ Marine growth- 2,000 tonnes
- ❖ Caisson- 9 for miscellaneous services (e.g. process sump, utility sump, seawater lift caisson etc.), supported by jacket structure
- ❖ Deck- 3 main deck levels (10,000 m2)
- ❖ Helideck- YES
- ❖ Pipe- 32,000 m (6 inches) oil pipeline, 19,000 (6 inches) gas pipeline

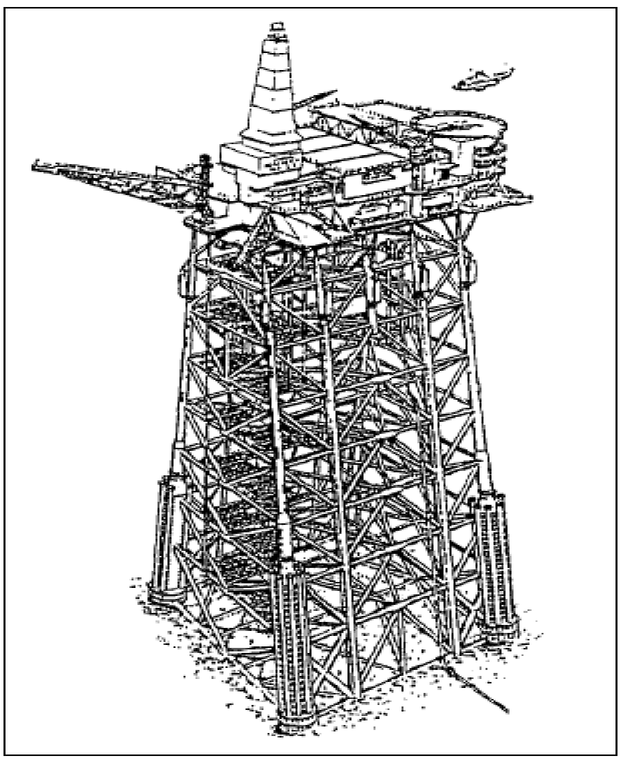

Figure 8: Heather Platform

(Hustoft and Gamblin, 1995)

The decommissioning program was broken down into several phases so that the technical and operational feasibility of options can be properly evaluated. The conceivable decommissioning plan variations could then be examined and the specialized, security, ecological and business ramifications of the distinctive plans evaluated. The diverse stages are:

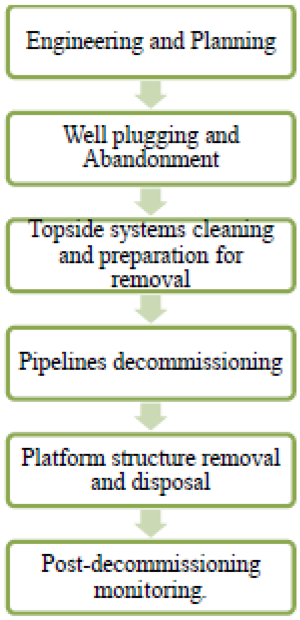

Figure 9: Heather Platform Decommissioning Stage (Hustoft & Gamblin, 1995).

CHAPTER 3
METHODOLOGY

3.1 RESEARCH METHODOLOGY

A thorough study was carried out in to make sure the research methodology is achievable. The study was conducted through online and also offline reading of past papers, journals, books, websites, conference proceeding and etc. Project plan was developed to accomplish the research within timeframe.

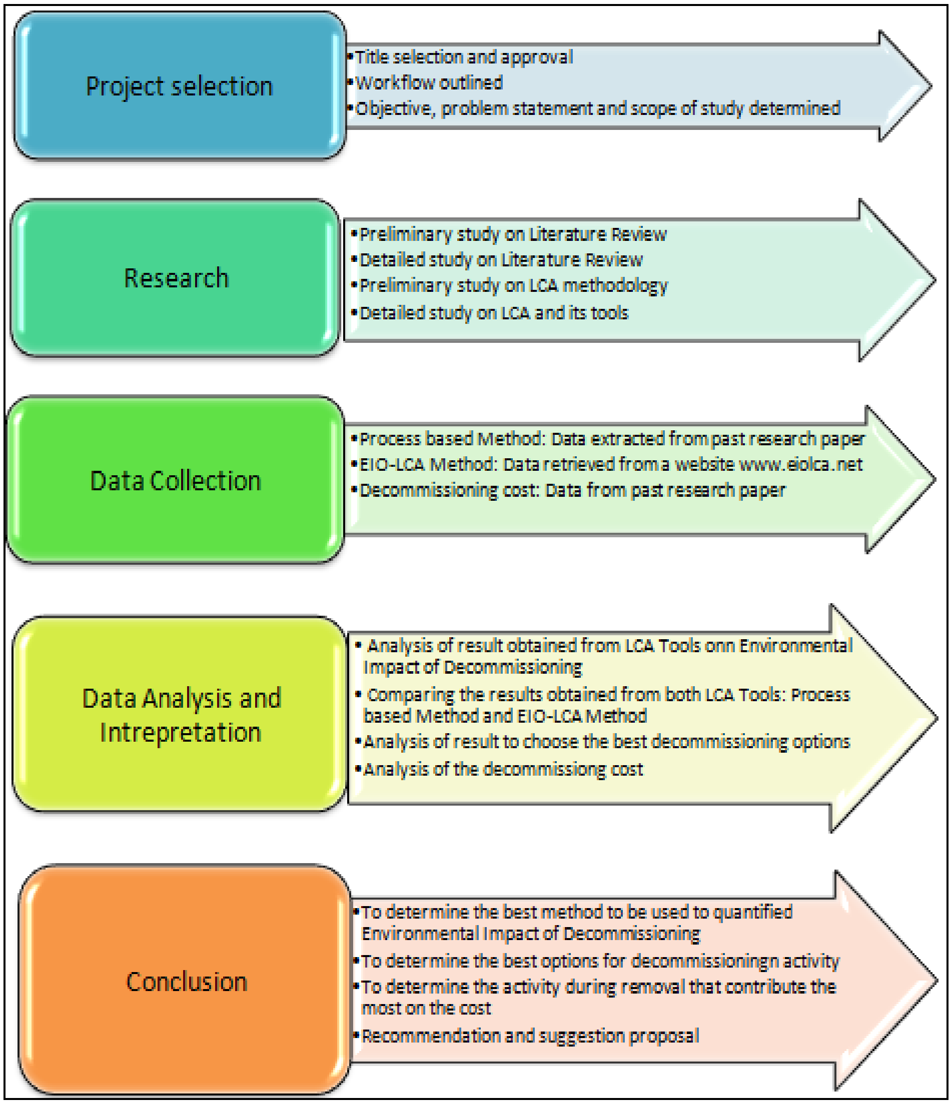

Figure 10: Research Methodology

3.2 GANTT CHART

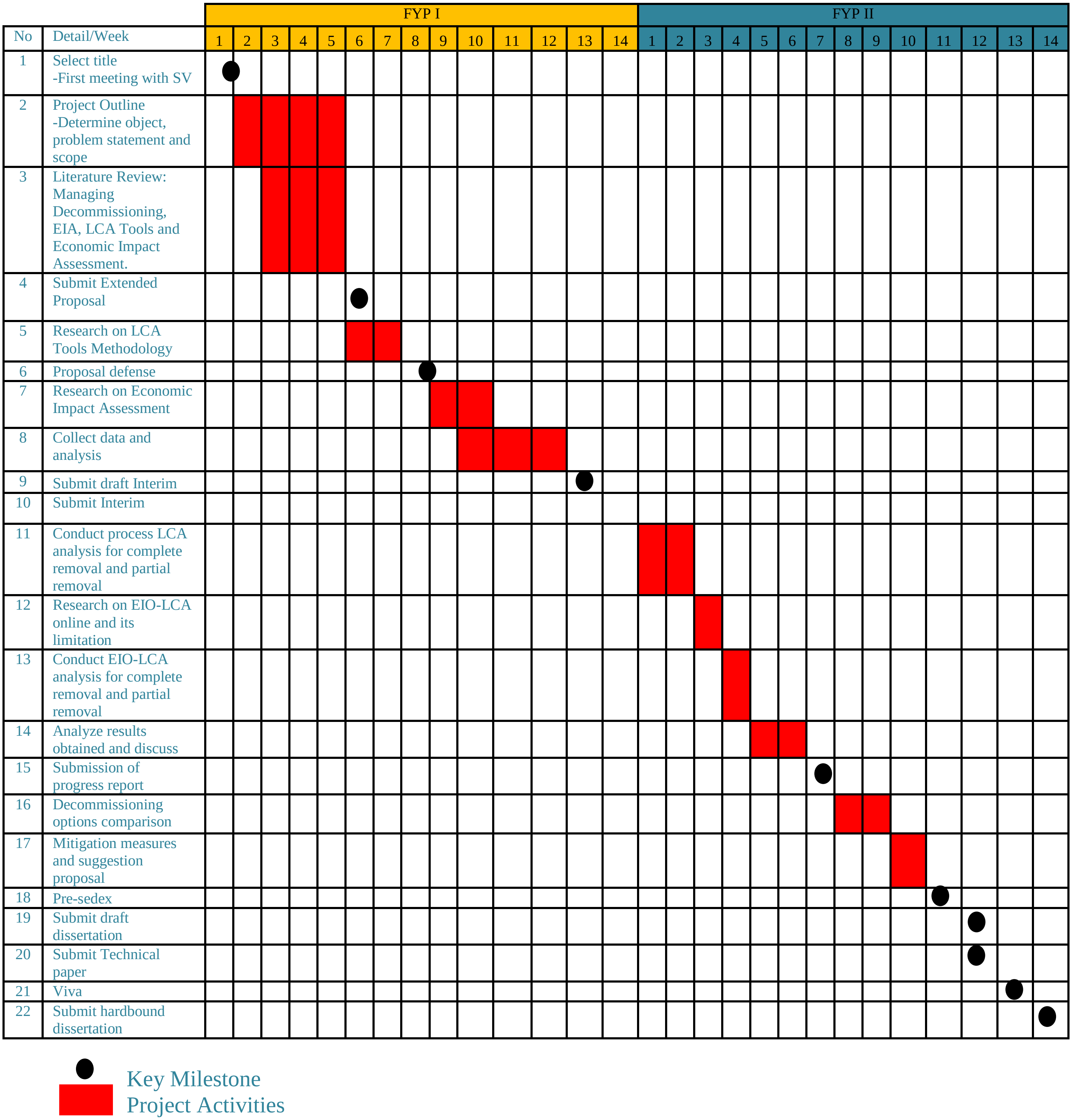

Figure 11: Gantt chart

3.3 LCA METHODOLGY

Based on ISO standardization, LCA framework consists of four phases: Goal and Scope Definition; Life Cycle Inventory; Life Cycle Impact Assessment and lastly is Interpretation. The following will described the assumptions and limitation that is considered for both Process based Method and EIO-LCA Method.

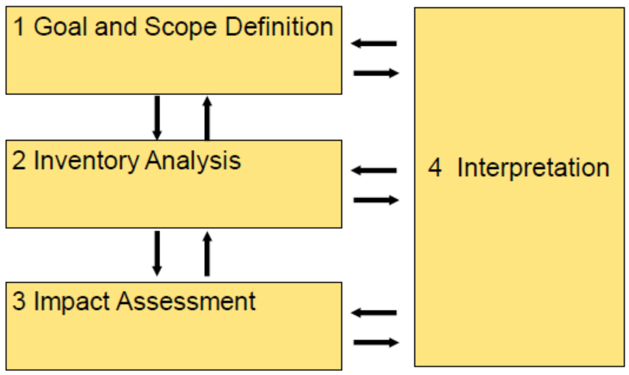

Figure 12: LCA Framework

3.3.1 ASSUMPTION AND LIMITATION FOR PROCESS BASED METHOD

Assumption and limitation for process based method must be taken into account as the data available for energy consumption and gaseous emissions is limited. Therefore, this research needs extensive analysis on informative and relevant resources. The data for process based method were extracted from a published study paper *An Estimation of the Energy Consumption and Gaseous Emission Associated with Heather Platform Decommissioning Option* published in 1997. The authors, Side, Kerr and Gamblin found that the usage of aviation fuel emit 5% different of carbon dioxide when compared to the data from European Union (2013). Thus, to ensure the data is valid, the authors of this dissertation confirmed their unit conversion factors with the published rate by Department of Energy & Climate Change (2013) and concluded that the differences are not significant. Besides that, the unit conversion factors related to onshore and offshore dismantling, removal and fabrication were produced based on the review from related experience by demolition contractors. With respect to that, this further proved that the data published by the authors are applicable and can be referred to.

The unit conversion factors and constants for energy consumption and gaseous emissions related to onshore and offshore, and round trip distance, scrap vessel haulage, engine, marine vessels and helicopter usage, recycling processes and fuel consumption during decommissioning activity used in process based method are attached in the Appendix.

3.3.2 ASSUMPTION AND LIMITATION FOR EIO-LCA METHOD

The data applied in EIO-LCA is found to be uncertain and extensively different over years. Besides, it is incomplete as the EIO-LCA model is based on the national statistical computation which is data obtained from the compilation of various surveys and forms submitted by numerous sectors of industries to the government. The model is selected among the price model from US Producer National Model specifically from US 2002 Benchmark Model with 428 sectors taken into account for statistical computation purposes. The results from this data are valid and can be referred to for this research as the statistical computation is including the economic and environmental data from a single group of sectors which is for decommissioning process, it is under Mining and Utilities group of sectors. In addition, Green Design Institute has updated the economic input output constants applied in the model from 2002 to 2009, the latest version.

3.3.3 PHASE 1: GOAL AND SCOPE DEFINITION

The goal or objective of this research is as the following:

i) To assess and compare the Environmental Impacts of Decommissioning Offshore Platform in North Sea quantitatively using LCA Tools; Process-Based Method and EIO Method.

ii) To compare the Economic Impacts from two decommissioning options for fixed platform: complete and partial removal.

iii) To recommend relevant Mitigation Measures related to the environmental and economic concerns addressed from decommissioning process.

The research case Heather Field is selected as for assessing the energy consumption and gaseous emissions as well as the cost. The scope of the study will be narrowed down into Environmental Impact and Economic Impact by comparing and assessing two decommissioning options which are complete removal and partial removal. In the research paper of Heather Platform energy consumption and gaseous emissions, Side, Kerr and Gamblin had considered some rules and boundaries for the assessment to ensure the consistency in data evaluation and to avoid energy data and gaseous emissions data is not double counted.

- Rule No. 1: For the purpose of energy analysis, indirect cost of plant and equipment not altered by decommissioning activity, are disregarded.
- Rule No. 2: Trivial energy cost is ignored.
- Rule No. 3All renewable energy and materials are considered as cost free.
- Rule No. 4: All non-renewable material lost must be replaced with comparable quality and quantity.
- Rule No. 5: All non-renewable material that is recycled will be considered as substitute material.

3.3.4 PHASE 2: LIFE CYCLE INVENTORY (LCI)

This phase includes the collection and evaluation for both input and output data on the life cycle system (Rebitzer et. al., 2003). In this dissertation, for environmental impact assessment of platform decommissioning, the Life Cycle Inventory (LCI) parameters for input would be the energy consumption whilst, the output would be the gaseous emissions focusing on the main greenhouses gaseous contributed during decommissioning of offshore platform which are Carbon Dioxide (CO2), Nitrogen Oxides (NOx) and Sulphur Dioxide (SO2) and Equivalent Carbon Dioxide.

As mentioned previously, process based method and EIO-LCA method will be utilized in this dissertation. As for process based method, the data were extracted from the published research paper in 1997 by Side, Kerr and Gamblin on *Estimation of Energy Consumption and Gaseous Emissions associated with Decommissioning of Heather Platform*. The decommissioning aspects are breakdown into seven aspects for the result analyses of process based method as shown in Figure 13 below:

Options	Aspects	Related Variables
Complete Removal and Partial Removal	Temporary steelwork	• Energy consumed for transportation and manufacturing, haulage, fabrication, dismantling and recycling of temporary steelwork such as grillages, sea fastenings, lifting aids and structural strengthening • Miscellaneous steelwork
	Platform facility dismantling	• Recovered platform materials • Fuel consumption for transportation for recycling and dismantling activity.
	Marine vessel utilization	• Fuel consumption • Gaseous emission produced
	Platform running	• Product of platform running • Fuel consumption
	Helicopters	• Estimated helicopter flying man-hours • Fuel consumption.
	Platform materials recycling	• Recycling products
	Platform materials left at sea	• Material left in-situ products
Partial Removal		•

Figure 13: Breakdown of Decommissioning Aspects with Respective Parameters

The data variables used in energy consumption and gaseous emissions evaluation for each decommissioning aspects can be referred to Appendix.

On the other hand, for EIO-LCA data, it is estimated based on the monetary value. Since Heather Field is situated in the North Sea, the cost data are based on the report on decommissioning cost specifically for platform located in North Sea, *Decommissioning Insights published by Oil & Gas UK in 2012.* From a survey, it is found that to remove the topside module the cost is estimated to be around £4200 per tonne, meanwhile the jacket will cost around £3100 (Oil & Gas UK, 2012). However, these values are not consistent and depending on several factors such as the field location, experience in decommissioning, weather and the age of the platforms. The total weight for complete removal of Heather platform was calculated to be about 35,600t which will cost about £123.89 million, equivalent to 194.63 million USD. From this total, the cost around £51.66 million and weighted about 12,300t comes from the topside module, while the cost around £72.23 million, weighted about 23,300t comes from the jacket (Side, Kerr and Gamblin, 1997).

As for partial removal, the jacket is left at sea at 55meter from the seabed and the rest will be removed. According to Hustoft and Gamblin (1995), 55meter of jacket from the seabed weights about 20% (4,660t) from the overall weight of the jacket. Thus, the total cost for partial removal is the summation of 20% (about £14.45 million) from the overall weight of jacket and marine growth (about £9.40 million, weight 3,029t) added with topside weight cost around £51.66 million which gives the total of £75.53 million equivalent to 118.66 million USD which is lower than complete removal option.

Since decommissioning cost data was presented in British Pound Sterling, the value must be converted in US Dollar before used for environmental and economic assessment in EIO-LCA model. The daily fluctuation of currency rate is considered not significant when compared to decommissioning cost as the value is very small, thus it would not affect much and can be ignored. Lastly, an EIO-LCA method will be performed online to evaluate the total energy consumption and gaseous emissions during decommissioning of offshore platform. The criteria and procedures to use the model are summarized as in Figure 14 below:

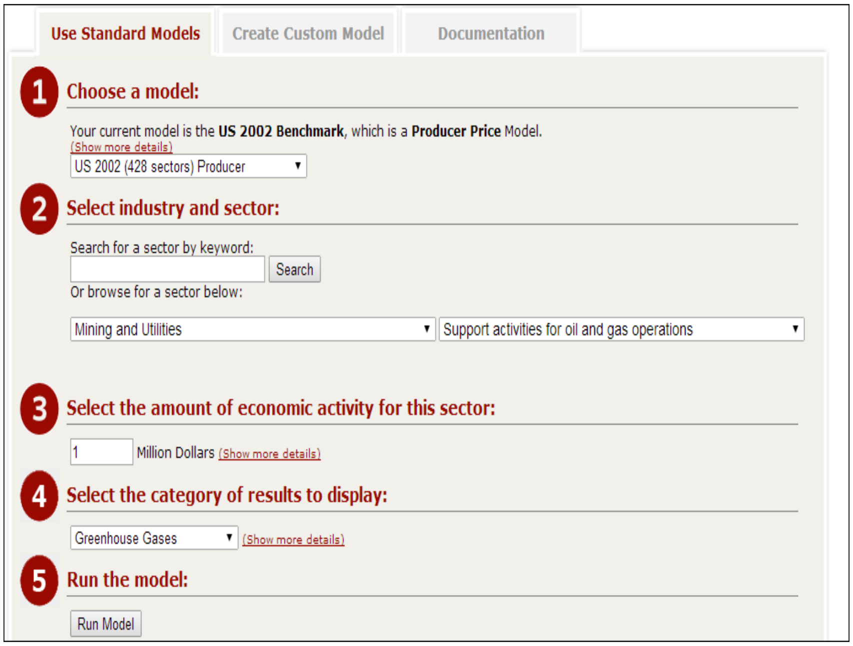

Figure 14: EIO-LCA Procedure

The display on the result category in step number four (4) can be changed according to the input that wants to be reviewed. In this dissertation, the inputs were reviewed on Greenhouse Gases, Conventional Air Pollutants and Economic Activity to obtain the data for Carbon Dioxide, Sulphur Dioxide and Nitrogen Oxide and Economic activity respectively.

3.3.5 PHASE 3: LIFE CYCLE IMPACT ASSESSMENT (LCIA)

This phase is aimed at evaluating the importance of potential environmental impacts using the results of the life cycle inventory analysis. The inventory procedure is as the following:

i. parameters will be grouped into several categories of impact
ii. Then modeled according to the category
iii. The category will be arranged with impact priority
iv. Lastly, the weight age of each impact will be identified

In this dissertation, the impacts are the gaseous emissions. Mitigation approach will be proposed for each impact and the focused on the one that contribute greatest risk to the environment.

3.3.6 PHASE 4: INTREPRETATION

In this phase, the result which is based on the inventory analysis will be concluded. From the conclusion made, mitigation measures to reduce the impacts will be proposed.

CHAPTER 4
RESULT AND DISCUSSION

4.1 RESULT AND DISCUSSION

4.1.1 EIA: PROCESS BASED LCA METHOD

As stated in Chapter 3 the data on energy consumption and gaseous emissions produced during decommissioning activity of Heather Platform were imported from a published research paper in 1997, *"Estimation of Energy Consumption and Gaseous Emissions Associated with the Decommissioning of Heather Platform"*. Based on the methodology, the authors of the paper, Side, Kerr and Gamblin, they calculated the results after the evaluative rules, relevant boundaries and assumptions were taken into consideration. For Process based Method results, the data were extracted directly from the paper and imported into a spreadsheet. The spreadsheet was used to perform the calculations of energy consumption and gaseous emissions into of tables, bar charts and pie charts for evaluation and analysis as shown in the Figures below.

Table 3: Complete Removal and Partial Removal Difference

Variable	Complete Removal	Partial Removal	Difference (Complete Removal – Partial Removal)	
			Unit	%
Energy Consumption (GJ)	939,479	881,309	58,170	6.19
NOx Emissions (Kg)	624,318	411,470	212,848	34.09
SO_2 Emissions (Kg)	631,674	452,688	178,986	28.34
CO_2 Emissions (Kg)	65,149,362	71,709,855	-6,560,493	-10.07
Equivalent CO_2 Emissions (Kg)	26,301,329	19,812,430	6,488,899	24.67
Overall CO_2 Emissions (Kg)	91,450,691	91,522,286	-71,595	-0.08

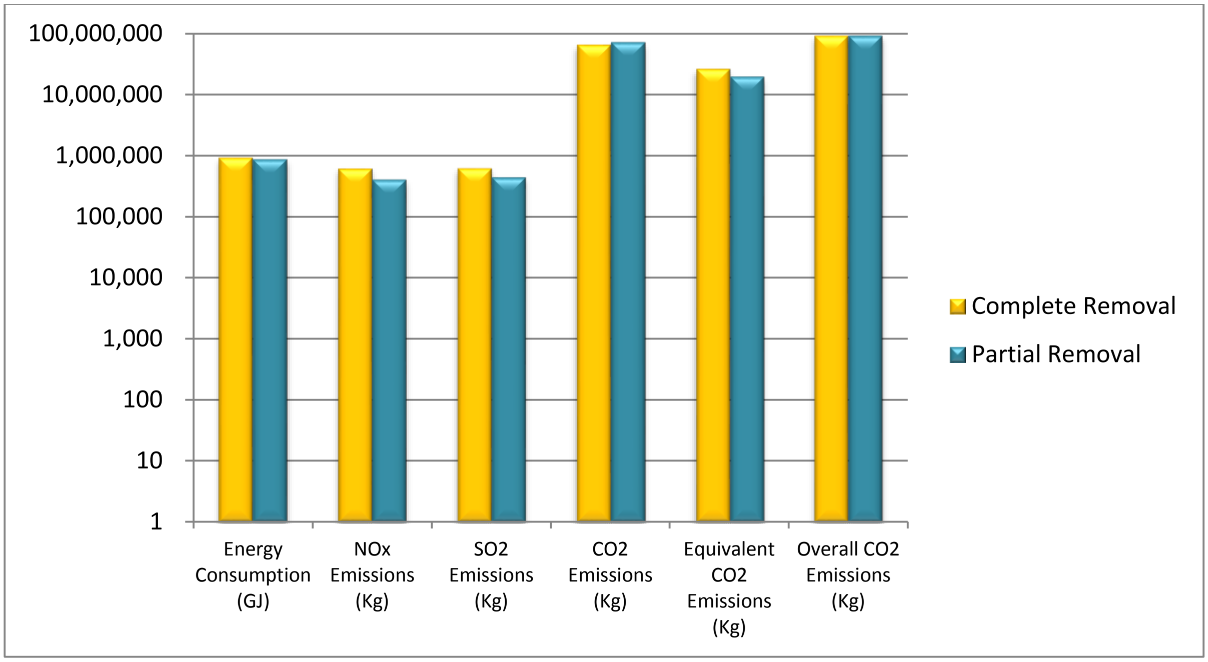

Figure 15: Comparison of energy consumption between complete and partial removal of Heather Platform.

Referring to Table 3, when compared to partial removal, the decommissioning activity for Heather Platform using complete removal option consumed 6.19% more energy, and emitted 34.09% more NO_x, 28.34% more SO_2, and 24.67% more Equivalent CO_2. Partial removal options shows 10.07% more emissions of CO_2 and 0.08% more Overall CO_2 emission. However, these values are not significant to conclude partial removal gives more negative impact to environment than complete removal as when calculated in total volume, complete removal appears as the higher over partial removal option.

In Figure 15, the differences between complete removal and partial removal become more immediately apparent. The total weight to be removed for complete removal is around 35,600t meanwhile for partial it is only around 19,989t. Thus, it is logic that in term of energy consumption and total gaseous emissions, complete removal is higher than partial removal as the more the quantity removed, the more energy needed for transportation from offshore to onshore for recycling purposes. From this standpoint, partial removal is concluded become the most favorable option for decommissioning activity.

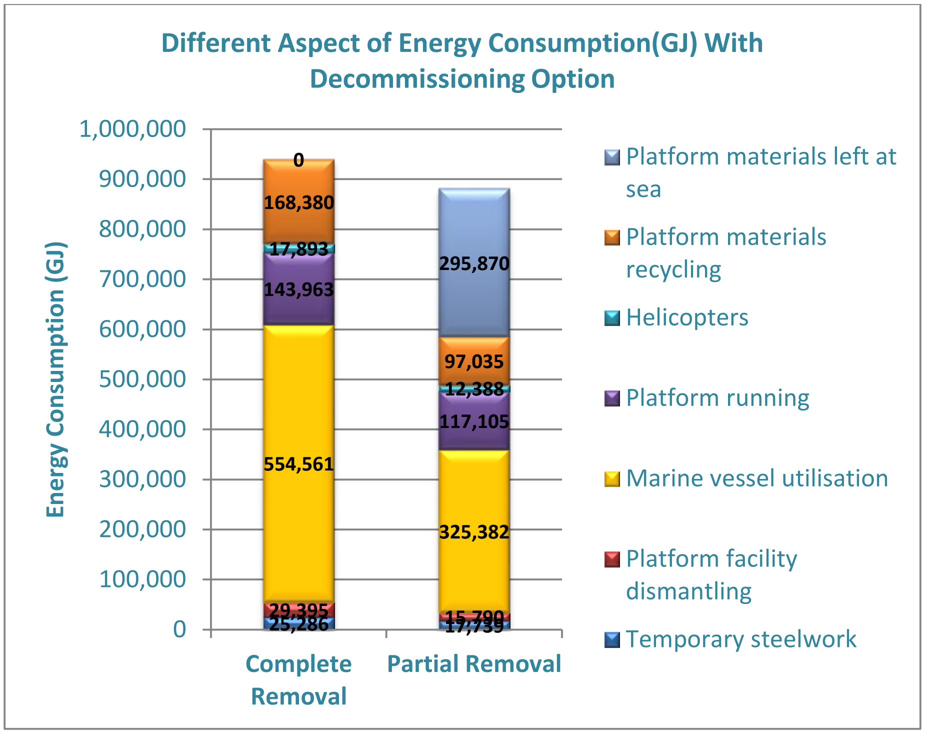

Figure 16: Breakdown of energy consumption for complete and partial removal of Heather Platform

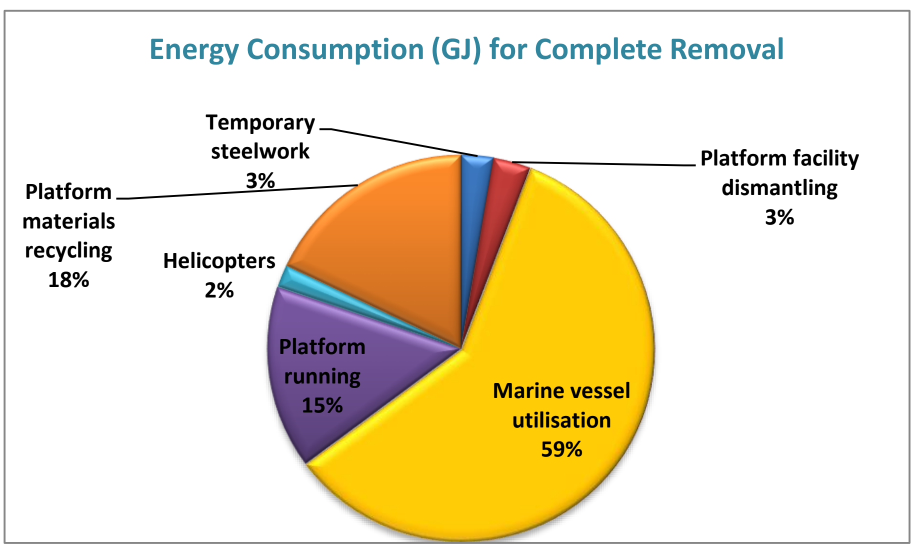

Figure 17: Energy consumption for complete removal of Heather Platform

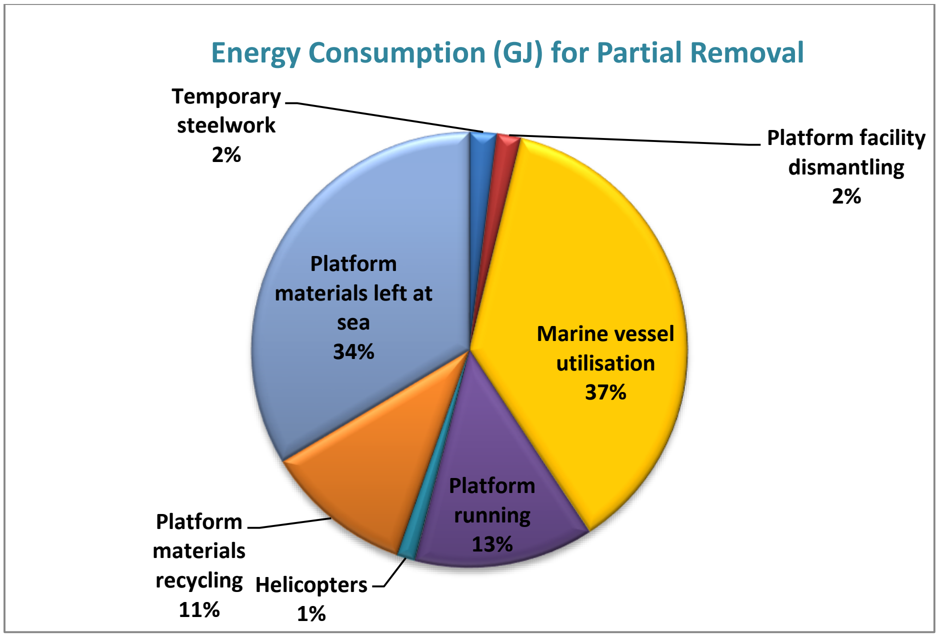

Figure 18: Energy consumption for partial removal of Heather Platform.

As shown in Figure 16, complete removal appears to be higher over partial removal. For complete removal, the breaking down of energy consumption with respective decommissioning aspects in Figure 17 indicates that the greatest energy consumption was during the marine vessel utilization (59%), followed by platform material recycling (18%) and platform running (15%). On the other hand, for partial removal, as appeared in Figure 18, the energy consumption is the greatest during marine vessel utilization (37%), followed by platform material left at sea (34%), platform running (13%) and platform material recycling (11%). However, platform material left at sea is not comparable to be counted as the energy is actually not consumed but wasted due to recyclable steel jacket is left in the sea. Thus, it can be concluded that, the utilization of marine vessel, followed by platform running and platform material recycling are among the greatest aspects of decommissioning that consume energy the most.

In term of gaseous emissions, CO_2 is the highest gaseous produced during the decommissioning of offshore platform. For the analysis purposes, overall CO_2 will be considered and focused. However, both CO_2 and Equivalent CO_2 emissions are the main factor for global warming that causing in the rise of sea level and heat waves. It is obvious as in Figure 19, that complete removal is slightly higher over partial removal on equivalent CO_2, it generates 24.67% greater than partial removal. However, for overall CO_2 emission, complete removal only shows 0.08% difference over partial removal.

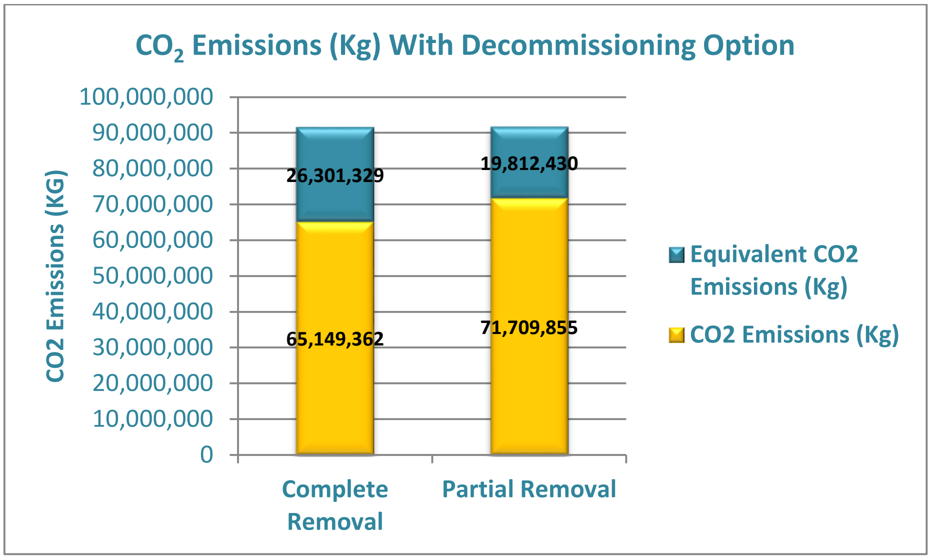

Figure 19: CO_2 emissions for complete and partial removal of Heather Platform

From the breaking down of decommissioning aspects with respective options as shown in Figure 20, the overall CO_2 for complete removal and partial removal only has 0.08% difference. This very little difference of overall CO_2 emission is due to the consideration to include the reduced of gaseous emissions from activity left material at sea that has saved the energy consumption for recyclable material transportation to onshore. For complete removal, Figure 21 indicates that CO_2 emissions shows the greatest during the utilization of marine vessel with 67% emissions, followed by platform material recycling with 15% emissions and then platform running with 12% emissions. On the other hand, for partial removal, as illustrated in Figure 22, CO2 emissions shows the greatest during utilization of marine vessel with 39% emissions, followed by platform material left at sea with 38%, lastly platform running and platform material recycling with 9% emissions respectively. Without considering the platform left at sea as explained previously, thus, it can be concluded that, the utilization of marine vessel, followed by platform running and platform material recycling are among the greatest aspects of decommissioning that produce greatest amount of CO_2.

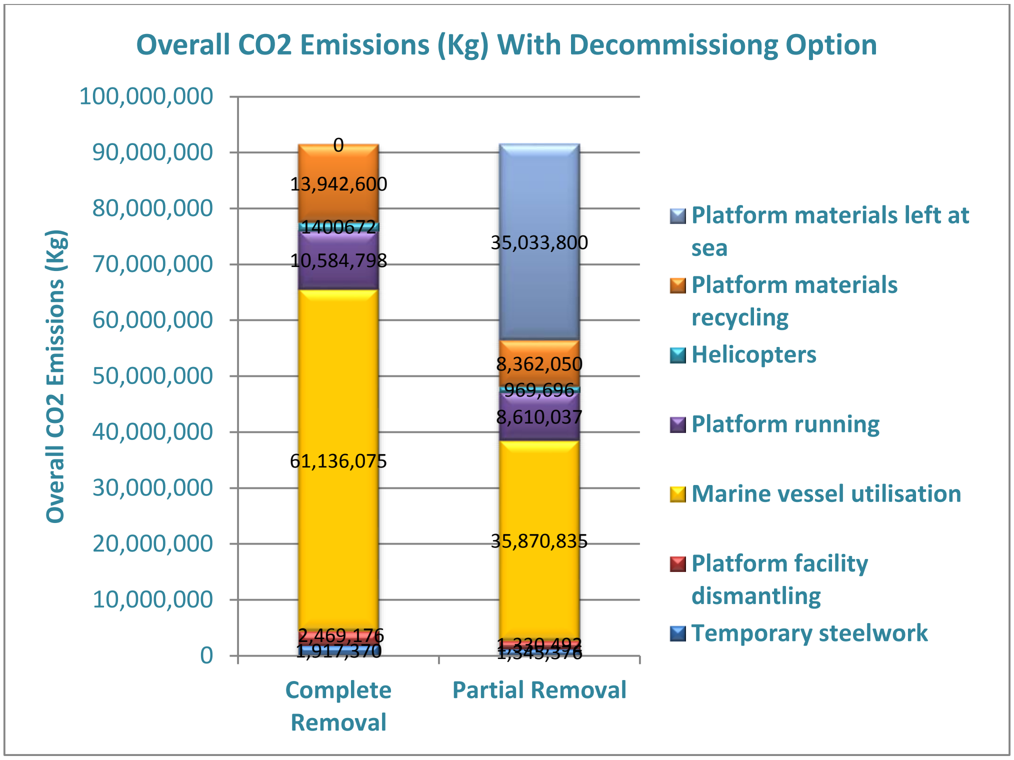

Figure 20: Breakdown of Overall CO_2 emissions for complete and partial removal of Heather Platform

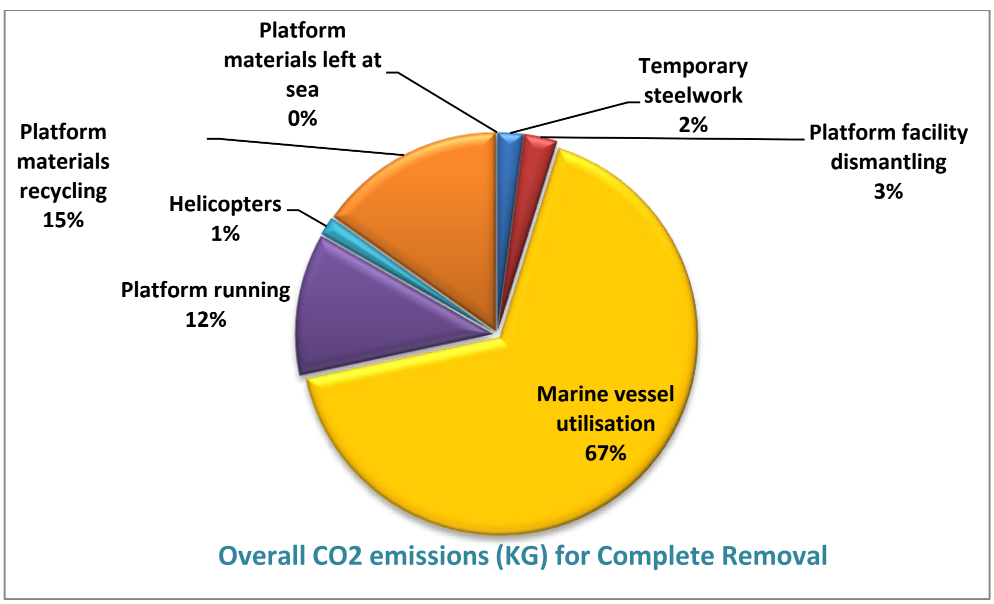

Figure 21: Decommissioning aspects of Overall CO_2 emissions for complete removal of Heather Platform

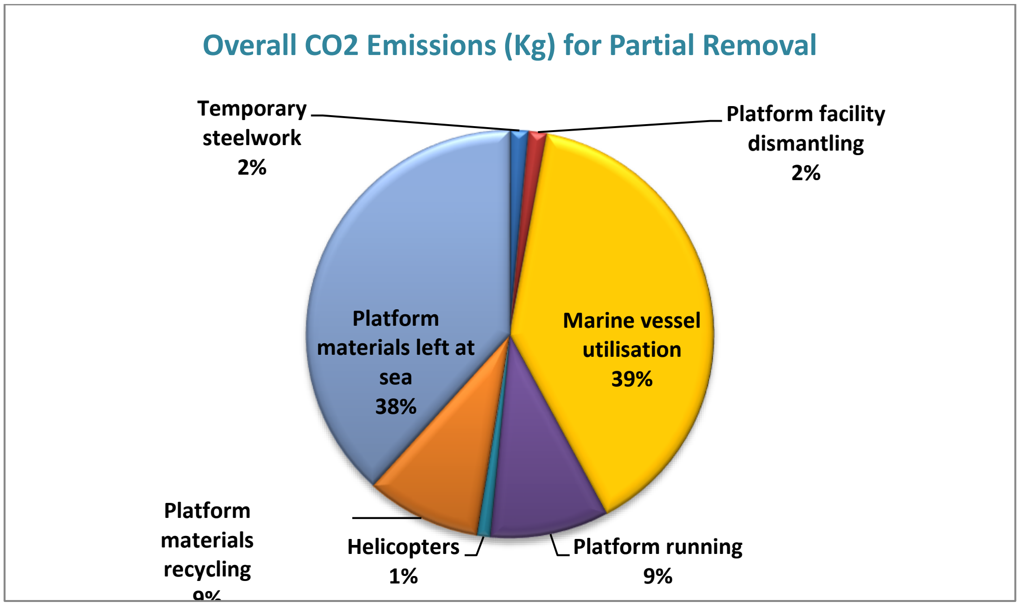

Figure 22: Decommissioning aspects of Overall CO_2 emissions for partial removal of Heather Platform

SO_2 and NO_x are the next highest gaseous emission after CO_2. These pollutants when emitted into the atmosphere will react with water and other compounds to form an acidic compound which is very detrimental to public's health, accelerated decay of buildings and harm on sensitive forest. Figure 23 below indicates that complete removal produces higher SO2 and NOx with 28.34% and 34.09% greater over partial removal respectively. This is best explained due to the greater usage of marine vessel for steel jacket transportation followed by platform material transportation for recycling purposes.

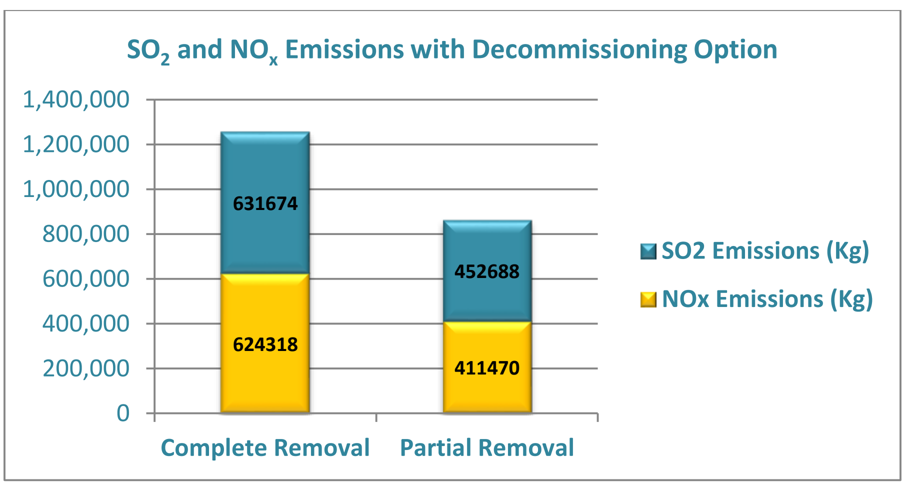

Figure 23: SO_2 and NO_x emissions for complete and partial removal of Heather Platform

After the evaluation and analysis of the results for Process based Method, complete removal option is found to be not favorable for decommissioning option due to the great amount of energy consumption and emissions of greenhouse gaseous. Of the seven decommissioning aspects, the utilization of marine vessel is found to be the greatest contributor of degradation in environment quality.

4.1.2 EIA: EIO-LCA METHOD

As stated in Chapter 3, EIO-LCA method is based on monetary value. The data were performed online at www.eiolca.net designed by Green Design Institute. The model is selected among the price model from US Producer National Model specifically from US 2002 Benchmark Model with 428 sectors under support activities for oil and gas operations. The energy consumption and gaseous emissions in that model are presented as standard unit for economic value of 1 USD and attachment can be referred to Appendices. To calculate the total cost of energy consumption and gaseous emissions, the cost data are referred to estimate data cost by Oil & Gas UK (2012).

Table 4: EIO-LCA result for complete removal and partial removal of Heather Platform

Variable	Standard unit (1 million USD)	Complete Removal (194.63 million USD)	Partial Removal (118.66 million USD)	Difference (Complete removal-Partial removal)	
				Unit	%
Total Energy Consumption (GJ)	7,790.00	1,516,167.70	924,361.40	591,806.30	39.03
NO_x Emissions (Kg)	6,330.00	1,232,007.90	751,117.80	480,890.10	39.03
SO_2 Emissions (Kg)	1,890.00	367,850.70	224,267.40	143,583.30	39.03
Overall CO_2 Emissions (Kg)	650,000.00	126,509,500.00	77,129,000.00	49,380,500.00	39.03

From the Table 4 above, the statistic from the online model shows CO_2 emissions during decommissioning process in term of 1 million USD are the highest among the parameters. However, the difference between complete and partial removal is depending on the cost estimated for platform located in North Sea. Thus for Heather Platform, in term of energy consumption and gaseous emissions, complete removal gives 39.03% difference compared to partial removal.

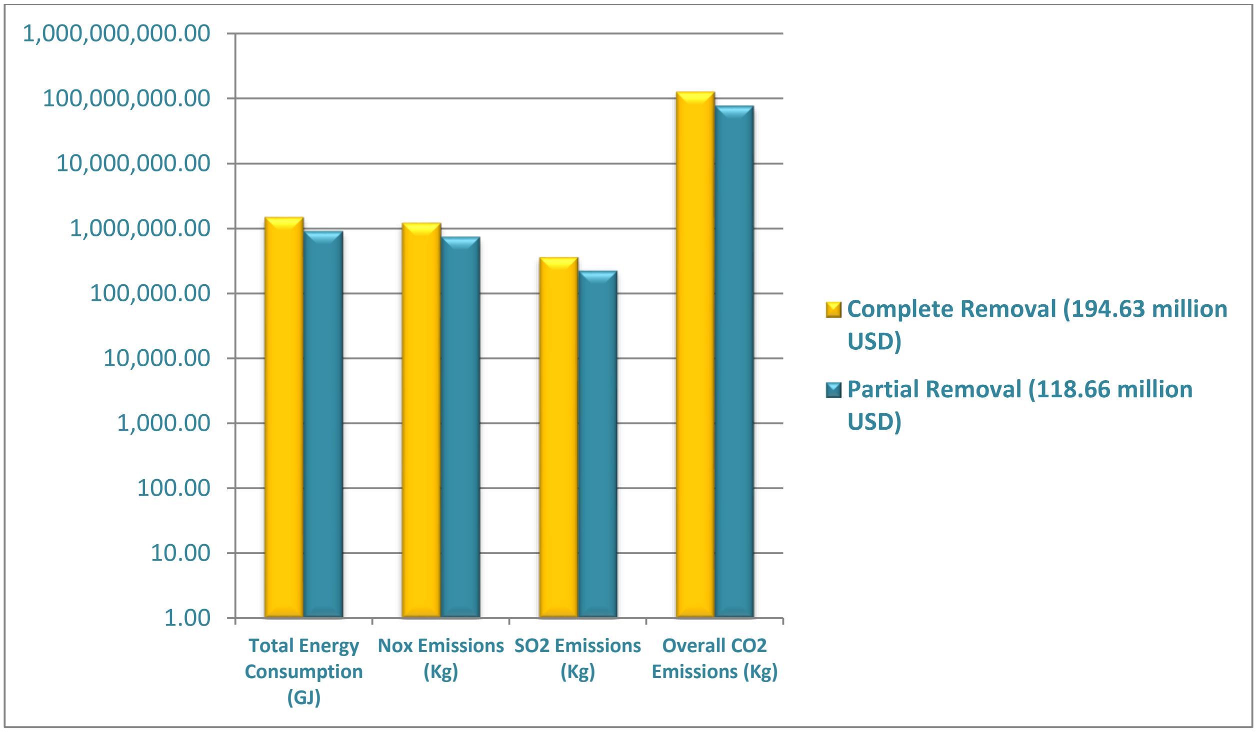

Figure 24: Comparison between complete removal and partial removal on energy consumption and gaseous emissions

The apparent difference between complete removal and partial removal can be seen as in Figure 24 above. It is clearly illustrated that complete removal is higher than partial removal in term of energy consumption and greenhouse gaseous emissions.

The take away from Process based Method and EIO-LCA Method are summarized as the following:

i. Complete removal is not favorable for offshore decommissioning due to the impact on environment. Thus, partial removal is recommended.

ii. The utilization of marine vessel for recyclable material to onshore is the major contributors to environmental impact during decommissioning process.

4.1.3 PROCESS BASED METHOD AND EIO-LCA COMPARISON

Referring to the process based and EIO-LCA result, the difference between complete removal and partial removal regarding the energy consumption and gaseous emission varies from -0.08% to 34.09% and 39.03% respectively. In the following paragraph, the comparison between these two tools, by computing their differences on each considered decommissioning option will be made to know specifically after the selection of decommissioning options, which tool is more appropriate for the computation of energy consumption and gaseous emissions.

Table 5: Comparison between Process based and EIO-LCA

Variable	Complete Removal		% Difference (Partial removal - Complete Removal)	Partial Removal		% Difference (Partial removal - Complete Removal)
	Process based	EIO-LCA		Process based	EIO-LCA	
Energy Consumption (GJ)	939,479	1,516,168	-61.38	881,309	924,361	-4.89
NOx Emissions (Kg)	624,318	1,232,008	-97.34	411,470	751,118	-82.54
SO2 Emissions (Kg)	631,674	367,851	41.77	452,688	224,267	50.46
Overall CO2 Emissions (Kg)	91,450,691	126,509,500	-38.34	91,522,286	77,129,000	15.73
∑ Difference			**-155.29**			**-21.24**

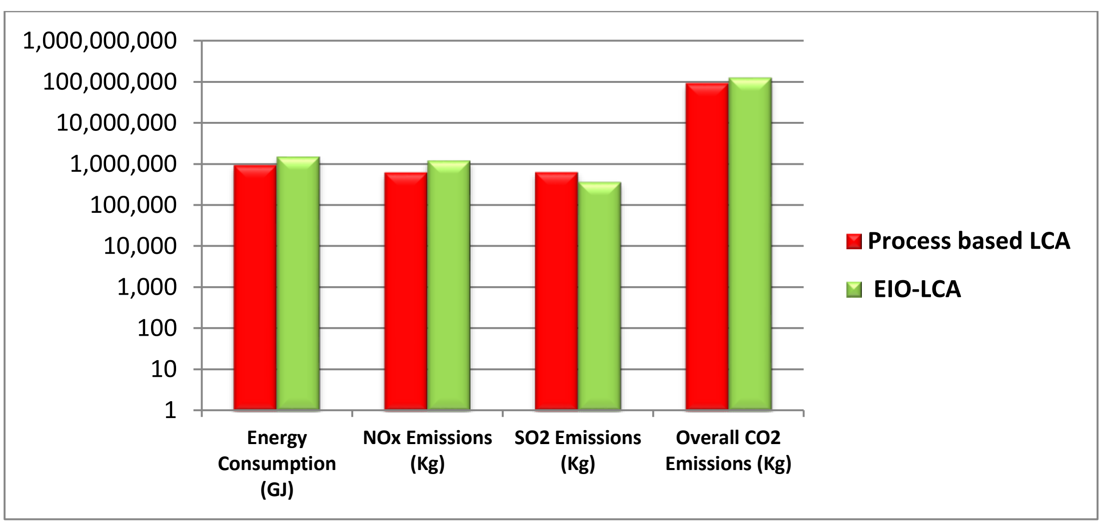

Figure 25: Comparison of process based LCA and EIO-LCA for complete removal

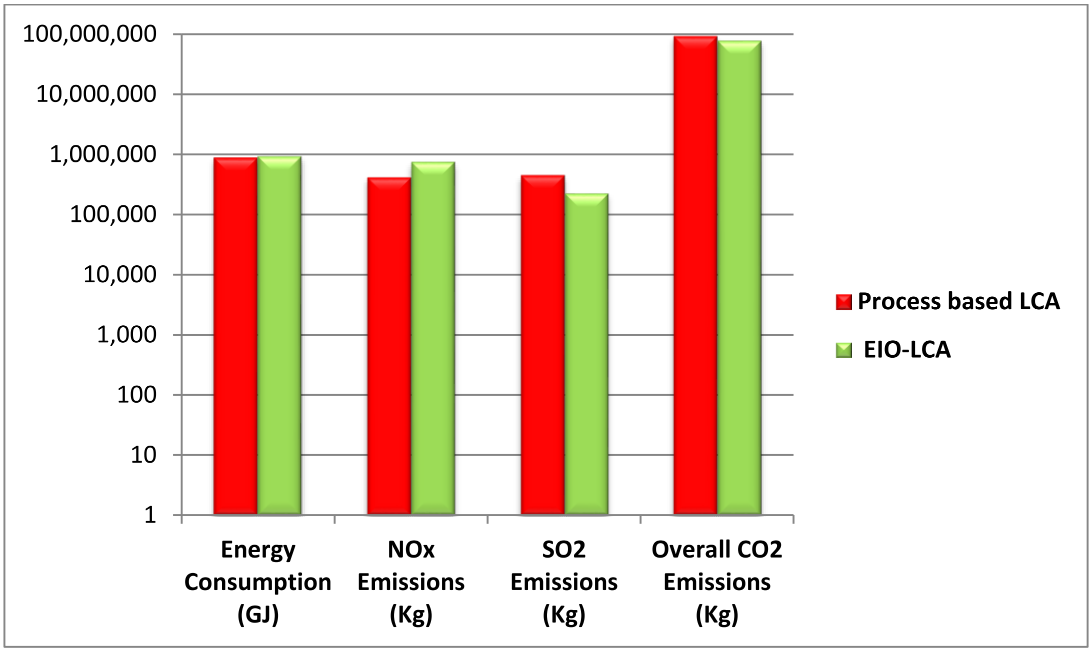

Figure 26: Comparison of process based LCA and EIO-LCA for partial removal

Based on Table 5, it is clear that for complete removal option, EIO-LCA method indicates more energy consumption (61.38%), more NO_x production (97.34%) and more CO_2 production (38.34%) but lesser SO_2 production (41.77%) over process based LCA method. On the hand, for partial removal option, EIO-LCA method indicates more energy consumption (4.89%), more NO_x production (82.54%) but lesser CO_2 production (15.73%) and lesser SO_2 production (50.46%) over process based LCA method. To make the comparison between both tools easier, the total summations of the percentage difference are taken. In this case, by implementing EIO-LCA Method, the environmental impact results from offshore platform decommissioning are 155.29% higher than Process based Method for complete removal and 21.24% higher than Process based Method for partial removal. The differences between LCA Tools for complete removal and partial removal option become more apparent as presented in Figure 25 and 26.

4.1.4 ECONOMIC IMPACT BETWEEN COMPLETE REMOVAL AND PARTIAL REMOVAL OPTIONS

From previous subtopic, it can be concluded that either by using Process based Method or EIO-LCA Method, assessment on the energy consumption and gaseous emissions generated during decommissioning of offshore platform, has shown that complete removal option appears to be not favorable as it gives more degradation in environmental quality compared to partial removal option. However, for marginal market purposes, energy consumption and consequently energy cost and gaseous emissions cannot be the decisive factor for one option. Besides, it is economic to assess the platforms installed in same region based on cumulative annually cost up to certain years in order to get comparable cost between the decommissioning options. Scheelhaase (1998) in her study stated that in other to make the cost between complete removal and partial removal comparable, the assessment is better done for all platforms located in same region and certain areas should be analyzed; decommissioning cost for each option, employment for each option, fiscal aspect, and the recycling effect. The economic cost impact data for this dissertation is taken from a published paper in 1997, *Platform Decommissioning- Socio Economic Impacts* for platform installed in North Sea and North East Atlantic. The decommissioning economic cost impact is aggregated cumulative up to 2020.

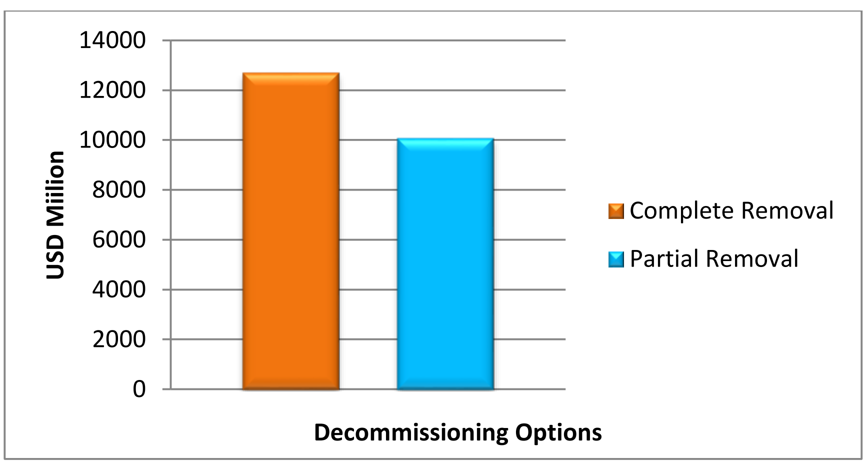

Figure 27: Total decommissioning cost up to 2020

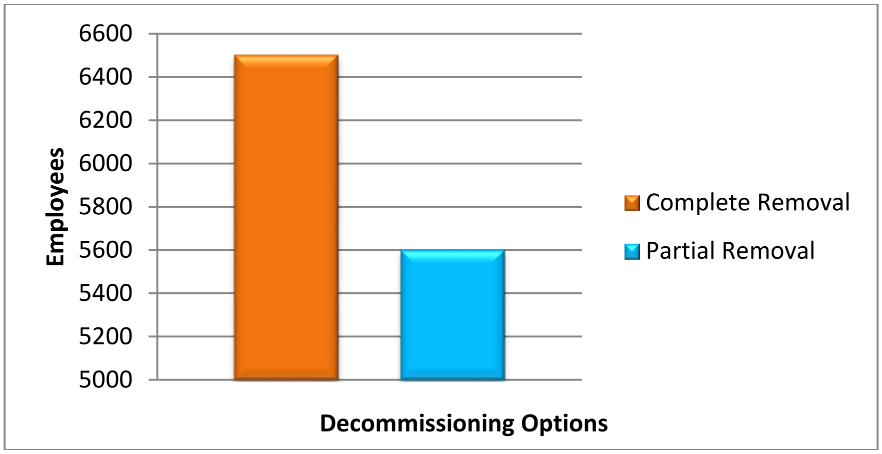

Figure 28: Direct and Indirect Employment

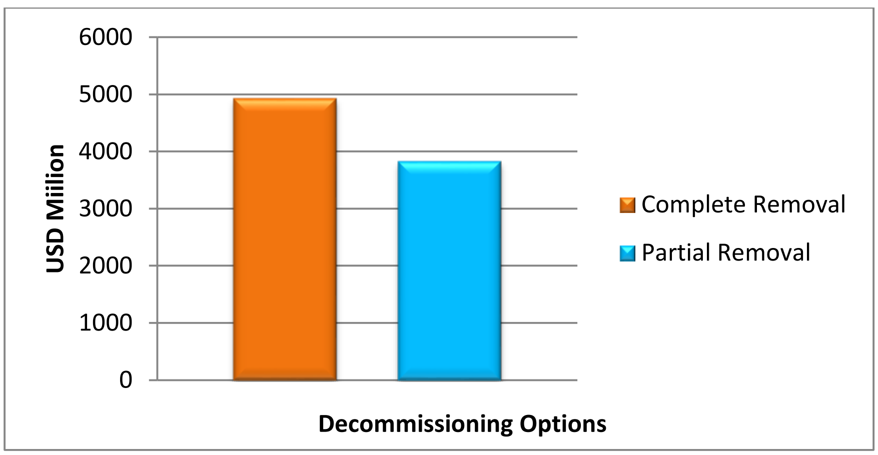

Figure 29: Fiscal effect- Net Government Expenditure

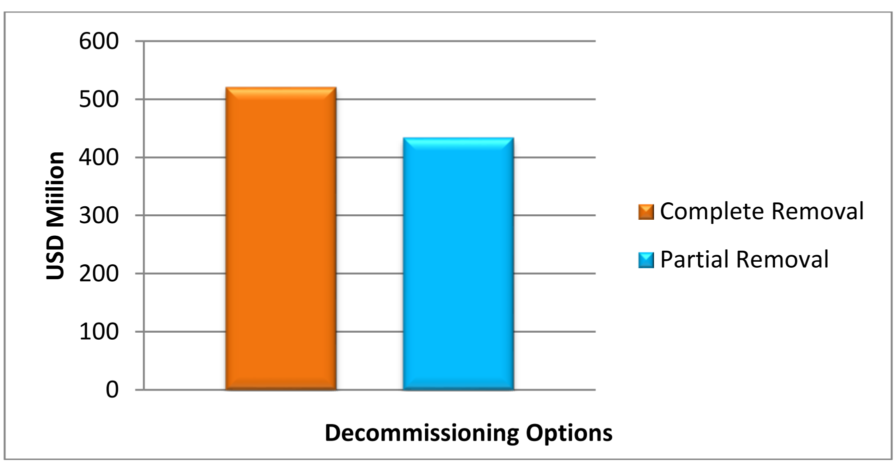

Figure 30: Sales of scrap-Recycling

As indicated in Figure 27, 28, 29 and 30, it is obvious to conclude that complete removal has higher decommissioning cost, higher employment, higher fiscal cost effect and higher return from scrap selling compared to partial removal. This shows that, for long term and short term decommissioning activity, partial removal is recommended due to is favorable impact on environment as well as economy.

4.2 PROPOSED MITIGATION MEASURES

The conclusion that can be withdrawn from the quantification of the results is that the utilization of marine vessel becomes the main factor to degrade the environmental quality. More scholars, governments and some related parties are aware to put efforts in addressing some measures to protect the environment. The proposed mitigation measures can be divided into technical and operational strategy and also through provision and regulation as presented in Table 6 below. Figure 31 shows the potential fuel and CO_2 reduction from technical approaches.

Subject to Mitigate	**Mitigation Measures**	**Approaches**	**Source/ Reference**
Marine Vessel Utilization to reduce fuel consumption and CO_2 emission	Technical measures	• Propeller must be well maintained, frequent upgrading • Propeller polishing and regularly cleaned to reduce frictional losses and trailing turbulences • Replace damaged propeller • Hull cleaning and coating to prevent marine growth from being attached to the surface and then provide unnecessary weight/load to the vessel. Hull coating is done using docking cycle which will be determined by the amount of energy consumption and hazardous gaseous emissions. • Optimized shaft power by setting constant RPM. • Save fuel consumption	• Lloyd's Register (2012) • European Commission (2015)
	Operational Strategy to reduce harmful gaseous emissions	• Route planning- taking consideration the distance, current and weather forecast, loading capacity, optimized speed to reach just in time • Using renewable energy such as wind engines and heat recovery which able to reduce CO_2 up to 10% while generating thrust to provide some propulsion and reducing fuel cost.	• Transport & Environment (2012)
NOx and SO_2	Provision and Regulation	• International Convention for the Prevention from Ships (MARPOL Convention) in 1997: set a global cap of 4.5% of sulphur content of marine fuel • Enforcement through incentive-driven government policy is another effective way to mitigate NO and SO_2 emission from vessel utilization • United States Environmental Protection Agency: Introduce Cap and Trade policy in order to mandate a limit on the emissions of air pollutants and other form of exhausts which is rewarded in the form of trade-offs or benefits such as allowance banking or other economic incentives; One of the success stories from the Cap and Trade policy is the Acid Rain Program which mandates the power sector to reduce its SO_2 and NO emission by improving the efficiency of its power generation units.	• United State Environmental Protection Agency (2012)

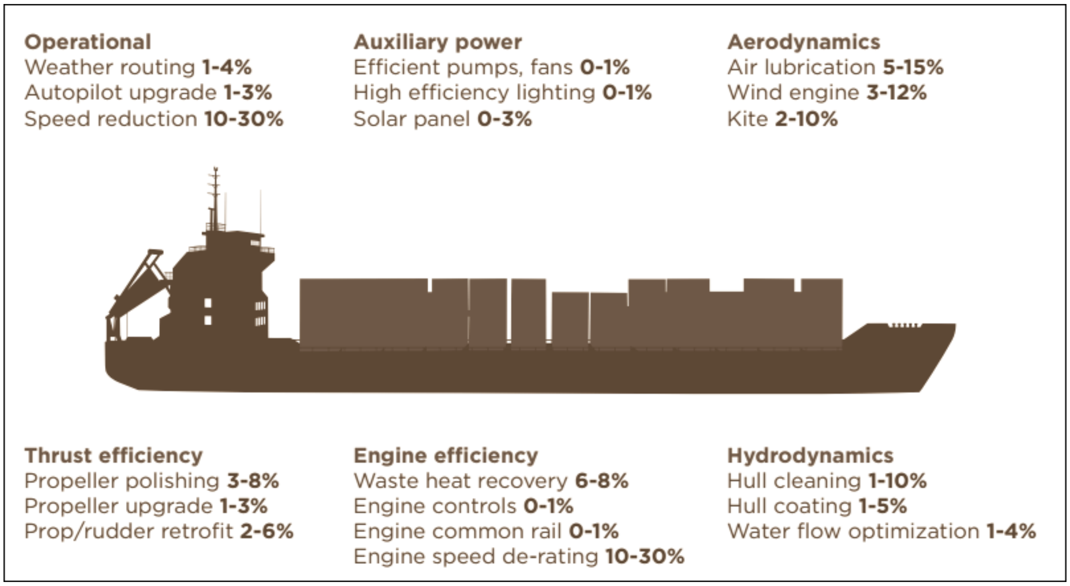

Figure 31: Potential fuel and CO2 reductions from various efficiency approaches (Wang and Lutsey, 2013)

CHAPTER 5
CONCLUSION

5.1 CONCLUSION

The exploration of oil and gas is getting increased by years thus, the number of offshore installation also increasing. Once the service life of a platform is reaching their production life, the decommissioning activity of that platform is being planned and executed. Therefore, in the upcoming years, the scale of decommissioning activity is expected to grow. The issue with decommissioning of offshore platform is that it will give negative effects to the environment and in economic view, it is costly. In conjunction to this issue, the study on quantifying the environmental impacts in term of energy consumption, emissions of harmful gaseous that focusing on CO_2, SO_2 and NO_x as well as the economic view between complete and partial removal have been carried out. The methods used to quantify the environmental impacts are LCA tools that comprised of process based LCA and EIO-LCA method. In the meantime, for economic impact assessment, decommissioning cost is assessed by taking consideration the cost removal elements. Other components that influenced the cost of such as fiscal effect and direct and indirect employment cost also have been discussed so that cost comparison between those options is more comparable.

The input data to perform LCA analysis is presented based on actual North Sea Facility- the Heather Platform. The data for process based LCA is extracted from a published paper on estimation of total energy consumption and gaseous emissions associated with decommissioning of Heather Platform. On the other hand, for EIO-LCA analysis, the data is retrieved online provided by the Green Design Institute's online tool on www.eiolca.net. The cost data for energy consumption and gaseous emissions is obtained from Oil & Gas UK (2012). Due to limited data on the decommissioning cost for complete and partial removal of Heather Platform, thus for both options are compared from the total energy consumption as energy cost. However, some cost components have been taken into account to calculate the overall costs. For this purpose, the data is taken from published study of general fixed platform economic assessment.

The result concluded that both tools (process based LCA and EIO-LCA) are capable to evaluate the environmental impacts associated from decommissioning activity however, the limitation and assumption of data will affect the result. Although the numerous differences are clearly indicated in the results, the both LCA tools has similar observation that complete removal as overall, consume the most energy and produce greatest amount of those harmful gaseous emissions.

The finding has clearly shown that the utilization of marine vessel during decommissioning process is the main factor to the environmental impacts during platform decommissioning in terms of energy consumption and harmful emissions. Thus, some mitigation measures have been suggested related to the reduction of energy consumed, as well as the emissions of discussed harmful gaseous.

In conclusion, the objectives of this study have been achieved. The environmental impacts have been quantified using the LCA tools and both complete and partial removals of Heather Platform were compared in terms of environmental impacts as well as the cost. Besides, few suggestions have been proposed to reduce the environmental impacts related to decommissioning of offshore platform.

5.2 RECOMMENDATIONS FOR FUTURE STUDY

This dissertation has assessed the environmental impacts and the feasibility of two decommissioning options, complete platform removal and partial platform removal. The advantages, limitations and assumptions of using LCA Tools on quantifying the environmental impacts have been clearly defined. The outcomes can be used as a basic guideline for future offshore platform decommissioning plan in order choose the most feasible option in term of energy consumption, gaseous emissions and economic view. For future research, this study can be extended to the development in new technology or methodology in assessing the impacts from offshore platform decommissioning program.

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APPENDICES A

(FOR PROCESS BASED METHOD)

APPENDIX 1: UNIT CONVERSION FACTORS & REFERENCES

Conversion	Unit Conversion Factor		Source / Reference
Steel Plate and Shape From Ore	Energy Consumption	19 GJ/t	Ogivile (1992), Iron and Steel Institute (1990), Philip et al (1995)
	SO_2 emissions	2 kg/t	
	NOx emissions	1.5 kg/t	
	Equivalent CO2	60 kg/t	
	CO2 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	
	NOx emissions	1.0 kg/t	
	Equivalent CO2	40 kg/t	
	CO2 emission	360 kg/t	
Engine Diesel	Calorific Value	45.4 GJ/t	Munday and Farrar (1989), Brown and Root (1993)
	SO_2 emissions	5 kg/t	
	NOx emissions	5.8 kg/t	
	Equivalent CO2	238 kg/t	
	CO2 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	
	NOx emissions	45 kg/t	
	Equivalent CO2	1905 kg/t	
	CO2 emission	3100 kg/t	
Propane	Calorific Value	50 GJ/t	Munday and Farrar (1989)
	SO_2 emissions	0 kg/t	
	NOx emissions	3 kg/t	
	Equivalent CO2	120 kg/t	
	CO2 emission	3007 kg/t	

APPENDIX 2: DATA VARIABLES FOR ENERGY CONSUMPTION AND GASEOUS EMISSIONS

Temporary Steelwork (Tonne)	Topsides Temporary Steel Used Jacket Temporary Steel Used
Topsides Piecesmall Dismantling Offshore (Tonne)	Structural Steel Quarters Timber / GRP (Tonne) Pipework Equipment Electrical and Instrumentation Paint and Galvanised Coatings
Topsides Modular Dismantling Onshore (Tonne)	Structural Steel Quarters Timber / GRP (Tonne) Pipework Equipment Electrical and Instrumentation Paint and Galvanised Coatings
Jacket Dsimantlings Onshore (Tonne)	Steel Non-ferrous Materials (Aluminium) Other (Cement, Timber, Coating, Etc.) Marine Growth
Conductor Dismantling Onshore (Tonne)	Steel Other (Cement Grout) (To Landfil)
All Dismantling (Tonne)	Total Steel Total All Non-ferrous Material Total Others Incl. Marine Growth (To Landfill) Grand Total
Materials Left At Sea (Tonne)	**Topsides** Structural Steel Quarters Timber / GRP (Tonne) Pipework Equipment Electrical and Instrumentation Paint and Galvanised Coatings
	Jacket Steel Non-ferrous Materials (Aluminium) Other (Cement, Timber, Coatings, Etc.) Marine Growth
	Conductors Steel Cement Grout
Platform Running (Days)	Well Plugging & Abandonment (Pre-Production Shutdown) Well Plugging & Abandonment (Post-Production Shutdown) Topsides Decommissioning (Post-Well Abandonment) Topsides Removal

APPENDIX 3: FUEL CONSUMPTION CONVERSION FACTORS FOR PROPANE AND DIESEL DURING FABRICATION AND DISMANTLING WORKS

Unit Conversion Factors (Fabrication and Dismantling)	Propane Consumption (Kg/Tonne)	Diesel Consumption (Ltr/Tonne)
Temporary Steelwork		
Fabrication	0.5	5
Dismantling	2.4	11
Topsides Piecesmall Dismantling Offshore		
Structural steel	2.4	14.5
Quarter timber/GRP	0	14.5
Pipework	2.4	14.5
Equipment	0.6	14.5
Electrical and instrumentation	0	14.5
Topsides Modular Dismantling Onshore		
Structural steel	2.4	11
Quarter timber/GRP	0	11
Pipework	2.4	11
Equipment	0.6	11
Electrical and instrumentation	0	11
Jacket Dismantling Onshore		
Steel	2.4	11
Non-ferrous materials	0	11
Marine growth	0	11
Other materials	0	11
Conductor Dismantling Onshore		
Steel	2.4	11
Cement grout	0	11

APPENDIX 4: FUEL HELICOPTER FUEL CONSUMPTION FACTOR

Helicopter Fuel Consumption	37 Ltrs Jet A-1 Fuel/Passenger Flying Hour

APPENDIX 5: AVERAGE DAILY FUEL CONSUMPTION FOR MARINE VESSEL

Vessel	Average Daily Fuel Consumption By Location (Tonne MDO/Day)			
	In Port	In Transit	Working	W.O.W.
Diving support vessel (Jacket)	3	20	10	10
Heavy lift vessel (Topsides)	20	60	35	35
Anchor handling tug for HLV	2	10	10	10
Semi-submersible crane vessel (Jacket)	50	100	50	50
Anchor handling tug for SSCV	2	10	10	10
Multi-support vessel (Topsides)	2	20	25	25
Multi-support vessel (Jacket)	2	26	25	25
Cargo barge tug (Topsides)	2	10	10	10
Cargo barge tug (Jacket)	2	10	10	10
Launch barge tug (Topsides)	2	15	15	15
Launch barge tug (Jacket)	2	15	15	15
Special tug (Jacket)	3	22	15	15
Flotel (Topsides)	10	40	20	20
Safety boat	1	8	4	4
Supply boat	2	10	5	5

APPENDIX 6: ENERGY CONSUMPTION AND GASEOUS EMISSIONS FOR EACH DECOMMISSIONING ASPECTS FOR BOTH COMPLETE AND PARTIAL REMOVAL

Decommissioning Aspect	Complete Removal	Partial Removal
Temporary steelwork	25286	17739
Platform facility dismantling	29395	15790
Marine vessel utilization	554561	325382
Platform running	143963	117105
Helicopters	17893	12388
Platform materials recycling	168380	97035
Platform materials left at sea	0	295870
All Decommissioning Aspects	**939479**	**881309**
Temporary steelwork	5276	3707
Platform facility dismantling	11641	6331
Marine vessel utilization	549675	322515
Platform running	18392	14961
Helicopters	7696	5328
Platform materials recycling	31638	17243
Platform materials left at sea	0	41385
All Decommissioning Aspects	**624318**	**411470**
Temporary steelwork	6608	4641
Platform facility dismantling	11145	6070
Marine vessel utilization	549675	322515
Platform running	15855	12897
Helicopters	3078	2131
Platform materials recycling	45313	24404
Platform materials left at sea	0	80030
All Decommissioning Aspects	**631674**	**452688**
Temporary steelwork	1703231	1194887
Platform facility dismantling	1979619	1064222
Marine vessel utilization	37866500	22217700
Platform running	9830100	7996140
Helicopters	1092832	756576
Platform materials recycling	12677080	7672330
Platform materials left at sea	0	30808000
All Decommissioning Aspects	**65149362**	**71709855**
Temporary steelwork	214139	150488
Platform facility dismantling	489557	266270
Marine vessel utilization	23269575	13653135
Platform running	754698	613897
Helicopters	307840	213120
Platform materials recycling	1265520	689720
Platform materials left at sea	0	4225800
All Decommissioning Aspects	**26301329**	**19812430**
Temporary steelwork	1917370	1345376
Platform facility dismantling	2469176	1330492
Marine vessel utilization	61136075	35870835
Platform running	10584798	8610037
Helicopters	1400672	969696
Platform materials recycling	13942600	8362050
Platform materials left at sea	0	35033800
All Decommissioning Aspects	**91450691**	**91522286**

APPENDICES B

(EIO-LCA METHOD)

APPENDIX 7: TOTAL ENERGY CONSUMPTION (TJ)

	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 8: NO_X AND SO_2 EMISSIONS (TONNE)

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

APPENDIX 9: OVERALL CO_2 EMISSIONS (KG)

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