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Group decision making of fixed offshore platform decommissioning in Indonesia

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Abstract: The selection of decommissioning methods should consider several essential points such as costs, stakeholders, availability of tools, and the environment. Due to the relatively significant cost challenges, the complexity of stakeholder issues, and the fact that several offshore fixed platforms are no longer operational, the development of decommissioning in Indonesia has yet to match these challenges. The objective of this study is to facilitate decision-making in the decommissioning of fixed offshore platforms based on group decision-making using the Analytical Hierarchy Process (AHP). Several questionnaires with numerical score values were provided to experts to perform pairwise comparisons of the criteria and alternatives related to decommissioning for further analysis using the AHP method. The results for the decommissioning alternatives showed different tendencies for each stakeholder, owing to their contrasting interests. However, all stakeholders agreed that the cost of decommissioning was a crucial factor in deciding the method. As a result of using the AHP method, the leave-in-place alternative was identified as the best decommissioning method, considering various aspects such as cost, socioeconomic factors, engineering, health and safety, and environmental impact. For future research, a more in-depth analysis of each criterion can be conducted.
Keywords: *AHP, Fixed offshore platform, Group decision making, Jacket platform, Offshore decommissioning.*

1. Introduction

Since the commencement of commercial oil and gas production in 1971, Indonesia has operated 613 offshore structures, of which 54.7% are over 20 years old and 24.6% are between 16 and 20 years old [1]. As the offshore platforms age, their structural integrity deteriorates, potentially causing damage. Regular inspections and structural integrity assessments are essential for extending their service life and for enabling prompt repairs when structural issues arise. In addition to repairs, a new support structure or small platform may be installed to reinforce the adjacent aging platform and provide additional space for the jackets or topsides of new facilities [2]. These platforms can be decommissioned when they become obsolete. In 2021, 100 offshore platforms, comprising 73 Pertamina Hulu Energi Offshore North West Java, 11 Pertamina Hulu Energi Offshore South East Sumatera, 7 Pertamina Hulu Energi West Madura Offshore and Pertamina Hulu Kalimantan Timur, and one each for the Energi Mega Persada Malacca Strait and Kangean Energy, ceased operations [3].

The Deputy Operations of the Special Task Force for Upstream Oil and Gas Business Activities [1] estimates the decommissioning cost for the Attaka Block at US$ 6–7 million per platform. The Coordinating Ministry for Maritime Affairs and Investment estimates an IDR 13 trillion cost for dismantling 100 non-operational offshore platforms [4].

Statistical studies have projected an expenditure of US$ 40.6 billion for decommissioning offshore oil platforms worldwide in 2040; this budget is an 89% increase from the 2015 spending cost listed by Mactec Offshore [5]. The cost increase aligns with the World Bank's Blue Economy initiative, driven by countries adopting sustainable ocean sector practices amid environmental, socio-economic, and safety

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challenges. A study estimated that US$ 210 billion was spent on complex decommissioning, with half the amount being allocated to the plugging and abandonment (P&A) of subsea wells [6]. Despite the substantial cost challenges, complexity of issues involving stakeholders, and shutting down of several fixed offshore platforms, decommissioning in Indonesia has not yet progressed to match these circumstances. Therefore, further research on group decision-making for decommissioning fixed offshore platforms in Indonesia is required.

Research on decommissioning continues to develop, the focus of discussion regarding costs in the process of decommissioning activities is carried out in research [7-9]. Apart from the costs of decommissioning, there is research with the topic of discussing rules or regulations regarding decommissioning activities, this is applied to research [10-13]. Research on the question of how decommissioning affects several industries, including the environment, has been equally extensive [9, 14-16]. In addition, several studies have also discussed estimates and decision-making during decommissioning [6, 8, 17-30]. There are several interesting studies that discuss the technical aspects of decommissioning, such as the development of a lifting system for decommissioning [31] and the removal of nonessential components of the structure prior to final decommissioning [32]. Research on decommissioning not only explore offshore platforms but also subsea pipelines [33]this study discusses the decommissioning guidelines for subsea pipelines which are a supporting part of offshore platforms. Asset and integrity management are also required to ensure the success of decommissioning [34, 35].

When decommissioning it is essential to prioritize the identification of stakeholder awareness, views, and values and the development of a multidisciplinary process for the purpose of decision-making [6]. The benefits and effects of decommissioning offshore structures must be understood by all stakeholder groups to make decisions that are consistent with the prevalent trends in other areas of ocean management [30]. Numerous peer-reviewed studies have assessed whether the current evaluation procedures for the decision-making process are appropriate for the decommissioning of offshore platforms (comparative assessments, multi-criteria decision approaches, and life cycle assessments). These studies have frequently concluded that the numerous aspects involved in offshore decommissioning have not yet been thoroughly considered. This is a result of both incomplete knowledge (knowledge gaps) and the challenges of evaluating connected but cross-disciplinary concerns, as well as the ambiguity, or "knowing differently," of stakeholder opinions [24, 36, 37].

Previous research, such as the study by Li and Hu [27] has explained some of the attributes of decision-making in offshore oil and gas facilities that do not show in the group decision-making section. In addition, Capobianco, et al. [24] discussed political, economic, social, technological, legal, and environmental (PESTLE) issues in the decommissioning of offshore platforms using semi-structured interviews with several stakeholders in Italy; however, this did not continue to the decommissioning decision stage. This was developed by De Lima, et al. [38] where there were multi-criteria and alternative selections based on two stakeholders, namely, the proponent and the regulator in Brazil. Based on several previous studies, this study presents the existence of multi-criteria and decision-making is conducted based on three stakeholders involved in the decommissioning of fixed offshore platforms in Indonesia. This study makes significant contributions to academia and industry. On an academic front, it fills the gaps in the existing literature by providing a qualitative perspective on the key entities typically involved in decommissioning projects. This enhances our understanding of their viewpoints and addresses a specific gap in oil and gas research. For the industry, the findings of this research can serve as a valuable resource for practitioners when making decisions regarding the most suitable decommissioning methods. The perspectives presented shed light on the reasons behind their preferences, helping to ensure that decommissioning methods comply with environmental regulations and safety standards, while considering factors such as cost and technical feasibility. The innovation and significance of this research lie in its approach to group decision-making, which involves multiple stakeholders, including oil and gas companies, contractors, and regulators.

The remainder of this paper is organized as follows: Section 2 describes some of the materials constituting the literature review and the methods used in this study. Section 3 explains the results of the analysis using the Analytical Hierarchy Process (AHP). A discussion of the results of this study and those of previous ones is presented in Section 4. Finally, Section 5 concludes the research, summarizing the results, innovations, limitations, and contributions of this study.

2. Materials and Methods

2.1. Fixed Offshore Platform

To assist the exploration and production of oil and gas, offshore structures are being installed in the marine environment, primarily in the sea. Other significant structures, for harnessing power from the sea, offshore bases, and offshore airports, are also being developed. Offshore platforms are not only designed to withstand environmental loads but must also endure dynamic forces such as ship collisons [39]. Considering that there is no fixed access to dry land, it may be necessary to remain in that position at all times. Offshore structures may float or fasten to the seabed. A floating structure can be dynamically positioned using thrusters, tethered to the seafloor, or left to drift freely [40]. Fixed offshore structures are platforms anchored to the seabed and rise above sea level [35]. Fixed offshore structures are typically installed at shallow depths of approximately 10–200 m. Bottom-supported structures are either "fixed" (jackets and gravity-based structures) or "compliant" (guyed towers and compliant towers). The jacket platform is supported by a steel truss composed of support plates, or a deck truss structure consisting of stacked weld-together tubes on the seafloor [41].

The most popular types of offshore structures are fixed offshore structures. Approximately 95% of all offshore platforms worldwide employ fixed platforms [42]. The number of offshore structures has increased significantly, mostly in the sector of renewable energy [43]. This fixed platform consists of a topside, a jacket, and a pile [40]. The top side of an offshore platform is a major facility and is located above the water surface; it controls the operation of the platform.

There are various types of topside constructions, and the number, level of completion, and amenities offered depend on the platform's primary purpose [40]. Each fixed offshore platform serves a variety of functions, including extraction, drilling for exploration, crude oil and natural gas processing, and storage [44]. A steel truss composed of support plates, or a deck truss structure supported by welded tubes placed on the seabed supports the platform. Jacket is the name for the steel frame utilized underwater at depths of 500 m or less [42]. In the design of fixed offshore platforms, the size, shape, strength, stiffness, ultimate strength, and natural frequency are all optimized [45]. In addition, the impacts of wind, seismic vibrations, and ocean waves are considered. Furthermore, the crane's top weight, the power plant weight, and any potential vibrations caused by icebergs or ships are taken into account [46].

2.2. Offshore Platform Decommissioning

Decommissioning is the final stage of an offshore platform's life cycle, in which any equipment, initially set up for activities, are removed from the seabed, all wells are sealed off and abandoned, and any existing platforms and facilities are removed [8]. As platforms experience fatigue due to long-term exposure to wave loads and operational stresses, Cuong and Anh [47]have shown that fatigue assessment must incorporate dynamic wave loading effects, especially when water depths on crease, to ensure accurate evaluations and safe decommissioning decisions. A previous study defined decommissioning as the process of shutting down an industrial facility while minimizing its effects on the environment, human welfare, and financial costs [10]. Da Cunha Jácome Vidal, et al. [37] explained that the decommissioning process is complicated, lengthy, and expensive and involves numerous parties, including operators, reverse supply chains, governments, environmental organizations, and other sea users. There are several important points regarding platform decommissioning costs, people (stakeholders), the availability of tools, and the environment. Figure 1 illustrates the conductor cutting process on an offshore platform during the decommissioning procedure.

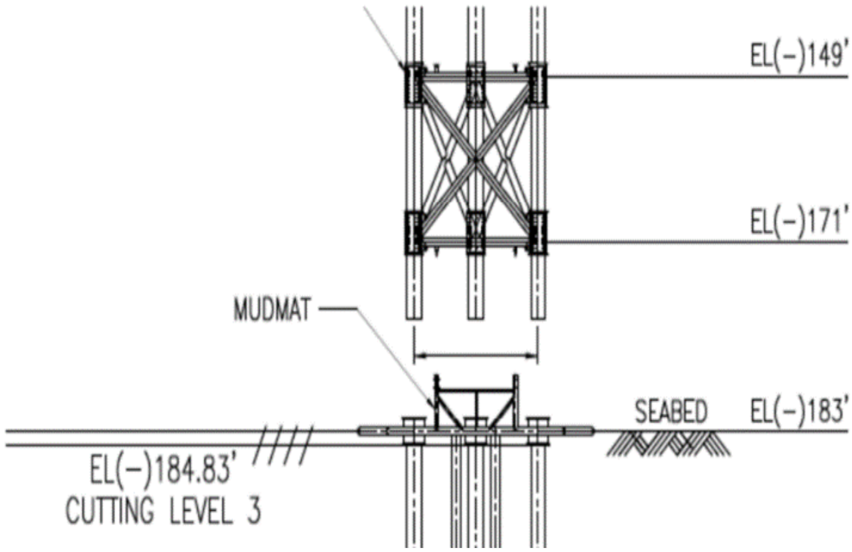

Figure 1.
Conductor cutting process during offshore platform decommissioning.

Despite their dire importance, first-generation structures dating back to the 1950s have not been built with decommissioning in mind [36]. To this end, offshore decommissioning has garnered significant attention from both industry and academia. Li and Zhiqiang [29] outlined three major phases of the decommissioning process: pre-decommissioning, decommissioning execution, and post-decommissioning. The pre-decommissioning stage largely entails personnel and material planning, and the government permits acquisition with respect to certain constraints, such as costs, risks, and environmental hazards. Third-party services, such as consultancies or classification societies, may also provide additional perspectives [29]. Next, the process moves to the execution stage, where the decision models in the preceding stage come into play. For instance, the structure in question may be subject to total or partial removal [29]. All wells supported by the platform are plugged. Conductors, piles, and jackets located below the surface are typically cut at least 4.572 m (15 ft) beneath the mudline for removal and transport to the shore [48]. Typically, three or more cement plugs are installed during the complete closure of a well. If the cement plugs in the reservoir are properly placed, the risk of leakage is minimal and serious accidents can be prevented [29]. The removal of the jacket is a crucial task because it is the heaviest structure within the subsea equipment on an offshore platform [37]. Finally, the post-decommissioning stage acts as a clean-up phase, largely comprising monitoring, validation, and reporting in adherence to government requirements [29].

As of now, offshore platform decommissioning activities in Indonesia are governed by the regulations contained in the Government Regulation of the Republic of Indonesia Number 17 of 1974, concerning supervision of the implementation of Oil and Gas Exploration and Exploitation in offshore areas, Article 21 which states that "A mining installation that is no longer in use must be completely dismantled within the period determined by the Director General, by taking appropriate measures to ensure the safety of work and shipping flows", Government Regulation No. 35 of 2004 concerning upstream oil and gas business activities, Article 78, Paragraph 1 which states that "All goods and equipment directly used in upstream business activities purchased by the Contractor become state property/property whose guidance is carried out by the government and managed by the implementing agency" [49].

In 1989, the International Maritime Organization (IMO) established the minimum global standards for the removal of offshore installations and structures, titled “Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone.”

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While guidelines are typically considered recommendations, the United Nations Convention on the Law of the Sea (UNCLOS) specifies that abandoned or disused installations must be removed in accordance with the generally accepted standards set by the competent international organization, in this case, the IMO. Therefore, for any state that has ratified UNCLOS, adherence to these guidelines is mandatory and legally binding [10]. The UNCLOS revisited the concept of installations that remained in place. Although the 1982 Convention aligns with the 1958 Convention in its approach, it offers greater flexibility in the removal of abandoned or disused seabed structures. Article 60(3) specifies that "Any installations or structures which are abandoned or disused shall be removed to ensure safety of navigation, taking into account any generally accepted international standards established in this regard by the competent international organization. Such removal shall also have due regard for fishing, the protection of the marine environment, and the rights and duties of other states. Appropriate publicity shall be given to the depth, position, and dimensions of any installations or structures not entirely removed [13].

Article 2 of the Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia states that cooperation contract contractors (C3) are obliged to carry out postoperative activities whose implementation uses postoperative activity funds. Article 1 states that "Post-Operation Activity Fund is an accumulation of funds reserved and/or deposited by contractors to carry out Post-Operation Activities"[50]. However, in 2017–2018, a polemic of denial of responsibility for the decommissioning fund, often called the Abandonment Site Restoration (ASR) fund, was made by an old contractor. The Attaka Block and East Kalimantan Block, which were initially managed by Chevron, were handed over to Pertamina but were later returned to the Ministry of Energy and Mineral Resources. According to Pertamina, this was because the two blocks would be uneconomical if ASR funds are obligated to dismantle the platform abandoned by Chevron [51].

In recent years, anecdotal evidence suggests a rapid increase in the number of offshore installations left in situ. More than 600 offshore platforms were projected to be decommissioned between 2015 and 2020, with a substantial escalation which was anticipated to reach approximately 2,000 platforms between 2021 and 2040 [13]. However, cost-effective and environmentally safe post-decommissioning regulations are scarce. For instance, the total removal of installations may be the safest alternative; however, technical feasibility and financial constraints hinder its application. However, conversion towards artificial reefs introduces potential risks to maritime ecosystems, necessitating ongoing monitoring, maintenance, and pollution prevention strategies [13]. This underscores the necessity of assessing decommissioning methods with respect to multiple stakeholders and various perspectives.

Table 1.
Previous research on offshore decommissioning.

Ref	**Methods**	**Objective**
Kaiser and Liu [52]	Case Study	Develop models for forecasting decision-making decommissioning in deep waters
Martins, et al. [53]	Literature Review, Multicriteria Decision Analysis	Analyzing multi-criteria decisions on decommissioning problems
Capobianco, et al. [24]	Literature Review	Analyzing decision-making on decommissioning using PESTLE
Vuttipittayamongkol, et al. [21]	Experimental	Develop data for decision support on decommissioning
Melbourne-Thomas, et al. [17]	Literature Review	Analyze research needs and decision-making on decommissioning
Zagonari [22]	Interview, Case Study	Analyze decision-making for sustainable development on decommissioning
Zhang, et al. [31]	Experimental	Developing a lifting experiment system for decommissioning
Colaleo, et al. [54]	Case Study	Assess the life cycle, environment and economy on decommissioning
Yang, et al. [55]	Case Study	Develop optimization of decommissioning time for decision making
Li and Zhiqiang [29]	Literature Review	Analyzing multi-attributes in decision-making on decommissioning

Several decommissioning methods have thus garnered significant attention in literature, such as leave-in-place, partial removal, and complete removal [17, 29, 30, 37, 53]. The decommissioning method implemented in Indonesia is the conversion of rig to reefs, converting fixed offshore platforms for coral reef cultivation. Table 1 summarizes the research methods and objectives of offshore platform decommissioning, based on a literature review.

2.3. Group Decision Making

Decision-making can be defined as the process of choosing a suitable alternative from a list of options to achieve a goal. Many choices are fraught with ambiguity. Over the past few decades, the decision-making process has evolved into a more sophisticated method that incorporates expert opinions, cost-benefit analysis, risk analysis, and numerous other tools for the collaborative modeling of complex socio-technical systems in unpredictable environment [56]. Public sector decisions are frequently complicated and cover a wide range of interests and perspectives. Additionally, they often leave a long-term legacy. Therefore, it is essential to foster diligent group decision-making processes to encourage diverse stakeholders to make decisions that are effective, strong, fair, and consensual in the long run [57].

This development has resulted in an expanded selection of decision-making tools, leading to the creation of multi-criteria decision approach (MCDA) tools that provide a rigorous decision analysis framework for group decision-making [56]. Recently, multi-criteria group decision-making (MCGDM) problems regularly appear in many different fields, such as medical diagnostics, emerging management, coalfield investment, and green supplier selection, owing to the increasing complexity of actual situations. Consequently, numerous MCGDM problem-solving strategies have been investigated thoroughly. Owing to the significant risk and ambiguity present in most situations, it is challenging to make quick decisions in reality [58]. In group decision-making, the expressed opinion of a social individual may be inconsistent with or even opposite to his/her own private opinion or inner thoughts [59]. MCGDM methods, such as Elimination Et Choice Translating Reality (ELECTRE), Preference Ranking Organization Methods for Enrichment Evaluations (PROMETHEE), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and VlseKriterijumska Optimizacija IKompromisno Resenje (VIKOR) provide effective frameworks for renewable energy decision-making issues with multiple conflicting criteria [60]. A study by Başaran and Tarhan [61] using Multi-Objective Optimization by Ratio Analysis (MOORA) to select the most suitable location for offshore wind turbines. Multi-Criteria Decision-Making (MCDM) tools were also used by Baloyi and Meyer [62] in which MCDM has demonstrated a positive effect in facilitating a decision-making process to build a systematic approach to Mining Method Selection (MMS).

Some studies use the AHP method in multi-criteria decision-making; this was mentioned by Li and Hu [27] who stated that in multi-attribute decision-making, several methods can be used, one of which is AHP. Elboshy, et al. [63] used the AHP method to optimize multi-criteria feasibility for mapping locations. In addition, the AHP method has been applied to develop a decision support system for risk assessment [64]. Deniz and Ekinci [65] combined the AHP method with TOPSIS to determine the importance of attributes and rank the alternatives. A study by Yang, et al. [55] gives weight to indicators that combine the AHP group in the application of value assessment of historic buildings. In addition, research has been conducted using the AHP combined with fuzzy comprehensive evaluation [66]. Further research was conducted by Li and Hu [27] and Hu, et al. [66]. The AHP method was used to determine the risks encountered during the decommissioning process of offshore oil and gas facilities. This was achieved by integrating AHP with quality risk assessment. Finally, a Hierarchical Analyst Domino Evaluation System (HADES) was produced. In addition, the AHP was applied to develop models for multi-criteria decision-making in determining options for project decommissioning for offshore oil and gas structures.

2.4. Case Study

There is an example of a fixed offshore platform used as a case study in this research, which is called the XYZ platform. This platform was built and installed in 1991 and had a design life of 15 years. It is a jacket-template-type platform with three legs and one deck. This platform is in the Java Sea with a water depth of 42.06 m Mean Sea Level (MSL), A 100-year storm event is characterized by a maximum wave height of 8.3 m with a peak wave period of 9.3 seconds, a total tide height of 1.3 m, and a current velocity of 1.1 m per second at the surface (0% of depth).In addition, the XYZ platform has a marine growth thickness of 81 mm inches (MSL to -70'-0") and 51 mm (-70'-0" to mudline).

If we consider the year in which this platform was built and installed, the current age of the XYZ platform is 33 years, which is twice the specified design age. The platform has experienced some damage and is no longer operational. This is a problem for oil and gas companies because they must continue to pay to monitor XYZ platforms. In addition, a platform that is not actively operating can disrupt shipping routes in seawater. Therefore, an appropriate decision is required to decommission the platform.

2.5. Method

In this study, a literature review of several studies on offshore platform decommissioning was conducted. This study aims to determine the development and focus of research related to offshore platform decommissioning. In addition, a literature review was conducted to determine the criteria influencing offshore platform decommissioning. After mapping several criteria from previous research, validation was performed on several criteria that have been used in the next analysis. This validation was conducted through discussions with several experts in the field of offshore platform decommissioning. They are practitioners from companies that act as owners of offshore platforms and have considerable experience having worked for more than ten years in this field. After validating the criteria to be used, the analysis continued using AHP. To make it easier to calculate the AHP approach, Super Decision software is used; this tool is one of the tools that is often used [67]. In addition, there are also several other tools such as Expert Choice [68]. The AHP method has also been applied in several previous studies, such as that by Gao, et al. [60] who used an Analytical Hierarchy Process to determine the optimum system based on site characteristics.

The initial stage in this analysis involves determining the purpose of decision-making, followed by the distribution of satisfaction criteria and decision criteria that have been obtained from the review of previous research and validated by experts. Subsequently, several alternatives for offshore platform decommissioning were determined. The next step is to conduct a pairwise comparison and analysis of the alternatives based on each criterion. The process ends with the selection of decision making for offshore platform decommissioning; the process of research is shown in Figure 2.

To make it easier to get an idea of this study and how stakeholders determine alternative decommissioning processes the process has been illustrated in Figure 3.

Figure 2.
Research flow.

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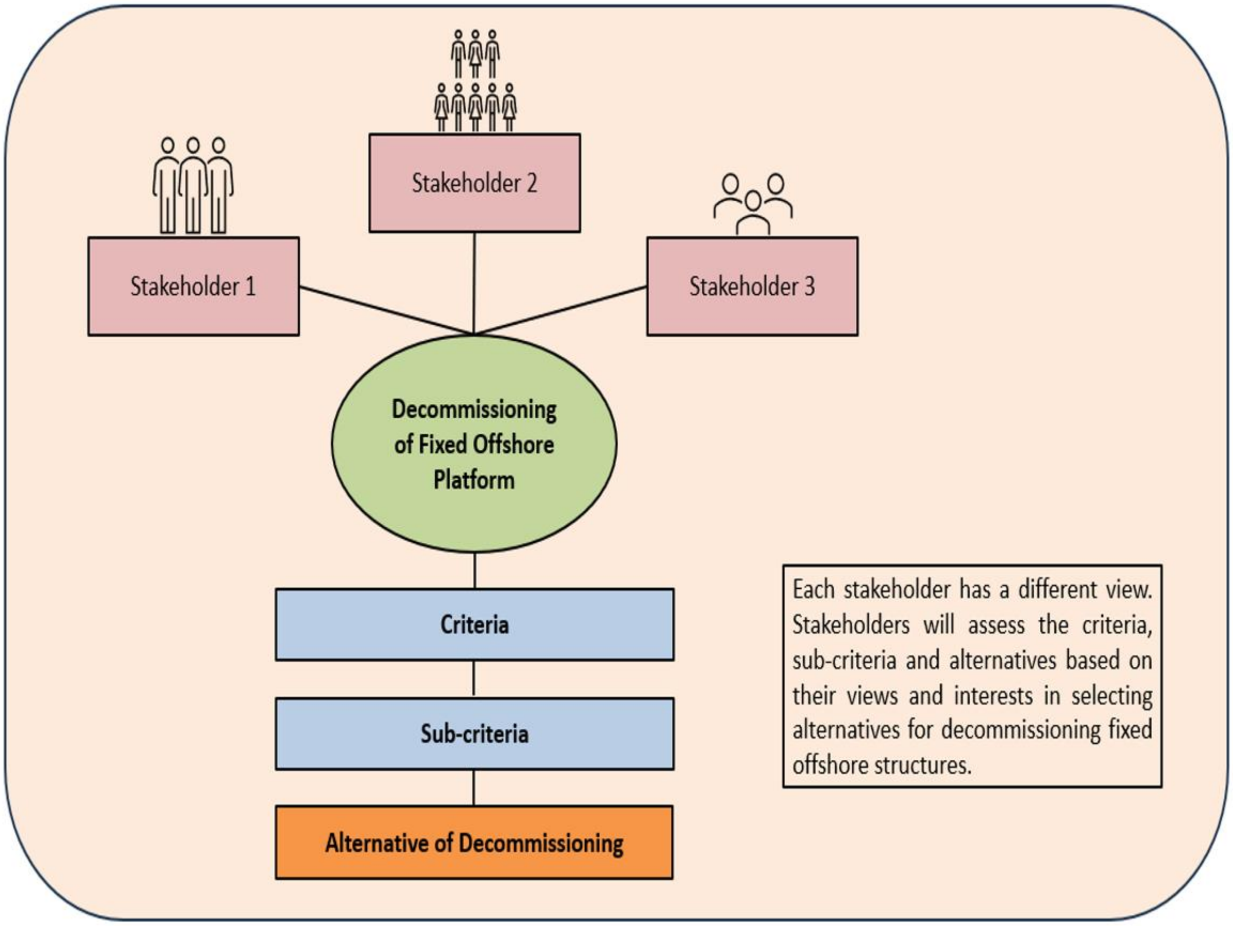

Figure 3.
Graphical abstract of research.

The verbal judgements "equally important," "moderately more important," "strongly more important," "very strongly more important," and "extremely important" are represented by the numerals 1, 3, 5, 7, and 9, respectively. For example, it can be seen in Table 2 that engineering is much more important than the environment because it has a score of 6 compared to the environment. Meanwhile, health and safety and socioeconomics are both given a score of 1, which means that they are equally important.

Table 2.
Questionnaire: for sub-criteria (D1) comparison.

Sub-Criteria A	Score to A	Score to B	Sub-Criteria B
Engineering / Technology	6		Environment
Engineering / Technology	1	1	Health and Safety
Engineering / Technology	1	1	Socio-Economic
Environment		6	Health and Safety
Environment		7	Socio-Economic
Health and Safety	1	1	Socio-Economic

Note: 1 means A & B is equally important

Table 3 shows the score results from the questionnaire given to the stakeholders.

Table 3.
Pairwise calculation of respondent (x) for sub-criteria (D1) comparison.

Sub-Criteria A	Sub-Criteria B			
	Engineering / Technology	Environment	Health and Safety	Socio-Economic
Engineering / Technology	1.00	6.00	1.00	1.00
Environment	0.17	1.00	0.17	0.14
Health and Safety	1.00	6.00	1.00	1.00
Socio-Economic	1.00	7.00	1.00	1.00
Total	3.17	20.00	3.17	3.14

Table 4.
Information of respondents.

Stakeholder	Notation	Respondent
Owner Company	Y1	X1 - X7
Contractor	Y2	X8 - X10
Regulatory & Others	Y3	X11 - X13

Assumptions:

1. The information of each stakeholder is presented in Table 4.
2. All the respondents and stakeholders are assumed to have the same importance. There are no important factors for a few respondents/stakeholders.
3. The normalization score is calculated by averaging the normalization scores from each stakeholder.

Equation (1) of Criteria & Sub-Criteria Scoring

$$A = \overline{C1_{xn}} \times \overline{C1.1_{xn}} \quad (1)$$

where A normalized score for a stakeholder, $C1_{xn}$ is the average score of the respondents in a stakeholder group at the Criteria Level, and $C1.1_{xn}$ is the average score of the respondents in a stakeholder group at the Sub-Criteria Level. It is noted that *C1* could be *D1* & *C1.1* could be *C1.2* or *D1.1*. Subscript *xn* depends on the respondent classification for each stakeholder. Alternative Scoring is presented in Equation (2).

$$B = \overline{E1_{xn}} \quad (2)$$

Similarly, *B* is the normalized score for a stakeholder, and $E1_{xn}$ is the average score of the respondents in a stakeholder group for the Alternatives Level. *E1* can be either *E2* or *E3*. The normalization scores of the stakeholder groups can be computed using Equations (3) and (4).

$$N_1 = P_s + \text{Sensitivity Percentage} \quad (3)$$

$$N_2 = P - \left[\left(\frac{P/P_s}{\Sigma P/P_s}\right) \times \text{Sensitivity Percentage}\right] \quad (4)$$

where N1 is the new value of the criteria score that would be added, and *N2* is the new value of the other criteria score that decreased owing to the added score of certain criteria. *Ps* is the criteria score of the criteria sensitivity parameter, *P* is the criteria score of the other parameters, and the sensitivity percentage is the added value for a sensitivity parameter. The sensitivity percentages are 10, 25, and 50%.

The purpose of AHP is to assist in developing correlated priorities from several alternatives based on several criteria for the decommissioning of fixed offshore platforms. This analysis begins by creating a hierarchical structure with objectives (decommissioning offshore fixed platforms), criteria (environmental, financial, socioeconomic, health and safety, and engineering), and alternatives (leave-in-place, partial removal, and complete removal). A pairwise comparison was then performed using input data from each respondent who completed the questionnaire. This pairwise comparison is used to describe the influence of something on the objectives or criteria at a hierarchical structure level, based on the level of importance of a criterion compared with other criteria in the decommissioning of offshore fixed platforms. Subsequently, calculations are performed to obtain the value of each criterion and alternative in the hierarchical structure. In the final stage, a consistency test is conducted to ensure that the assessment has sufficient or acceptable consistency.

3. Result

3.1. Criteria

When making decisions, there are several criteria, which are often called multi-criteria. In several previous studies, multi-criteria can be used to make decisions, which is commonly known as multi-criteria decision analysis (MCDA) [69]. MCDA presents a thorough framework for creating artificial intelligence that can accurately replicate the decision-making of experts and stakeholders [30]. In other research, MCDA tools have been created to assist decision-makers in decision-making for complicated problems, including a number of typically different decision factors. These tools are particularly useful for making environmental decisions Kerkvliet and Polatidis [70]. Martins, et al. [30]state that MDCA is a comparative support tool for evaluating various criteria in the evaluation of competing alternatives. It is frequently used as a decision-making tool when certain objectives are stated for the alternative that will be chosen. In this study, several criteria from previous research were considered and discussed, as shown in Table 5.

Table 5.
Criteria taken and discussed from previous research.

Criteria							
Ref.	**E**	**F**	**S**	**H**	**T**	**R**	**P**
Fowler, et al. [25]	Y	Y	Y	Y	N	N	N
Bressler and Bernstein [71]	Y	N	Y	N	Y	N	N
Capobianco, et al. [24]	Y	N	Y	N	Y	Y	Y
Li and Zhiqiang [29]	Y	Y	Y	Y	Y	N	N
Da Cunha Jácome Vidal, et al. [37]	Y	Y	Y	Y	Y	N	Y
Watson, et al. [6]	Y	N	Y	N	Y	Y	N

Note: Environmental (E), Financial (F), Socioeconomic (S), Healthy safety (H), Technical (T), Regulations (R), Political (P).
Y: It is stated that this affects decommissioning and is discussed in the paper
N: Not stated to affect decommissioning.

From Table 5, there are five criteria that have often been used in previous research: environmental, financial, socioeconomic, health and safety, and technical. These criteria were identified and discussed in 3-5 previous studies. Regulations and political criteria were identified in 2 previous studies. Thus, we removed these two criteria from this study.

To strengthen the criteria used in this study, a more in-depth discussion was conducted, and confirmation was received from stakeholders involved in decommissioning fixed offshore platforms. Environmental criteria have been discussed in several studies such as which explains that there is a negative impact of underwater activity on decommissioning [36, 71] mention not only the environment at sea but also the environment when there are activities on land, which is also supported by a statement from one of the stakeholders who states that environmental criteria are sometimes missed, but this is an important focus. Furthermore, financial criteria cannot be denied as a criterion for all the stakeholders involved. Added research by Kaiser and Liu [8] stated that there are large costs involved during and after decommissioning. The next criterion is socioeconomics, which is supported by Kaiser and Narra [26] who state that with decommissioning, the assessment considers demographics, retail or service value, service demand, employment and income indicators, and employment and income levels. Health and safety criteria are often prioritized by many stakeholders because they are concerned with the safety and lives of the workers involved in the decommissioning process [25]. Technical criteria are a challenge because they are related to the method chosen, equipment used, and standards referenced [6].

3.2. Considerable and Desirable Criteria

Considerable criteria are those that must be considered and sacrificed to obtain results, whereas desirable criteria are those that are desired and expected to be satisfied [72]. The considerable criteria in this study were divided into two categories: costs upon decommissioning and costs after decommissioning. The costs of decommissioning are those incurred during the decommissioning process. Costs after decommissioning are those incurred after decommissioning, which include marine monitoring costs and onshore processing costs. Considerable criteria in the form of costs during and after decommissioning must be considered at the beginning because this will certainly be incurred or sacrificed, and the costs of carrying out decommissioning both during and after this activity are quite high. There are several criteria included in the desirable criteria, namely, environmental, financial, socioeconomic, health, and safety. For a more detailed explanation of each desirable criterion, see the following discussion.

3.2.1. Criteria

Environmental criteria influence the impact of the demolition of offshore platforms on the environment. This criterion assesses the impact of existing demolition methods on the marine environment, living creatures, and marine biota in the platform area. Risks to the environment can be attributed to underwater activity, the impact of corrosion on structures, emissions that may be produced, and other demolition processes that have negative impacts [37]. After production has been completed, the owner must fully dismantle the production facility and return the seafloor to the way it was before the platform was built [14]. Consideration should be given to choosing a decommissioning method that considers the environment because of the possibility of residual pollution from the platform structure, contaminants disturbed and dispersed during the removal of shell mounds, and significantly increased air emission levels after complete removal, both on-site and at processing and disposal sites onshore [71].

3.2.2. Financial

The cost criterion considers the expenditure on the entire process of dismantling an offshore platform. This criterion is assessed based on the difficulty level of the demolition process using technology and workers with good credibility [25]. Financials are divided into two, namely, costs upon decommissioning and costs after decommissioning. Costs upon decommissioning are those incurred during the decommissioning process, which include project management, manpower, and operational costs. Costs after decommissioning include marine monitoring costs and onshore processing costs [8]. Oil and gas companies are required to provide data on decommissioning costs to allow stakeholders to assess the company's capacity to meet its obligation to decommission assets with minimal environmental damage [73].

3.2.3. Socio-Economic

The socioeconomic impact category describes how the decommissioning process affects local communities and the economy in the decommissioning area. This can happen in the tourism sector around the decommissioning area, which has an impact on local and regional economies [25]. Another impact of decommissioning is the difficulty in accessing sea users in areas near the platform where decommissioning is being conducted, which carries a significant risk [74]. A socioeconomic impact assessment considers demographics, retail or service value, demand for services, employment and income indicators, and employment and income levels. Social ideals heavily influence cost savings [26].

3.2.4. Health and Safety

Safety criteria affect worker safety. This criterion assesses the possible risks that could endanger workers during the process of dismantling an offshore platform. The risks that arise can be due to the possibility of failure in the operation of the tool owing to the difficulty of the disassembly process, which

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involves highly complex procedures, large structures, and hazardous materials [20, 75]. Operational safety depends on several variables, including the environment, project location, technical specifications, strength of any untested materials, team technical proficiency, and level of experience [76].

3.2.5. Technical

Technical feasibility criteria consider the allocation of available and required technologies for demolition. In addition, this criterion considers the scheduling of the dismantling process of the offshore platform [24]. Moreover, Cuong and Chinh [77] highlighted that the fatigue life of jack-up leg structures varies considerably depending on transit and operational conditions. Their method, which integrates both dynamic motion analysis and hotspot stress concentration, presents a more comprehensive evaluation framework for determining structural fatigue life before decommissioning. Technical feasibility must be considered; in fact, the selection of equipment is the main objective of technical feasibility analysis, which is required to combine the results into cost and risk parts [29]. Technical criteria are also required to create engineering design standards for actual offshore structure reuse/re-purposing scenarios, and to comprehend how structures and the seabed respond after their design life [6]

3.3. Alternative

Decommissioning methods, including leave-in-place, partial, and complete removal, have been developed [17, 29, 30, 37]. The first involves leaving offshore platforms in place, to be used as artificial reefs. The platforms left in place can sustain organisms living on them and offer various alternative uses such as aquaculture and tourism [78]. Before reefing, obsolete petroleum structures are inspected to identify potential environmental hazards. The decks (topside) where oil production occurs are dismantled and transported to the shore for recycling or reuse, to the extent possible. All equipment associated with the deck, including the drilling gear, tanks, pumps, and buildings, are removed during this process. The interiors of the legs are examined to ensure that they are petroleum-free. In addition, the wells beneath the structure are sealed by the company in accordance with established standards [48]. Recreational fishermen and some conservationists favor the leave-in-place option. However, commercial fishermen and other groups have expressed concerns about their impact on environmental and marine safety [37].

Furthermore, in the partial removal method the platform is cut into several parts and brought to the shore, and other parts remain abandoned in place [37]. The pieces of platform that are brought ashore are dismantled and recycled for other purposes. In contrast, different offshore components are reused for energy conversion, commercial, research, or multi-purpose platforms [8]. During partial removal, the jacket is not entirely removed. There are two options for this approach: either the top section is cut and transported to the shore, leaving the jacket behind as an artificial reef, or the top section is cut and placed beside the jacket, both of which are intended to serve as artificial reefs [37]. Partial removal is more cost effective, reduces the expense of removing shell mounds, and requires less effort. However, it is also important to consider the costs associated with reef enhancement and sea monitoring [79]. In comparison, complete removal can generate approximately 6.75 times more pollutants than partial removal [14]. On average, 80% of fish biomass and 86% of secondary fish production are retained after partial removal, with over 90% retention anticipated for both metrics on many platforms. However, partial removal is likely to lead to a reduction in fish biomass and production by species that typically inhabit the shallow areas of the platform structure [15].

The complete removal method involves dismantling of the entire offshore platform. The platform is brought ashore using a barge and then transported for next processes. There are several options [80]. During the complete removal process, all components and structures are removed from the sea. Although this option involves performing all the decommissioning steps mentioned earlier, the removal of subsea systems may or may not be included. However, this is the most expensive and complex method available. The farther the distance to the shore and the larger the platform, the higher the economic disadvantage of this option [37]. Efforts are underway to develop more efficient and cost-effective mechanisms for complete removal by transporting larger sections of infrastructure to the shore [81]. Complete removal would likely eliminate most of the existing fish biomass and the associated secondary production [15]. This could lead to localized biodiversity reduction, especially in areas with soft-bottom habitats. Structures contribute to the export of fish larvae to other areas, and complete removal would significantly reduce fish biomass, whereas leaving deeper structures in place would preserve over 90% of it [20]. The decommissioning method is shown in Figure 4.

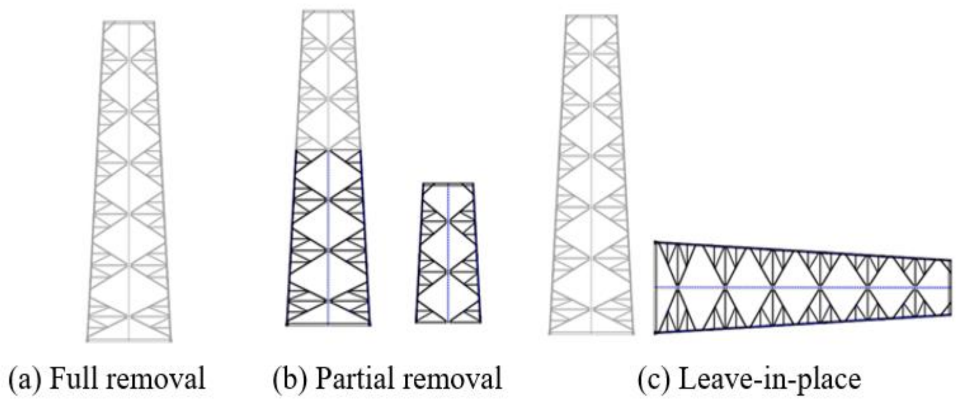

Figure 4.
Decommissioning alternatives: (a) Full/complete removal, (b) Partial removal, (c) Leave-in-place.

The list of decommissioning options can be modified to suit a specific decommissioning scenario without affecting the subsequent steps in the decision-making process [25]. Previous research discussing several alternatives was found in [25, 37]. An alternative hierarchy model is shown in Figure 5.

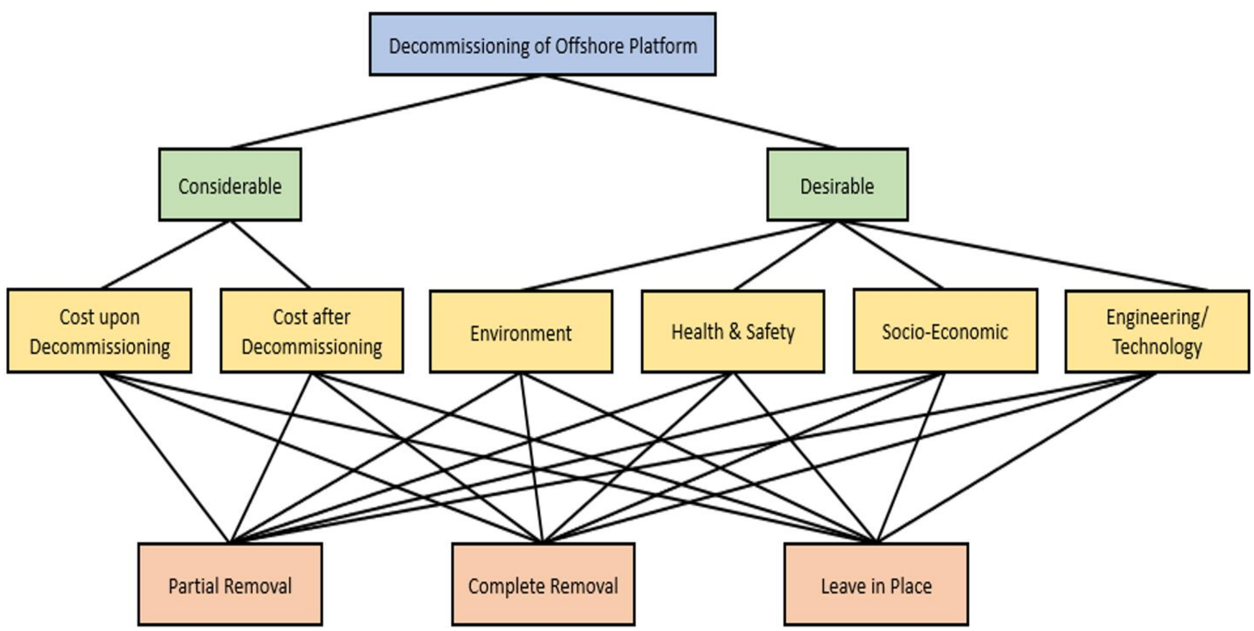

Figure 1.
Alternative decision hierarchy model for offshore platform decommissioning.

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Notably, making decisions throughout the decommissioning process is difficult because a number of factors and inputs from many institutional stakeholders and individuals are involved [37]. The effectiveness of the decommissioning process depends on the involvement of the various stakeholders. Decommissioning decisions become difficult when several stakeholder groups with varying interests are involved [25]. Each stakeholder has different considerations when determining the most effective decommissioning method. Some stakeholders prioritize decommissioning costs above everything else, while others prioritize the environment or lease agreement compliance as being of utmost importance [82].

3.4. Stakeholders Priority

The sub-criteria for a considerable number of variables included the cost upon decommissioning and the cost after decommissioning. There are four desirable sub-criteria: environmental, health and safety, socio-economic, and engineering/technology. Based on the AHP result, it can be seen in Table 6, that each stakeholder has similar priorities. Owners and regulatory companies tend to choose the costs upon decommissioning. Meanwhile, the contractor creates the same value for two priorities: cost upon decommissioning and cost after decommissioning. All stakeholders chose considerable criteria as priorities when selecting the decommissioning method.

3.5. Group Decision of Offshore Platform Decommissioning

As stated in the previous section, the alternatives provided in the decision model are decommissioning types. The available technology, technical aspects permitted by law, and stakeholders, all affect the alternatives. Table 6 shows the satisficing process used to obtain the value of each alternative for each stakeholder. From the decision results, the owner company tends to choose complete removal as the best alternative. This decision was based on the cost of the decommissioning criteria.

3.6. Sensitivity Analysis

The stability of the ranking alternatives must be investigated using sensitivity analysis. Six scenarios were introduced in this study based on the criteria that affect the choice of decommissioning method. Table 7 presents the sensitivity values of each criterion and stakeholder type. The initial value was assigned to each alternative, and to study the response of each stakeholder, the criteria sensitivity value was changed from 10% to 50%. The significant criteria were those that ultimately affected the choices made. If not, the criterion was deemed insignificant. Sensitivity analysis showed that initially, the contractor chose leave-in- place as an alternative but changed to complete removal when given a value of 50% of the engineering sensitivity criteria. Compared with contractors, environmental and health safety criteria sensitivity are criteria that change regulatory and alternative choices from partial to complete removal. As shown in Figure 7–9, sensitivity values are displayed graphically to simplify the understanding of the changes in criteria values for each stakeholder. For the contractor, one of the criteria affecting the top alternative result is Engineering / Technology shown in Figure 7. Regulatory & Others: The two criteria that affect the top alternative results are Environment (Figure 8) and Health-Safety (Figure 9). The contractor team prefers leave- in- place as the best alternative, which is affected by both the considerable criteria cost upon decommissioning and the cost after decommissioning. Regulatory authorities and others have chosen different alternatives for decommissioning, such as the partial removal method.

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Table 6.
Alternative assessment based on criteria and stakeholders

Alternatives	Criteria: Considerable		Criteria: Desirable				Decision Result
	Cost Upon Decom.	Cost After Decom.	Engineering / Technology	Environment	Health and Safety	Socio-Economic	
Stakeholders: Owner Company							
Complete Removal	0.38	0.40	0.63	0.72	0.40	0.43	0.52
Leave in Place	0.35	0.23	0.17	0.13	0.41	0.35	0.29
Partial Removal	0.28	0.37	0.20	0.15	0.19	0.22	0.19
Stakeholders: Contractor							
Complete Removal	0.10	0.14	0.63	0.75	0.52	0.14	0.27
Leave in Place	0.74	0.68	0.22	0.10	0.28	0.42	0.53
Partial Removal	0.18	0.18	0.15	0.15	0.19	0.44	0.20
Stakeholders: Regulatory & Others							
Complete Removal	0.25	0.34	0.12	0.48	0.57	0.10	0.34
Leave in Place	0.13	0.27	0.12	0.18	0.06	0.32	0.20
Partial Removal	0.61	0.39	0.76	0.34	0.37	0.58	0.46
Stakeholders: All Respondents							
Complete Removal	0.28	0.33	0.51	0.67	0.47	0.29	0.42
Leave in Place	0.39	0.34	0.17	0.14	0.30	0.36	0.32
Partial Removal	0.33	0.33	0.32	0.19	0.23	0.35	0.26

Table 7.
Sensitivity value based on different scenarios.

Criteria Sensitivity	Criteria	Initial Value	Sensitivity Value		
			+10%	+25%	+50%
CONTRACTOR					
Engineering/ Technology	Alternatives Result				
	Complete Removal	0.27	0.36	0.51	0.76
	Leave in Place	0.53	0.54	0.53	0.52
	Partial Removal	0.20	0.21	0.24	0.28
REGULATORY & OTHERS					
Environment	Alternatives Result				
	Complete Removal	0.34	0.36	0.38	0.42
	Leave in Place	0.20	0.17	0.18	0.18
	Partial Removal	0.46	0.48	0.44	0.40
Health & Safety	Alternatives Result				
	Complete Removal	0.34	0.37	0.41	0.48
	Leave in Place	0.20	0.16	0.14	0.10
	Partial Removal	0.46	0.47	0.45	0.42

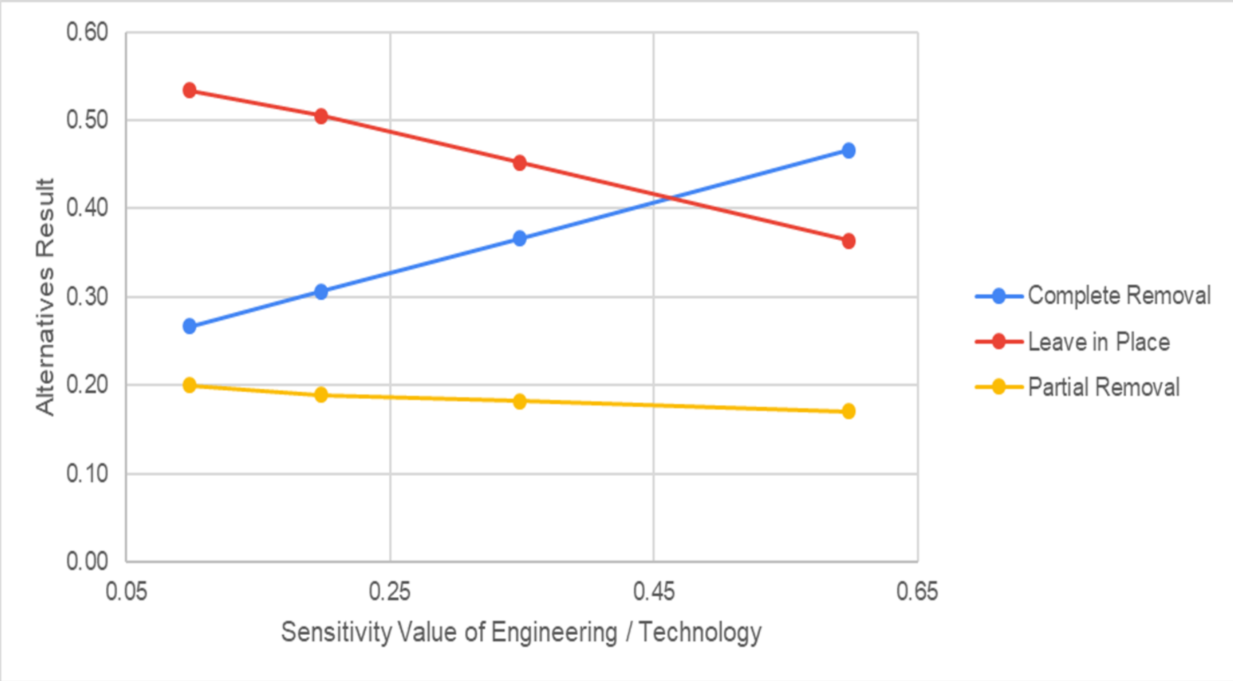

Figure 6.
Contractor's sensitivity value for engineering/technology.

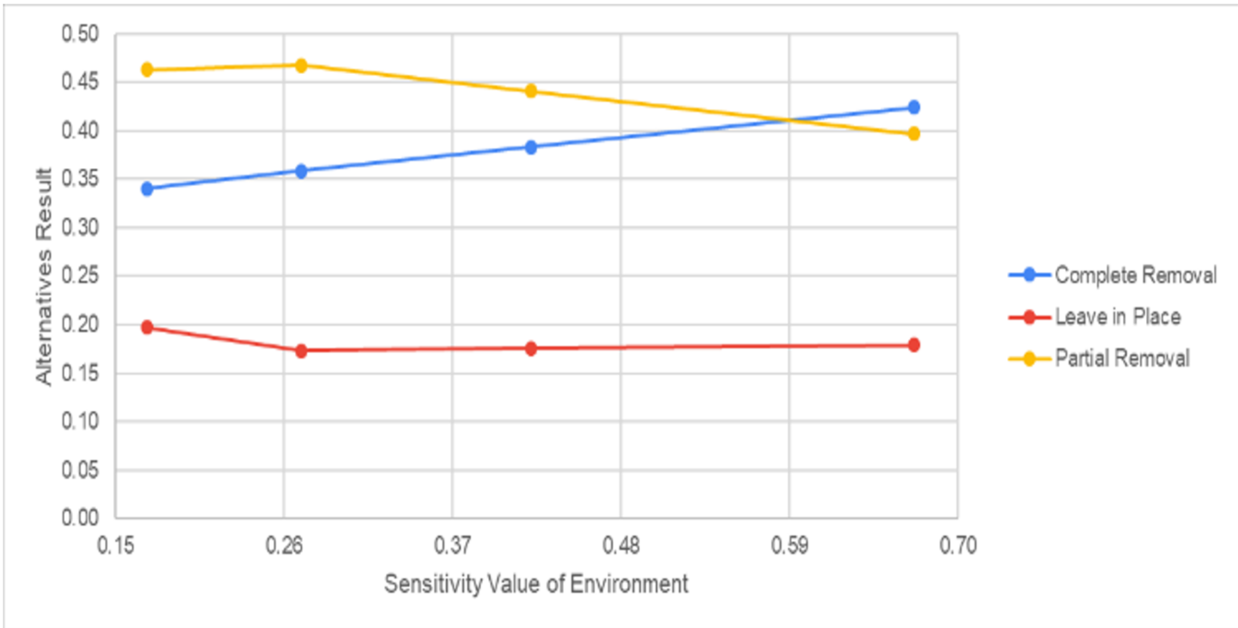

Figure 7.
Regulatory & others sensitivity value for environment.

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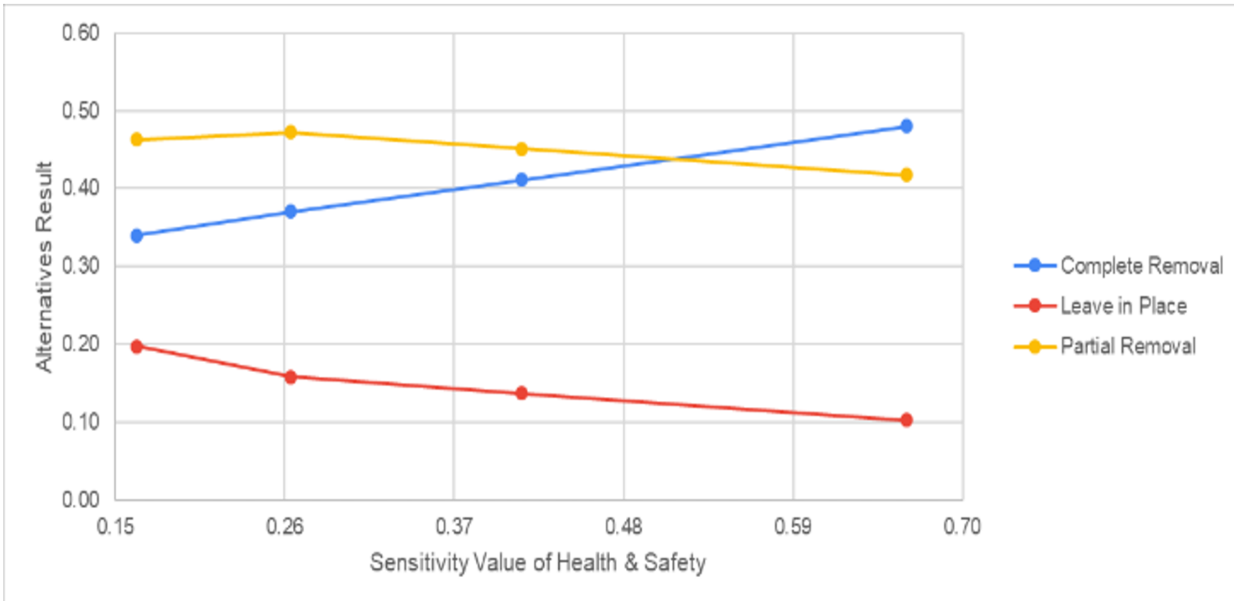

Figure 8.
Regulatory & others sensitivity values for health & safety.

4. Discussion

The group of stakeholders, composed of the owner company, researcher, and university, prioritizes the choice of suitable techniques and work-related procedures [37]. There are several discussions with parameters or criteria that are in accordance with previous research as can be seen in Table 8.

Table 8.
Discussions on similar parameters.

Criteria	Discussion from another research
Cost Upon Decommissioning	Cost upon decommissioning is a parameter that must be taken into account; this cost includes costs incurred during the decommissioning process, such as project management, labor, operational costs [8]
Cost After Decommissioning	Post-decommissioning costs are the costs incurred after the process is completed, including costs for marine monitoring and onshore processing; this requires more attention, as monitoring after decommissioning must be carried out periodically [79]
Environmental	Environmental risks can arise from underwater activities, the effects of corrosion on structures, emissions produced during the process, and other demolition procedures that have negative environmental impacts, such as additional emissions; therefore, environmental parameters should not go unnoticed [37]
Healthy-Safety	Operational risks may also stem from potential equipment failures due to the complexity of disassembly procedures, involving large structures, hazardous materials, and intricate processes. On the whole, decommissioning activity has a threat to personnel [20]
Socio-Economic	A socioeconomic impact assessment considers factors such as demographics, retail or service values, service demand, employment and income indicators, and overall levels of employment and income. Social ideals strongly influence the cost savings achieved; this parameter will affect sea users [26]
Engineering/Technology	Decommissioning is a complex activity, so technology and engineering are the main focus areas when facilitating decommissioning activities. Technical feasibility must be evaluated, as selecting the appropriate equipment is the main focus of the analysis, which is essential for integrating the findings into the overall cost and risk assessment [29].

As shown in the results, the owner group prefers complete removal as the decommissioning method, considering the safety of the workers, technical feasibility, environmental effects, equipment availability and cost, and sequence of operations [26]. The contractor emphasizes health- and safety-related activities, adopting practices and methods that reduce the safety risks associated with decommissioning activities, such as the danger of crashes, incidents, spills, and other issues [20]. Offshore installations are difficult to remove owing to their high complexity and risk. Therefore, a contractor may be better served by selecting the leave-in-place option.

It is further postulated that the owners' strong preference for complete removal during decommissioning is motivated by the aim of accident prevention [37]. Notable examples include the oil well explosion in 1969, the public outcry following the Brent Spar incident, and the oil spill in the Santa Barbara Canal [37]. The Sèmè oil field, located offshore along the border between Benin and Nigeria, played a significant role in Benin's energy sector during its brief period of operation. Initially discovered in 1968, oil fields began to be production in 1982 under a joint venture between the government of Benin and foreign oil companies. In 1998, when global crude oil prices were exceptionally low, oil production in this field was accompanied by a significant volumes of water [34]. Despite early optimism, the field faced a series of operational and economic challenges, which eventually led to its abandonment in 1998. Abandoned oilfields can pose a major risk to the environment because of potential oil leaks; therefore, attention and appropriate action are required to close and abandon offshore oil and gas wells [76, 83].

The results generally indicate that despite the technical complexities involved in fully removing offshore platforms, owners tend to favor approaches that reduce the potential for future repercussions. To demonstrate this, the Brent Spar incident underscored public apprehension regarding the disposal of oil installations, which, in the long run, would incur more costs to reduce these damages [84]. Hence, it is probable that owners are willing to accept higher costs for complete removal instead of opting for a cheaper alternative, recognizing that cost cutting may lead to significantly greater expenses in the future.

In contrast, contractors demonstrated a clear preference for retaining offshore platforms on site. This may be attributed to the relative ease of such approaches, thereby reducing the technical challenges involved and resulting in cost savings [48]. For instance, contractors may require cleaning of conductors and risers before their subsequent removal [37, 85]. Synthesizing our findings, Fam et al. [86] found that offshore jobs were mostly awarded to the contractor quoting the lowest-cost, justifying the contractor's motivation to minimize expenses as much as possible. Moreover, artificial reefs may be formed in the presence of obsolete structures, known as the rigs-to-reef program (RTR) [25]. One prominent example pertains to the Baram-8 structure, just eight nautical miles away from Tanjung Baram, Miri, Malaysia [9]. Leaving platforms in place seems to bolster biodiversity. Mohd, et al. [9] outlined the presence of large groupers in the lower section of the structure, along with other species, such as bannerfish, batfish, coral trout, and angelfish. The observed establishment of macrobenthic communities serves as a positive indicator of the sustainability of artificial reefs [9]. Hence, contractors' preference for leaving platforms on site may also be attributed to environmental concerns, preventing the loss of attached organisms and the dispersal of associated fish communities [82].

Government and Regulatory Agencies will have similar preferences and responsibilities involved in the decommissioning process. They primarily take action in defining legislation, defining the permitted processes, and approving decommissioning plans. Decommissioning may pose a financial risk if asset owners fail to meet their regulatory requirements because of insufficient resources [8]. Regulators tend to choose partial removal as the best alternative. Partial removal is less expensive, does not require shell mound removal, and requires less work; however, the costs of reef restoration [71] and sea monitoring [79] should be considered.

Their inclination towards partial removal methods may be regarded as a more 'pragmatic' strategy. However, these methods are less likely to harm the environmental aspects of the decommissioning process [20]. While complete removal results in a loss of the associated reef biota surrounding the structure [15], the presence of the structure can still bolster the surrounding biodiversity [20]. One prominent example pertains to installations in the North Sea, which facilitate the mollusk Mytilus edulis, altering the environment to create a more hospitable habitat for various other organisms [87]. Consequently, several governments have enforced a strong preference towards partial removal decommissioning methods, which resonates with our results. For example, Texas favors this method because of its alignment towards RTR programs [48]. Partially removed platform structures are considered optimal reefs because of their environmental safety, robust and stable construction materials, and pre-existing thriving reef ecosystems established over 30 years or more [48].

Data in multi-criteria decision-making are largely imprecise and subject to further changes [88]. Our approach entails the validation of results harnessing sensitivity analysis, wherein one may note which criteria would have the most significant influence. Our sensitivity analysis involved assigning weights (i.e., 10%, 25%, and 50%) to various input parameters and multiplying them to generate the overall score. Despite its simplicity and transparency, its efficacy may be hindered when dealing with intricate relationships. To synthesize our results, one may approach a sensitivity analysis with a modified version of the AHP, as proposed by Leal [89]. Leal [89] proposed an AHP approach that streamlined the AHP process by reducing the number of comparisons between criteria. This method involves comparing each element individually with every other element, remedying a significant limitation of conventional AHP procedures, which require an extensive number of comparisons for decision-making.

Specifically, Leal [89] suggested that for calculating the priority of each criterion, the decision-maker (in this case, the stakeholders) uses the alternative they consider the most important as the basis for comparison. This yields a vector of priorities that depict the importance of the criterion under consideration. However, the approach of Leal [89] hinges on the assumption that inconsistency primarily arises in assessments involving alternatives perceived as less crucial by the decision-maker, as well as necessitating multi-level objectives, both of which are outside the scope of this paper. In future, scholars may build upon this notion and conduct sensitivity analyses using AHP.

Several methods have been applied to multi-criteria decommissioning research. MCDA is expected to become the primary approach for future assessments of offshore oil and gas facility decommissioning [29]. Regarding the sub-criteria, the challenge of incorporating uncertainty and randomness into both qualitative and quantitative evaluations remains unaddressed. This implies that the entire MCDA framework must be more complex and integrated with cutting-edge technology to enhance its ability to handle random variables [30]. In another study, the combination of ELECTRE III with MCDA demonstrated that the performance of a model using only the four most critical sub-criteria, Cost, Operational Environmental Impacts, Safety Risk to Offshore Project Personnel, and Communities, was similar to that of a full model [53]. A separate study using the Exponential Portuguese expression TOmada de Decisão Interativa e Multicritério (ExpTODIM) found that the removal of all risers during pull-out and permanent in-situ placement of all flowlines, irrespective of the region, was a viable option [38]. The selected multi-criteria decision aid technique was the well-established PROMETHEE II outranking method, although other approaches may also be appropriate. These results align closely with the 2001 environmental impact assessment report, which recommended partial removal of the foundation as a suitable decommissioning method for the offshore wind farm in question [70].

5. Conclusions

The offshore structure decommissioning process is complicated, lengthy, and expensive, and involves many stakeholders. Hence, this study was carried out using the AHP to determine the best decommissioning option based on stakeholder considerations. The AHP analysis results in different tendencies for each stakeholder decommissioning alternative. This is due to the different interests of each stakeholder, such as the owner, who is more concerned with worker safety, technical feasibility, environmental impacts, availability, and equipment costs. Contractors focus more on health and safety risks. Government prioritizes regulations and rules. Although all stakeholders have different tendencies in alternatives, considerable criteria, specifically cost upon decommissioning, are the main considerations for choosing the decommissioning method. In this study, based on the AHP analysis towards each stakeholder decommissioning method, the leave-in-place method was determined to be the most suitable for decommissioning offshore structures. "By taking into account criteria combinations such as engineering and technology, environmental impact, socioeconomic factors, health and safety, and cost,".

The significant criteria influenced the final decision, whereas the insignificant criteria did not. The sensitivity analysis showed that the contractor initially chose to leave in place, but switched to complete removal when the engineering sensitivity criteria were valued at 50%. Unlike contractors, environmental and health safety criteria have shifted regulatory preferences from partial to complete removal. For contractors, engineering/technology is a key criterion, whereas for regulatory bodies, environmental and health-safety factors are decisive. The contractor team favored leave-in-place because of cost considerations both during and after decommissioning, whereas the regulatory bodies preferred partial removal.

The innovation and importance of this research lie in decision-making based on a group process involving multiple stakeholders, including oil and gas companies, contractors, and regulators. This is the primary finding of this study, as many other studies have overlooked the perspectives of different stakeholders. Consequently, this study presents a model for decommissioning decisions that incorporates multi-criteria and multi-stakeholder considerations. The decision outcomes from this research can serve as a reference for the oil and gas industry in executing or planning decommissioning activities as well as an inspiration for future studies.

However, this study was limited by the number of criteria and focused only on the three main stakeholders involved in the decision-making process. Future research could expand on this by incorporating additional criteria and stakeholders not included in this study. A more comprehensive and in-depth analysis can be achieved by involving all the relevant criteria and stakeholders specific to each country facing decommissioning challenges, as different nations are likely to have unique assessment factors and stakeholders.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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