SUSTAINABLE DECOMMISSIONING OF OFFSHORE PLATFORMS:
A PROPOSAL OF LIFE-CYCLE COST-BENEFIT ANALYSIS IN ITALIAN OIL AND GAS INDUSTRY

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Abstract

The decommissioning of offshore Oil & Gas platforms, at the end of their life cycle, has been a very controversial topic in recent years. Moreover, the decommissioning complexity increases if we consider a shift towards a linear economy to a circular one. The latter pushes to innovate business models and re-configure the value chain activities in a sustainable way. Starting from these considerations, this work aims to identify a cost-benefit model suitable for evaluating sustainable business models of offshore platforms. After a literature review of different models for analysing maintenance and decommissioning Real Options (ROs), the Life-Cycle Cost-Benefit (LCCB) analysis has been selected as the most adequate managerial tool for evaluating and comparing the Net Present Value (NPV) of platforms compared the maintenance and decommissioning costs. The LCCB tool could aid the managers in the oil and gas industry to quantify the decommissioning and maintenance costs including capital expenditure (CapEx) and risk expenditure (RiskEx). In the future steps, to test the LCCB model, an empirical analysis could be carried out on a sample of organizations interested in the sustainable decommissioning of offshore platforms.

Keywords: *offshore platform decommissioning, life-cycle cost-benefit (LCCB) analysis, Life cycle assessment, sustainable business model, Multi-Use Platforms at Sea (MUPS), circular economy*

1. Introduction

In the last twenty years, the decommissioning of offshore oil and gas platforms at the end of their life cycle has been a very controversial and debated issue. The offshore industry expanded rapidly to currently number over 12,000 offshore installations globally (Ars and Rios, 2017). Offshore platforms are situated on the continental shelves of 53 countries, making offshore oil and gas production a major global industry (Parente et al., 2006). Several nations require the complete removal of obsolete structures, which presents substantial engineering challenges and requires incredibly expensive and labour-intensive. Therefore, the considerable decommissioning costs have led to a gradual change in international regulations considering a more flexible approach (Henrion et al., 2015). Consequently, economic

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considerations have influenced the decisions of the oil and gas companies, which are increasingly inclined to postpone the removal process according to economic and technical conjectures. Our main research questions were: *"Is there a cost-benefit model suitable for evaluating sustainable business models for offshore platforms?* or rather: *"The eventual emerging analytic model is useful for an estimate the asset integrity in the Italian oil and gas industry?"* In particular, the adoption of Sustainable Business Models (SBMs), based on value creation (Nosratabadi et al., 2019) between the several actors involved as well as the environment and society, shed light on the possibility to reconfigure the value chain activities and reuse these structures to generate an opportunity from an economic, ecological and social perspective (Evans et al. 2017; Lozano, 2018). In this scenario, the offshore platforms (also known as Multi-Use Platforms at Sea, or MUPS) can represent an innovative solution to meet the growing pushes towards sustainability and circular economy. Likewise, MUPS represents a great opportunity for re-using or reconverting the end life structure, restricting the impacts on marine ecosystems as well as offering socio-economic benefits. In a MUPS scenario, some oil and gas platforms can be reconverted, a part of their structure can be used for activities related to a particular sector such as touristic-recreational, aquaculture (e.g., fish farming and shellfish farming), renewable energy, and hydrogen storage. However, these SBMs have not yet been assessed in the literature from a cost-benefit perspective and the economic sustainability of these initiatives is still unclear. Based on these considerations, this work aims to evaluate the initiatives of reusing the offshore platforms in favour of SBMs in terms of cost-benefits analysis. The emerging cost/benefit model links with a broader framework of assets and infrastructures subjected to obsolescence or final removal (e.g., bridges, wind farms, marine turbines, and offshore platforms). To reach this goal, different models for analysing maintenance and decommissioning Real Options (ROs) have been analysed to identify the most adequate managerial tool for evaluating and comparing the Net Present Value (NPV).

2. Literature Review

2.1 The life cost benefit analysis

The theoretical fundamentals of the Life Cycle Cost-Benefit analysis start from its antecedents that were: the Life Cycle Cost analysis (LCC) and Life Cycle Assessment (LCA). In table 1 are summarized the main literature on this topic. Life Cycle Cost analysis (LCC) and LCA have major methodological differences (Norris, 2001). LCC compares the cost-effectiveness of alternative investments or business decisions from the perspective of an economic decision-maker such as a manufacturing firm or a consumer. LCA evaluates the relative environmental performance of alternative production systems for providing the same function. This environmental performance is assessed as holistically as possible, aiming to consider all important causally connected processes, all-important resources, and consumption flow. Life-Cycle Cost-Benefit analysis is a term that is used in several different connections based on engineering knowledge, economic understanding, and mathematical experience. However, it refers in general to a tool, which may help to assess and estimate, a project or business proposal. Thoft-Christensen (2009) proposed a Life-cycle cost-benefit (LCCB) analysis for the bridges' building, but it also applies in designing maintenance strategies for other structures, as well as offshore platforms. The expected total LCCB of an infrastructure consists of the expected benefits for firms $B_{society}$, for the owners (agencies, private companies, etc.) of the infrastructure B_{owner}, for the users B_{user} and the expected benefits for the environment $B_{environment}$ (Thoft-Christensen, 2012). The formula is as follows (1):

$LCCB = B_{society} + B_{owner} + B_{user} + B_{environment}$ (1)

Instead, it is more useful also to estimate the expected costs in the lifetime of the infrastructure rather than only the expected benefits. Equation 1 is then integrated with Equation 2. That is:

$LCC = C_{society} + C_{owner} + C_{user} + C_{environment}$ (2)

According to Thoft-Christensen (2012), the benefit terms as well as the cost terms in Equations (1) and (2) are clearly uncertain and must be modelled by stochastic variables or processes. The Life Cycle Assessment considers the environmental aspects and the Social Life Cycle Assessment the social ones, the LCC integrates the three layers of sustainability by considering its economic aspects (Andrews, 2009). The three types of LCC can be identified as follow: I) Conventional; II) Environmental and III) Social. The recent contributions on sustainable and circular business models (Joyce and Paquin, 2016; García-Muiña et al., 2020; Basile, 2021). offer a wide analysis of the three-layered considered applied to specific case studies. The conventional LCC is the most used type of LCC and is based on an economic evaluation that takes into consideration all the costs in the various phases of the Life Cycle of an asset. The environmental LCC analysis is considered the costs related to the Life Cycle of an asset, incurred by the stakeholders directly involved. Costs defined by external and situational factors with respect to the Life Cycle are also taken into consideration, to internalize them to the analysis. This latter was developed by a Working Group (Hunkeler et al., 2008) of SETAC (Society of Environmental Toxicology and Chemistry), which gave rise to the guidelines on the methodology of environmental LCC, in conjunction with the LCA. The social LCC differs from conventional and environmental LCC because it takes into consideration all the stakeholders not directly connected with the production system of a product or service. Neugebauer et al. (2016) proposed a Life Cycle Sustainability Assessment (LCSA) framework developed for assessing the sustainability performance of assets through Life cycle assessment (LCA), Life cycle costing (LCC), and Social Life Cycle Assessment (SLCA).

Table 1. The main existing literature on asset integrity management and life cycle cost benefit analysis

Authors	Focus	Main empirical evidence
Norris, (2001)	Integrating life cycle cost analysis and LCA	*"…standard methods of LCA can and have been tightly, logically, and practically integrated with standard methods for cost accounting, life cycle cost analysis, and scenario-based economic risk modeling. The result is an ability to take both economic and environmental performance- and their trade-off relationships into account in product / process design decision making"*
Thoft-Christensen, (2009)	Life-cycle cost-benefit (LCCB) analysis of bridges from a user and social point of view	*"The main purpose of this paper is to present and discuss some of these problems from a user and social point of view. A brief presentation of a preliminary study of the importance of including benefits in life-cycle cost-benefit analysis in management systems for bridges is shown. Benefits may be positive as well as negative from the user point of view. In the paper, negative benefits (user costs) are discussed in relation to the maintenance of concrete bridges"*
Snyder et al., (2009)	Ecological and economic cost-benefit analysis of offshore wind energy	*" …we discuss the costs and benefits of the offshore wind relative to onshore wind power and conventional electricity production. We review cost estimates for offshore wind power and compare these to estimates for onshore wind and conventional power"*
Santa-Cruz et al., (2011)	Maintenance and decommissioning real options models for life-cycle cost-benefit analysis	*"Maintenance and decommissioning real options (RO) models are developed for life-cycle cost-benefit (LCCB) analysis of offshore platforms. Uncertainties about hydrocarbon prices, maintenance costs, environmental loading, structural capacity and damage due to*

	of offshore platforms	*deterioration are taken into consideration in the RO modelling. Expressions are derived for expected costs and benefits in terms of the availability function of the platform, which depends on the hazard and restoring functions, and on the annual probability of failure of the structure. Results show that the use of the net present value (NPV) approach can significantly underestimate the LCCB"*
Chandima Ratnayake et al., (2012)	Asset integrity management for sustainable industrial operations: measuring the performance	*"The main challenge for asset integrity management (AIM) is related to various aspects of its human dimension as apparent on organisational settings and associated cognitive dispensations. (...) The paper provides a review of AIM and a foundation for engineers and managers to analyse the general problem of managing PA' integrity to increase the sustainable value of an asset intensive business in a more holistic way"*
Thoft-Christensen, (2012)	Infrastructures and life-cycle cost-benefit analysis	*"Repair and/or failure of infrastructures will usually result in user costs greater than the repair or replacement costs of the infrastructure. For the society (and the users) it is therefore of great importance that maintenance or replacement of an infrastructure is performed in such a way that all costs are minimized not only the owners' cost"*
Kusumawardhani et al., (2016)	Asset integrity management: offshore installations challenges	*"The purpose of this paper is to identify the challenges facing asset integrity management(AIM) practices in the oil and gas industry, to continually develop AIM practices in organizations. (...) The paper identifies, analyses, and validates the challenges and factors that may impact the management of asset integrity on offshore installations. The challenges were discussed to develop an understanding of the root cause and thus aim to resolve underlying issues. (...) The identified challenges can be used by organizations to resolve underlying AIM challenges, improve their AIM strategy and obtain insights into current AIM practices in the petroleum industry"*
Neugebauer et al., (2016)	From Life Cycle Costing to Economic Life Cycle Assessment Introducing an Economic Impact Pathway	*"…Life cycle sustainability assessment (LCSA) framework has been developed for assessing the sustainability performance of products through Life cycle assessment (LCA), Life cycle costing (LCC), and Social life cycle assessment (SLCA). Yet, the focus of common economic assessments, by means of LCC, is still on financial costs"*
Lam et al., (2018)	Life-cycle cost-benefit analysis on sustainable food waste management: The case of Hong Kong International Airport	*"The aim of this study is to develop a Life-Cycle Cost-Benefit Analysis (LC-CBA) framework, through the integration of the life-cycle assessment (LCA) and cost-benefit analysis (CBA), to guide decision-making in sustainable food waste management"*
Animah et al., (2018)	Selection of the most suitable life extension strategy for ageing offshore assets using a life-cycle cost-benefit analysis approach	*"This paper presents a life-cycle cost-benefit analysis approach to identify the most suitable life extension strategy for ageing offshore assets by considering all the capital, installation, operational, maintenance and risk expenditures during the extended phase of operation. The potential of the proposed methodology is demonstrated through a case study involving a three-phase separator vessel which was constructed in the mid-1970s. The results from the application case indicate that the capital expenditure (CapEx) accounts for the largest portion of life cycle cost for the replacement strategy, while risk expenditure (RiskEx) is the major contributor to costs associated with life extension"*
Li et al., (2018)	Innovative energy islands: life-cycle cost-benefit analysis for battery energy storage.	*"We specifically put forward a life-cycle cost-benefit analysis model to evaluate the economics of battery storage systems used in small communities from a life-cycle perspective. In this research, we put forward a novel cost-benefit analysis model"*
Tang et al., (2019)	Risk identification and quantitative evaluation method for asset integrity management of offshore platform equipment and facilities	*"By analysing the disadvantages and shortcomings of the existing methods and adapting to the technology requirements of the Asset Integrity Management (AIM), a Streamline Failure Mode Effects and Criticality Analysis (SFMECA) was presented to achieve risk identification and quantitative evaluation based on the traditional FMECA and Borda scoring method"*
Nian et al., (2019)	Life cycle cost-benefit analysis of offshore wind energy under the climatic conditions in Southeast Asia–Setting the bottom-line for deployment	*"There is thus a need to evaluate the true benefits of offshore wind energy under the region's suboptimal climatic conditions. In response, this study employs the life cycle analysis approach to conduct a cost-benefit analysis of offshore wind energy in the context of Southeast Asia. Findings from study suggest that the cost of offshore wind energy remains high now for Southeast Asia"*

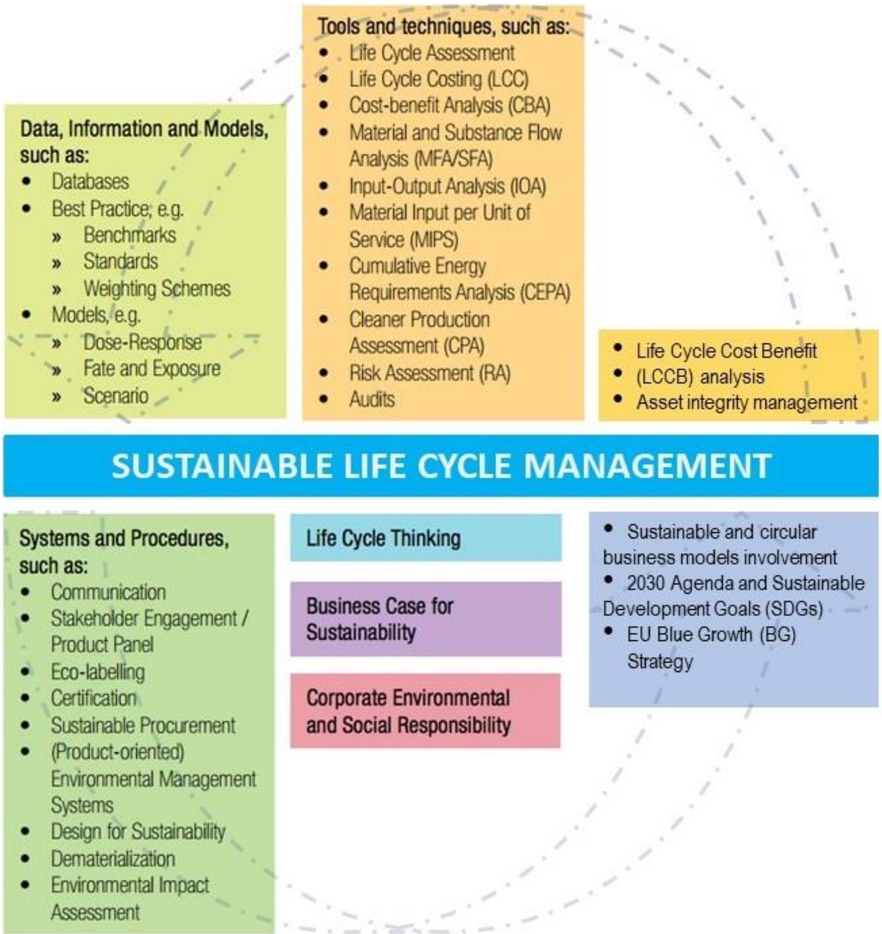
Giuffre et al., (2021)	Life-Cycle Costing Decision-Making Methodology and Urban Intersection Design: Modelling and Analysis for a Circular City.	*"The chapter presents a case study where the Life-Cycle Cost methodology is used to compare three alternative intersection projects based on their total life-cycle costs"*

Source: own elaboration.

2.1 Life cycle Management

The studies on life cycle cost (Fuller, 2010; Lam et al., 2018) integrate the Asset Integrity Management (AIM) contribution (Chandima Ratnayake et al., 2012; Kusumawardhani et al., 2016) into a holistic framework of Sustainable Life Cycle Management (SLCM). Generally, the Life Cycle Management (LCM) can be used to define, analyse and manage product-related information and activities towards continuous improvement along the product life cycle (Remmen et al., 2007). Sonnemann et al. (2015) state that Life cycle management is a concept applied in industrial and service sectors to improve products and services, while enhancing the overall sustainability performance of the firms and their value chains.

Fig. 1: Sustainable life cycle management framework



Source: adapted from Remmen (2007).

The upper side of the SLCM framework (Figure 1) has the following three blocks: 1) data, information and, models; 2) tools and techniques and 3) LCCB and AIM analysis. The lower side includes: 1) system and procedures; 2) life cycle thinking, the business case for sustainability; 3) corporate environmental and social responsibility and 4) Sustainable and Circular Business Model (SCBM).

3. LCCB analysis for evaluating the decommissioning of offshore platforms

The research methodology adopted is based on qualitative analysis and a descriptive approach (Blessing et al., 1998; Ezzy, 2013). Firstly, was carried out an analysis of the relevant academic literature (for the number of citations on Google Scholar, Scopus, and the Web of Science and for the quality of the academic Journals publishing the articles) on the asset integrity management and life cycle cost-benefit analysis (see table 1 in appendix). The in-depth review (Rowley and Slack, 2004) mentioned above was useful in selecting the managerial tool that is the Life Cycle Cost-Benefit model (LCCB). Among the various conceptual models proposed in the literature on BMs, the LCCB was the one that best fits with the sustainable decommissioning of offshore platforms. The LCCB model, in fact, could be applied to SBM in the following industries: aquaculture (which includes fish farming and shellfish farming) (Troell et al., 2009); tourist-recreational activities (which includes hotel accommodation, water restaurant, a hub for recreation leisure and sports activities, high-experience events and naturalistic tourism, etc.); renewable energy (Elginoz and Bas, 2017); hydrogen storage (Hou, 2017); carbon capture utilization and storage (Yao et al., 2018); non-profit organizations. LCCB is the method used to calculate the economic cost and benefit (revenue streams) of the entire life cycle of a product or service, starting from the phases prior to production up to its final disposal, with the aim of minimizing production and maintenance costs. The LCCB method for offshore platforms makes it possible to relate the quantitative data related to decommissioning costs to acquire an overview of the maintenance cost to estimate the feasibility of the sustainable business. The goal is to achieve better economic sustainability of the business project that you want to implement, and if it is possible. Conducting an LCCB assessment of a platform helps predict the costs that potential companies must incur to start a new business, from securing the former oil and gas platforms to its disposal. The LCCB method enabling much more informed business decisions. For example, the assessment of the LCCB of an offshore platform also considers the maintenance that could be decisive for the purchase of certain raw materials or plans expenditures. The results of the LCCB allow companies to make smart investments: when deciding which resources to opt for, one must not only consider their price but the general cost that the adoption of those certain resources will have on the entire Cost of the Cycle Life of a specific asset. The formulation of lifecycle cost-benefit (LCCB) analysis applied to offshore platforms considers maintenance and decommissioning that is the Real Options[5] (ROs) for management along with the service lifetime. The platform structure is subjected to deterioration, and thus the probability of structural failure due to extreme environmental events evolves with time. Maintenance can be provided, depending on findings from future inspections, and management will have the option to provide maintenance or not. Asset integrity management is a great issue for the oil and gas industry. Usually, the management of oil and gas companies prefer to decommissioning the platform, due to the difficulty of estimate the costs for reconversion. The life cycle cost-benefit analysis involves comparing the costs to the benefits

[5] The RO models are based on the Black and Scholes formulation for financial options.

of a project and then deciding whether to go ahead with the reconversion options. The costs and benefits of the projects are quantified in monetary terms after adjusting for the time value of money. We can summarize the LCCB analysis in terms of Net Present Value (NPV) and benefit-cost ratio. The formula for Net Present Value (NPV) and benefit-cost ratio is the following:

NPV = ∑ Present Value of Future Benefits – ∑ Present Value of Future Costs

Benefit-Cost Ratio = ∑ Present Value of Future Benefits / ∑ Present Value of Future Costs

NPV expresses the future benefits of offshore reconversion business (artificial reef, renewable energy production, aquaculture, tourism and diving activities, etc). Furthermore, need to consider the present and future costs (decommissioning, maintenance, and reconversion cost). To calculate the present value of future costs and benefits, we use the present value factor, which is 1/(1+r)^n. Where r[6] is the discount rate, and n is the number of years. The formula for calculating the present value is:

*Present Value of Future Benefits = Future Benefits * Present Value Factor*

*Present Value of Future Costs = Future Costs * Present Value Factor*

The Net Present Value can also be evaluated with the following equation:

NPV = ∑ Present Value of Future Benefits – ∑ Present Value of Future Costs

Therefore, if the Net Present Value (NPV) is positive, the project should be undertaken. If the NPV is negative, the project should not be undertaken. To calculate the Benefit-Cost Ratio, we consider the future benefits. and the present and future costs. After that, we calculate the present value of future costs and benefits. The benefit-cost ratio has the following formula:

Benefit-Cost Ratio = ∑ Present Value of Future Benefits / ∑ Present Value of Future Costs.

If the benefit-cost ratio is greater than 1, go ahead with the project. If the benefit-cost ratio is less than 1, you should not go ahead with the project.

4. Implications, research limitations and future lines of research

This work sheds light on the potentialities of the Life-Cycle Cost-Benefit (LCCB) analysis for evaluating and comparing the Net Present Value (NPV) of platforms compared to the maintenance and decommissioning costs. The LCCB tool could aid the managers in the oil and gas industry to quantify the decommissioning and maintenance costs including capital expenditure (CapEx) and risk expenditure (RiskEx). The results of the analysis highlight the great potential of the adoption of SBM from the oil and gas industry in favour of initiatives aimed at the re-use of offshore platforms. However, the importance of a clear and systems

[6] In general, the WACC can be calculated with the following formula: WACC= (E/V×Re) + (V/D× Rd × (1−Tc) where: E=Market value of the firm’s equity; D=Market value of the firm’s debt; V=E+D; Re=Cost of equity; Rd=Cost of debt and Tc=Corporate tax rate.

governance framework appears to be crucial to support the actors involved and the viability of these initiatives. In this sense, the study provides several insights for researchers and professionals in the oil and gas industry and in the governance field. In particular, the assessment of the LCCB tool could aid the managers in the oil and gas industry to quantify the decommissioning costs or estimate the maintenance costs for entrepreneurs who want to adopt SBMs for offshore platforms. Evaluating whether to start a particular business is very important for entrepreneurs especially for offshore oil and gas platforms. Using the LCCB method, firms can predict whether the ROI (Return of Investment) of a sustainable business is worth the investment they want to make. For an accurate ROI, one needs to consider the initial cost of decommissioning or reconversion of a platform, plus the future costs associated with it. Therefore, the LCCB model is useful to create a predictive and accurate budget for the total cost of the resources, for maintenance and decommissioning cost compared to prospective revenues. To define an accurate budget, firms must take into consideration: costs, revenues, and profit for the year.

In this sense, the purely investigative nature of the research does not allow us to generalize the results, although the insights that emerged from this first study on the subject can provide a foundation and useful stimulus for future theoretical and empirical studies, qualitative and quantitative. The main limitations of this contribution are related to the theoretical nature of the study. The literature review implies the complete reliance on previously published research and the availability of these studies using the method outlined in the search methodology (keywords, database) and the appropriateness of these studies with the criteria of the selection/exclusion procedure (coding). Therefore, in the future steps, the analysis of several international contexts could be carried out to broaden and generalize the emerged findings (Lucas, 2003) and improving the validity and reliability of further inquiring (Golafshani, 2003). Also, in order to test the LCCB model, it could be useful to adopt an empirical analysis on a sample of stakeholders interested in the business feasibility of the three decommissioning ROs, that is, fish farming, hospitality, and hydrogen storage.

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