UNIVERSITY OF ABERDEEN

LEGAL, ENVIRONMENTAL, AND ECONOMIC CHALLENGES OF DECOMMISSIONING OF OFFSHORE O&G PLATFORMS

EG5911 Individual Project in Petroleum Engineering

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Abstract

Decommissioning is the process related to the platform removal, disposal, and scrapping and the revitalization of the field's area which must comply with international and local regulations. The offshore decommissioning faces legal, environmental, and economic challenges that involve several stakeholders. There are three important decom regions in terms of activities, costs estimate, and industry experience: Gulf of Mexico, North Sea, and Brazil. The main objectives of the dissertation were to review the legal, economic, and environmental challenges of offshore decommissioning of platforms, to review of the decommissioning regulations and solutions applied in the Gulf of Mexico and the North Sea, to discuss the solutions applied in the new Brazilian decommissioning regulation and make recommendations for the country. The legal challenges presented are the collaboration between the industry and the regulators, the delineation of robust policies, and the residual liabilities. The environmental challenges are platform disposal, rigs-to-reefs policy, and NORMs management. The platform disposal can either be harmful to nature or help the area revitalization depending on the chosen solution, the rigs-to-reef program can lower decommissioning costs and help to revitalize the marine biome and the NORMs can be removed from the platform and managed either by taken it to specialized yards or by reinjecting them into a disposal well. The economic challenges are decom funding, cost estimation, and financial securities. The securities are a failsafe system that helps the authorities to ensure the implementation of the decom programs which depends on the estimates' precision such as the decommissioning funding. In comparison to the other regions, Brazil is advancing on the presented challenges with its new non-prescriptive decommissioning regulation, a modern and robust document that admits different decom solutions from the companies. Brazilian regulators, however, did not cover the decom funding and residual liability nor defined guidelines for the decom cost estimation and the country does not have specialized decom yards or a permanent radioactive waste storage facility. The regulators have developed a regulation draft for the financial securities which must be thoroughly discussed with the stakeholders. It is recommended that the country develops a solution database to assist the operators with operational issues, design strategies, and guide the cost estimations. Also, Brazil must project and construct sites for decommissioning activities and NORMs management and storage.

Notation

ANP: *Agência Nacional do Petróleo, Gás Natural e Biocombustíveis* (Brazil)
B: billion
BEIS: Department for Business, Energy & Industrial Strategy (UK)
BOEM: Bureau of Ocean Energy Management (USA)
BPEO: best practicable environmental option
BPFO: best practicable financial option
BPPO: best practicable political option
BPSO: best practicable safety option
BSEE: Bureau of Safety and Environmental Enforcement
CGS: Concrete Gravity-Based Structure
CNEN: *Comissão Nacional de Energia Nuclear* (Brazil)
CT: Compliant Towers
EEA: European Environment Agency
E&P: exploration and production
EOR: enhanced oil recovery
FPSO: Floating Production Storage and Offloading
FSO: Floating Storage and Offloading
FSU: Floating Production Unit
HEA: habitat equivalency analysis
HLV: heavy lift vessel
IBP: *Instituto Brasileiro de Petróleo, Gás e Biocombustíveis* (Brazil)
IMO: International Maritime Organization
IOC: International Oil Companies
IOP: Institute of Petroleum
IOR: improved oil recovery
GoM: Gulf of Mexico
£: United Kingdom Pound Sterling (Currency)
M: million
NCS: Norwegian Continental Shelf
NPD: Norwegian Petroleum Directorate
O&G: oil and gas
OGA: Oil and Gas Authority (UK)
OGUK: Oil and Gas UK
OPEX: operating expenditures
OSPAR Convention: Convention for the Protection of the Marine Environment of the North-East Atlantic
PLET: pipeline end termination
P&A: plugging and abandonment
R$: Brazilian *Real* (Currency)
SS: Semi-submersible
TLP: Tension Leg Platform
ton: short ton (2,000 pounds-mass)
UKCS: United Kingdom Continental Shelf
UNCLOS: United Nations Convention on the Law of the Sea
US$: United States Dollar (Currency)

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Chapter 1

1 Introduction

Decommissioning is the process related to the removal, disposal, scrapping, or re-use/repurpose of installations and equipment of an oil and/or gas field on both onshore and offshore environments [1]. The Bureau of Safety and Environmental Enforcement (BSEE) [2] includes in its definition of decommissioning the necessity of returning the field area to its pre-lease condition. In the international Oil and Gas (O&G) industry, the definition of ‘decommissioning’ (or ‘decom’) is not standardized and several countries and conventions adopt different terms like ‘abandonment’, ‘dismantling’, ‘disposal’ and ‘removal’ to describe the activities, however, that does not fully characterize the process, being all of these terms only parts that integrate the decom program [3].

The decommissioning process must comply with regulations set by each country, normally based on international legal requirements involving the appropriated technical application – commonly known as ‘best practices’ –, safety and environmental impacts, waste management, and post-decommissioning site monitoring [3]. This makes the offshore O&G decommissioning one of the biggest challenges in the industry in a process that potentially involves many stakeholders, such as the field operators and other contract holders, the government – represented by the naval authority and O&G regulatory body –, international and local ecology Non-Governmental organizations (NGO), the supply chain and subcontractors, the fishing communities, and even the common citizens [4].

Although the field is normally abandoned only at the end of its production life, sometimes it is necessary to decommission facilities/equipment that are redundant, aged, idle, technologically obsolete, or that have expensive operational costs, such as the Brent Spar [5]. These platforms can be decommissioned in different ways: conversion to an artificial reef or other purposes; mothballing on site which is the maintenance of the facility in a protective inert state without contaminants; relocation for another site for production; removal to land for disposal or recycling; on-site toppling or deep water disposal [6].

Anthony et al. [7] affirmed that over 10,000 offshore facilities have been installed worldwide in the past decades, mostly in the Gulf of Mexico (GoM) and the North Sea. Consequentially, these areas have the most experience in decommissioning. Although most of these installations are steel jackets located in shallow waters below 75 m of depth, in the latest years, deep-water exploration and production (E&P) have been rising, which increases the complexity of the decommissioning activities. By 2011, there were over 7,000 offshore operating platforms worldwide (or 'rigs'). The estimated costs of the worldwide decommissioning processes range from US$ 100 B to 200 B (approximately £80 B ~ 160 B) until 2050, being most of the platforms placed in shallow waters and having to be decommissioned by 2035 [8].

Because of its legal compliance requirements, multidisciplinary nature, and different stakeholder involvement, the decommissioning is a very complex procedure composed of the following main factors: environmental, economic, legal/regulatory, and technical. This dissertation will explore these first three key elements of decommissioning, discussing their challenges and impact on the operators' and regulators' decision-making.

2 Aims and Objectives

This dissertation aims to review the legal/regulatory, economic, and environmental challenges concerning the offshore decommission of O&G platforms. Thus, its goal is to provide an insight into the literature, legal and regulatory framework, and industry practices of the decommissioning processes. Additionally, to assess the impact of the key drivers in the decommissioning that could lead to minimize the environmental impacts of that activity and reduce the costs, safeguarding the stakeholders.

The dissertation will also involve a review of the decommissioning solutions with the focus on the Gulf of Mexico and the North Sea and discussions on resolutions that could be applied in the Brazilian context. Thereby, the specific objectives are:

- Provide an insight into the literature and regulatory/legal framework;
- Identify the main solutions available and the industry examples for offshore decommissioning;
- Evaluate the legal, environmental, and economic issues related to the decommissioning;
- Review the examples of solutions that could be applied in the Brazilian context.

3 Methodology

The methodology established for this dissertation involved, at first, defining the objectives and scope of the project to establish what main concerns had to be analyzed and discussed. Then, a literature review was made to gather sufficient data and knowledge about the challenges of decommissioning projects in different countries. This review focused on the determined scope, investigating scientific papers and articles, books, and other dissertations to gain insights into the economic, environmental, and legal challenges of the decommissioning processes across the world.

From the literature review, three different offshore regions were chosen for this analysis: Gulf of Mexico, North Sea, and Brazil coast. This choice was made based on the different decommissioning stages that each region is at present and the importance of these regions. The literature review pointed that the Gulf of Mexico had the most number of platforms and experience in decommissioning processes, the North Sea had a smaller yet significant number of rigs and the more costly processes, and Brazil which in expecting expressive decom costs in the next years, however, has decom industry still in development that could avail from the other countries experience.

Additionally, to assist the development of this project, O&G industry webinars, cases, studies, and reports were analyzed to give a more pragmatic view of the decommissioning issues, aiming to associate the practical application of the decommissioning process to the theoretical considerations and regulations. To understand the legal aspects of the decommissioning process, a data collection of the international treaties and agreements, regulations, laws, and guidelines related to the matter. For the regulatory view of this dissertation, the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), International Maritime Organization (IMO), United Kingdom and Norway Petroleum Acts, and Brazilian laws and regulations were used as references.

Chapter 2

4 Background

This section will present the literature review made for the development of this dissertation based on scientific papers and articles, and books, and the necessary information and relevant theories needed to better understand the discussion of the project. The section shows information about the life cycle of a field and the period when the decommissioning is done, the decommissioning process and some technical solutions, the number of platforms installed and removed in each of the chosen areas, the international conventions and regulations, decommissioning cost estimates, and important environmental and economic aspects.

4.1 Life Cycle of a Field

The decommissioning is the final step in the conventional life cycle of an oil and gas field. The lifecycle of an O&G field can be chronologically divided into five stages: exploration, appraisal, development, production, and decommissioning [1]. At the exploration stage, normally done after a license (Figure 4.1) is granted by a competent authority enclosed by an agreement [9], the company allocates resources to identify and assess a prospect by gathering and analyzing geological/geophysical data and drillings exploration wells to discover a hydrocarbons reservoir [10]. During this period, the licensed area is commonly known as an exploratory block/sector.

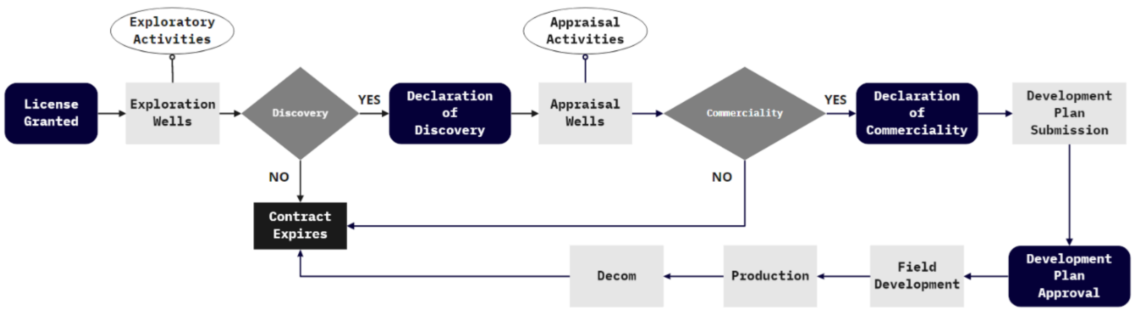


Figure 4.1: Fluxogram of a common licensing system showing the stages that a filed operator passes from the licensing to the decommissioning of a field. [Self-made]

According to Bret-Rouzaut & Favennec [9], when a hydrocarbon discovery occurs in a volume high enough to attract further evaluation, the appraisal stage begins, and wells are drilled aiming the collection of more information about reservoir properties. The contract holder is required to notify the regulatory body about that discovery and present an evaluation project. If the discovery is commercial, based on the volume of hydrocarbons discovered or the productivity rate of the well, a field development and production plan – field development plan – is elaborated and submitted to the authorities for approval. With the plan approval, the development phase commences. However, the development of the field phase can begin after the discovery or years later, after a more extensive appraisal of the reservoir or delineation wells have been drilled [10].

Jahn, Cook, & Graham [1] present some activities that are done during the development phase and before the first production: design of the facilities; acquisition of the materials; fabrication and installation of the facilities; and commissioning facilities and equipment. The production period starts after the development with the field's first oil which is the first production of a commercial hydrocarbon volume. The expected production profile determines the facilities' requirements and the number of wells – producers and injectors – needed to exploit the field's reservoirs. There are three main stages of a common production profile (Figure 4.2): build-up period, plateau period, and decline period [1].

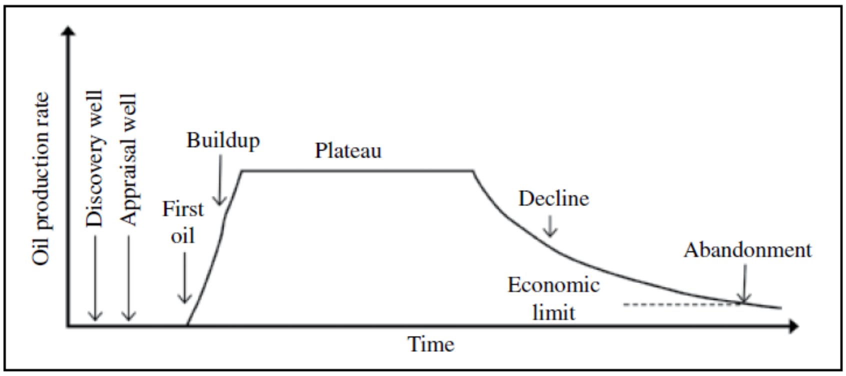


Figure 4.2: Typical production profile of an oil field from the exploration to the abandonment, showing the production's first oil, build-up, plateau, and decline until the economic limit of the field. [10]

The build-up initiates after the first oil is produced and goes until the plateau period, usually due to the facility and/or equipment limitations or process bottleneck. The plateau can also derive from reaching the reservoir maximum productivity. After the plateau, the hydrocarbon production will decline until the field's economic limit and it is decommissioned [10].

The contractual duration of the production period depends on the contract type and country's agreement policy. Production is usually authorized for an initial period, typically 20–25 years, which may be renewable for 10 years or more if further production is economically viable [9].

Kaiser [11] and Jahn, Cook, & Graham [1] define the economic limit of a field as the period at which the net cash flow becomes negative, as seen in Figure 4.3. After this point, the asset's revenue from the oil/gas sale becomes lower than the costs of its production, i.e., the asset costs more money than it generates. To produce hydrocarbons beyond is to accept financial losses, which defeats the purpose of economic activity, but it could happen for strategic or other reasons.

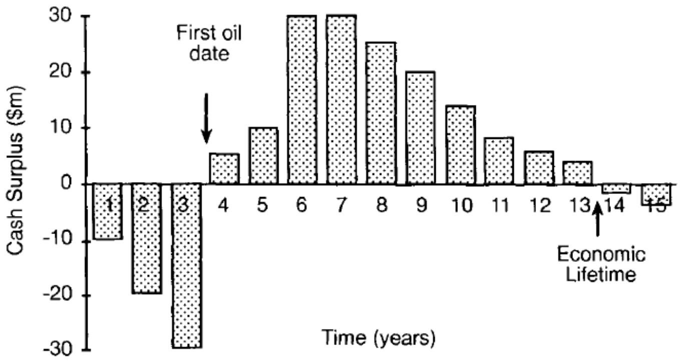


Figure 4.3: Expect pattern of a field's annual net cash flow with a negative number in the first three years representing the investment in the field and the positive number representing the income/revenue. [1]

When a field reaches its economic limit, other options for extending the production can be used, such as the implementation of enhanced oil recovery (EOR) techniques – utilization of miscible gases, chemicals, and/or thermal energy in the reservoir to displace oil – and improved oil recovery (IOR) activities which comprehend EOR and incorporate other activities, for example, reservoir characterization, well workovers, improved reservoir management, and infill drilling [12]. Jahn, Cook, & Graham [1] indicate that the economic viability of EOR techniques is sensible, depending on the recoverable volume of hydrocarbons, cost of implementation and the oil price, being difficult for the company to attain a favorable combination of these factors, especially in the offshore environment.

Although a partial decommissioning can be done to replace or upgrade facilities and equipment extending the field life cycle, the decommissioning plan will be carried after these options have been exhausted, the production has ceased and the company has no further interest in investing in the field.

4.2 Decommissioning Process

The decommissioning process comprehends several technical activities from the cessation of operation to the post-monitoring of the field's area, including, but not limited to the following: decontamination, dismantling, and demolishing facilities; remediation of contaminated areas/site rehabilitation; managing different types of waste, including legacy waste that have been collected and kept over the years; transportation, storing and disposing of materials and waste [13]. This multidisciplinary program will manage the most appropriate method to cease the field's production and shut down operations in compliance with laws and regulations, following company expectations regarding safety issues in a cost-effective approach. However, a partial decommissioning can also be required for the plant optimization to maintain field production for a longer period since facilities and platforms experience aging effects and/or obsolescence [9].

As stated by ICF Incorporated [14], the decommissioning process goes from planning to offshore operations. The process will respect a workflow defined by every company that might include some activities divided into three stages:

- Pre-decommissioning: planning, collecting/retrieving data, inspecting the facilities, performing studies, surveys and engineering analyses, determining specific procedures, permitting, bidding, and other pre-job activities and preparatory work;
- Execution: platform preparation and cleaning, well abandonment, cutting, lifting, pipelines cleaning and flushing, removal of installations, equipment and materials, transporting, towing, dismantling, scrapping, and waste management;
- Post-decommissioning: site clearance/verification, decommissioning reporting, and post-decommissioning surveys and monitoring.

According to Neilson & Gorman [6], many decom options can be adopted by the field's operator based on the environmental protection, cost, health and safety, available technology, public view, regulatory and legal aspects, and politics. For the offshore decommissioning, the project must also consider the oceanography, geolocation, biogeography, water depth, surrounding habitat, material transport, and disposal, among other factors. The rigs destination, for example, is one of the environmental discussions involving the field's abandonment.

The industry and the regulators developed a variety of possible outcomes, as seen in Figure 4.4, to know [15, 16]:

- Leave in place: Leaving the platform in the same place after the cessation of production and cleaning of the structure, equipment, and lines;
- Monitoring: Leaving the platform *in-situ* and periodically monitoring the structure and associated materials;
- Toppling: performing the minimum required activities to cover the health, safety, and environmental aspects and topple the structure horizontally on the seabed;
- Partial Removal: removing the topside and transporting it to shore and leaving the jacket *in-situ*, also known as 'topping;'
- Recovery or Total Removal: The removal and transport to the shore of the platforms and its components for dismantlement and recycling or landfilling;
- Reefing: in place, shallow waters diving/fishing sites or deep-sea to create artificial reefs;
- Deep-sea disposal: The removal, transport, and abandonment of the structure and components at a deep-sea location, away from any possible human interaction and with minimal negative environmental impact;
- Alternative uses such as offshore hotel, mariculture/aquafarming, wind/wave power generation.

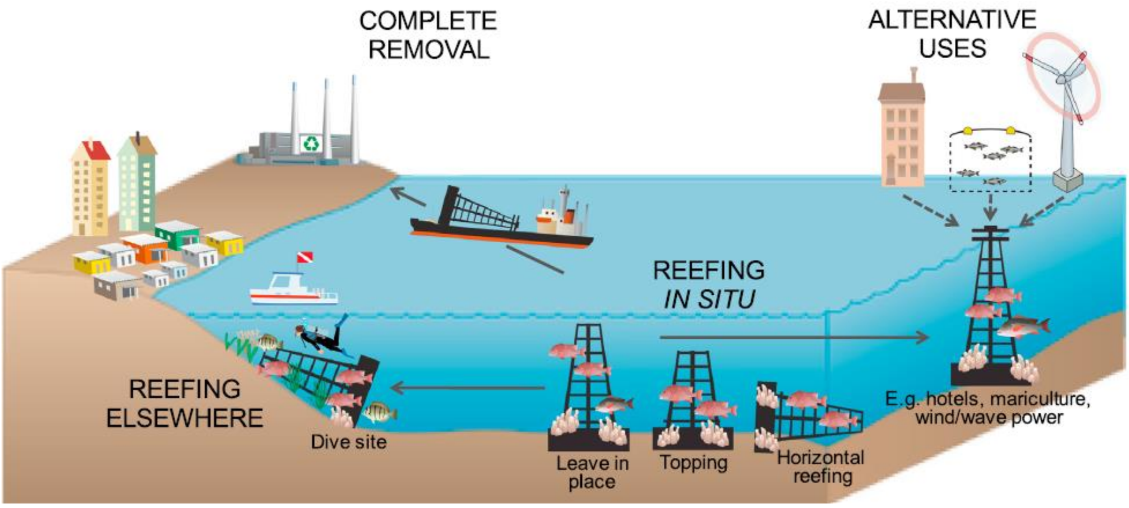


Figure 4.4: Conceptual model of platforms decommissioning options showing different outcomes, removal and disposal options, and alternatives use of the installations after decommissioning. [16]

4.2.1 Offshore Structures

Offshore structures comprehend all the installations, facilities, and equipment located in waters that can be used for the hydrocarbons production or to support the production platform, e.g., housing and powering vessels, towing boats, oil and gas tankers, etc. The components present in the subsurface are of a great variety: wells and components (wellheads, subsea tree, tubing hanger, etc.), lines (umbilicals, pipelines, flowlines, jumpers, and risers), pipeline end termination (PLET), anchors, buoys, manifolds, compression and energy supply systems, etc. The implementation of fields' subsea factories will increase even more the number of structures that can be placed on the seabed either in shallow or in deep waters.

Since, the scope of this dissertation will relate to economical, legal, and environmental aspects of the decommissioning process of offshore production platforms, setting aside the technical feature of the related activities, it is important to know the types of production platforms. The types of platforms characterize different decommissioning solutions and challenges because they can represent a significant change in the costs and disposal options since, for example, the fixed platforms represent due to their design a greater challenge for removal and disposal then moored/tethered facilities [6]. There are several types of offshore surface structures: Fixed Steel Jacket, Steel Monopod, and Concrete Gravity-Based Structure (CGS), Semi-submersible (SS), Floating Production, Storage, and Offloading Vessel (FPSO), Floating Storage and Offloading (FSO), Floating Production Unit (FSU), Tension Leg Platform (TLP), Compliant Towers (CT), Control Buoys, and Spars [14]. Figure 4.5 presents some of the most used offshore production facilities:

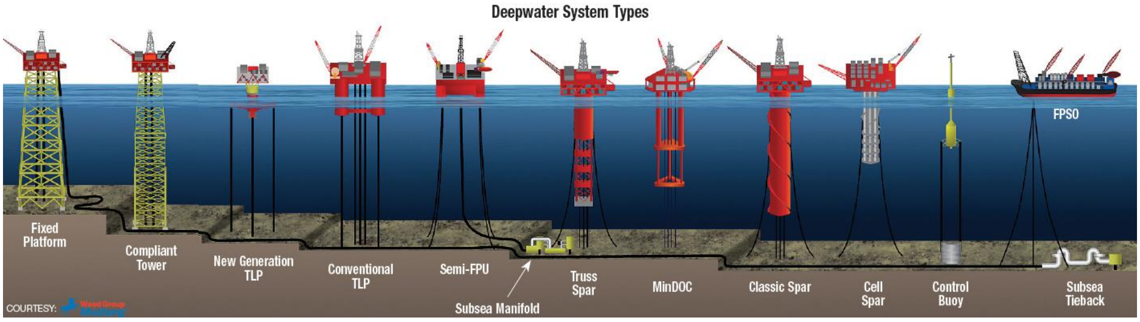


Figure 4.5: Types of offshore structures used in the field's development and production stages to produce, store, and export the hydrocarbons. [17]

Other vessels play some role in the field development, such as the Construction Support Vessel (CSV), Dive Support Vessel (DSV), Pipe Laying Support Vessel (PLSV), and Anchor Handling Tug Supply (AHTS), etc. [18], however, they do not represent a permanent field structure and, therefore, are not studied in this dissertation.

4.3 Platforms Installed and Removed

To better understand the dimension of the expected decommissioning activities worldwide, it is important to understand the history of the offshore operations, know the number of existing structures that might go through this process, and how many platforms each region has decommissioned.

This dissertation features three different offshore regions with distinct decommissioning industry development: Gulf of Mexico, in the United States of America (USA), that has the highest number of platforms installed and removed and a well-developed decommissioning industry; the North Sea, comprising the UCKS and the NCS, that has the highest expected abandonment costs, hundreds of offshore structures, an industry in development and regulators aiming for cost-effective solutions; and Brazil, with a continuously growing offshore production industry, but an infant decommissioning industry and regulation.

4.3.1 Gulf of Mexico (USA)

Even though the GoM is a major area in the petroleum industry, the first offshore fields in the American continent are known to have produced in the Central California Coast. In the last decade of the 19th century, the Summerland field, located in California – USA, began drilling and producing by wooden piers and derricks about 400 m from the coast at water depths that reached over 10 m [19]. Griggs [20] considers that the first true offshore in the USA was built on the coast of Louisiana, in 1937. In the same period, those offshore facilities needed to be decommissioned because of deterioration, fires, or storm damage. However, there were not adequate policies or techniques for decommissioning of the structures during the early development of the American O&G industry [21].

Over the years, there was an exponential growth in the number of platforms worldwide. In the GoM, there were over 1,000 platforms in 1963, 4,000 platforms in

1996, and 6,000 in 2000 [19]. Until 2017, 7,053 structures have been installed in the region of which 97 were in a deep-water environment, being 48 floaters, three compliant towers, and 46 fixed platforms [11]. As of April 2019, there were about 1,862 platforms in the gulf [2].

Griffin [22] states that the first records of decommissioning in the Gulf of Mexico began in 1973 when small structures started to be removed. According to the Bureau of Ocean Energy Management (BOEM) [23], at the end of 2019, nearly 5,300 structures have been decommissioned in GoM, including platforms and equipment, almost all in shallow water. Figure 4.6 shows the location of the offshore installations in 2020 from BOEM's, where the black hexagons with dots representing the platforms [24]:

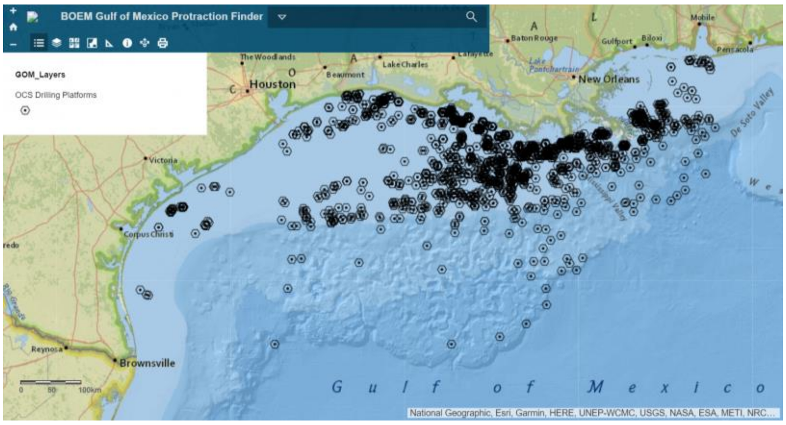
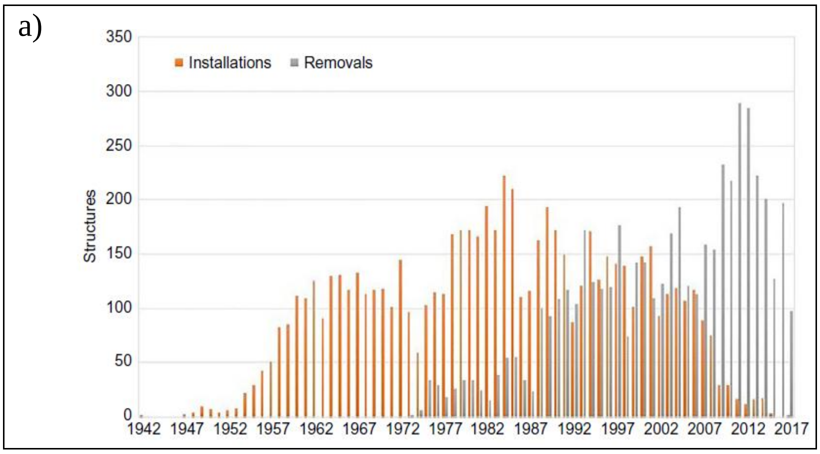


Figure 4.6: Location of platforms in the Gulf of Mexico waters. Each black mark represents a platform currently placed in the GoM waters. [24]

Figure 4.7 (a) and (b) shows the evolution of the number of structures installed and removed in the Gulf of Mexico in shallow and deep waters, respectively, during the last decades:



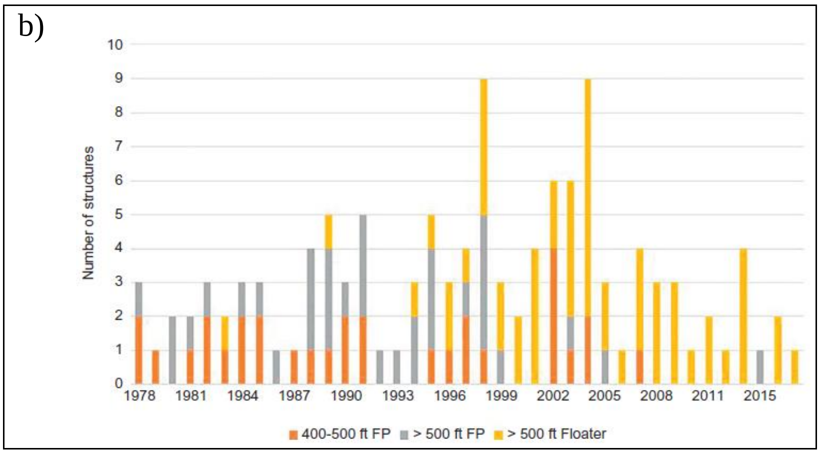


Figure 4.7: Evolution of the number of structures installed and removed in (a) shallow and (b) deep waters of the Gulf of Mexico in the past decades. [11]

4.3.2 North Sea

Since the 1960s, hundreds of oil and gas facilities have been placed in the United Kingdom Continental Shelf (UKCS). The sum of all the other sectors of the North Sea combined, such as Norway, Denmark, the Netherlands, and Ireland make a similar number of offshore installations. They comprehend a full range of types, including platforms made of either steel or concrete, which sit on the sea-bed, floating production systems, often including floating offshore installations, subsea equipment, and pipelines [6].

By 2016, the UKCS had more than 320 structures, considering platforms and equipment which must be decommissioned or re-used [25]. From 2019 until 2028, the number of fields with expected decommissioning activity across the Northern North Sea, West of Shetland, Central North Sea, Southern North Sea, and the Irish Sea is equal to 230 and the projected number of topsides to be removed is 87 [26].

At the beginning of 2017, the Norwegian Continental Shelf (NCS) had 500 installations, considering platforms and equipment. The Norwegian Petroleum Directorate (NPD) indicates that the Norwegian continental shelf had 80 production fields and 23 that ceased to produce by the beginning of 2017. From the closed down fields, 12 fields have been fully decommissioned, 1 partly decommissioned, 2 had their platforms removed, and 8 were to be abandoned during the following years. By the end of 2020, the NPD expected up to 20 other fields, mostly small-sized, to stop their production [27].

As seen in Figure 4.8, the North Sea installation and decommissioning of structures are dominated by the United Kingdom and Norway.

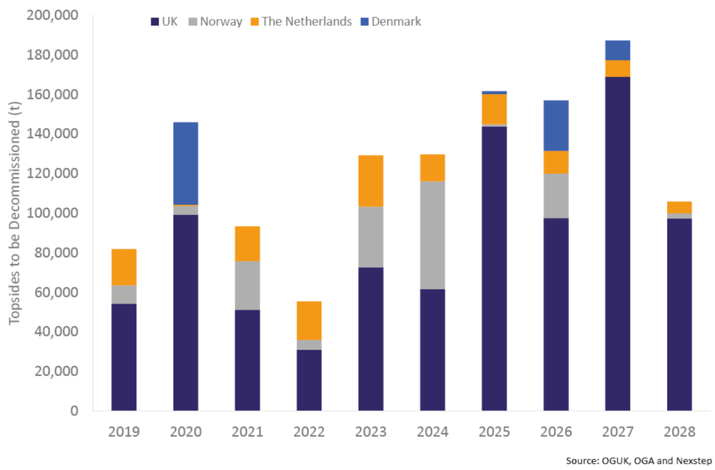


Figure 4.8: UK, Norway, Netherlands, and Denmark topsides decommissioning activity forecast from 2019 to 2028 measured by the weight. [26]

Until 2010, only 20 platforms were decommissioned in the North Sea, remaining over 400 installations to be decommissioned [9]. In 2019, according to the OSPAR Commission [28], there were over 570 operational platforms in the North Sea and the Norwegian Sea, and 105 platforms had already been decommissioned. Circa 85% of the North Sea installations currently in place are fixed steel platforms – around half are in the UKCS –, less than 12% are floating and gravity-based platforms and around 3% are other types of platforms.

Figure 4.9 shows the location of the offshore installations in 2017, extracted from the OSPAR Commission Data System (ODMIS), showing red dots for the decommissioned installations and orange dots for the still operational [29].

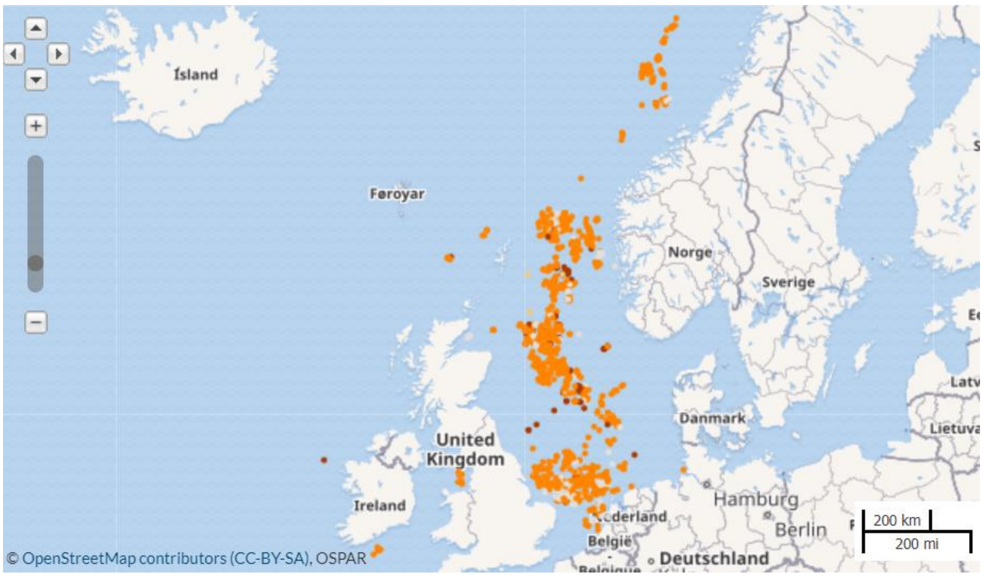


Figure 4.9: OSPAR Commission offshore installations inventory in the North Sea (2017). The red dots represent the decommissioned installations and the orange dots represent the operational platforms. [29]

4.3.3 Brazil

The first Brazilian oil discovery happened in 1939 in Lobato – BA, however not in a commercial volume. Around 1947, the offshore exploration began in Brazil in the *Recôncavo* Basin, extending the onshore Dom João field into shallow waters, resembling the beginning of the offshore industry in Summerland. Only in 1968, Petrobras – a state-owned company – made its first offshore discovery in the *Guaricema* field, on the coast of Sergipe, at water depths of about 80 m [30].

In 2018, Brazil had 158 offshore platforms being 88 fixed – steel and concrete – platforms, 48 Floating Production Storage and Offloading (FPSO) vessels, 16 semi-submersibles, 4 Floating Storage and Offloading (FSO) vessels, 1 Floating Production Unit (FSU), 1 Tension Leg Platform (TLP) [31, 32]. As indicated by ANP – Brazilian National Petroleum Agency (*Agência Nacional do Petróleo, Gás Natural e Biocombustíveis*) – less than 70 platforms, from both fixed and floating types, were producing in May 2020 [33]. Figure 4.10 shows the location of Brazilian offshore platforms, which are more concentrated in *Campos* and *Santos* basins:

Figure 4.10: Brazilian inventory of offshore installations in 2020 with each dot color representing a different field operator. The platforms are concentrated in *Campos* and *Santos* Basins in the southeast direction. [33]

Brazil's health and safety regulations require special attention for aged platforms, indicating 25 years of operation before the scheduled obsolescence of offshore rigs. After this period, the platforms need an extra inspection to maintain the production. Considering the offshore Brazilian platforms, 66 have more than 25 years, 23 between 15 and 25 years, and 69 have less than 15 years of production [31, 32].

In comparison, in 2012, the South East Asian had already 444 offshore installations that have been in service between 20 and 30 years, and another 389 that have exceeded the typical 30-year service life of such installations and are still in operation [3]. Brazilian Navy, via its Directorate of Ports and Coasts (*Diretoria de Portos e Costas*), indicates that Brazil has 183 platforms, a number that includes smaller facilities and installations that are currently out-of-commission [34].

These numbers show how Brazil has an infant decom industry, having performed no full-field offshore decommissioning and the expected growth of the industry during this next decade. The country had less than 10 floating platforms decommissioned after the creation of the Brazilian O&G regulatory agency (ANP) in 1998, and yet no fixed platform removed from offshore. Before that, only 6 fixed offshore platforms have been decommissioned by the Brazilian National Oil Company (NOC), Petrobras. The first offshore decom happened in 1980 and the following also occurred in a period when the country had no O&G regulators or local specific abandonment legislation [35].

The first full-field decommissioning process to be completed is of *Cação* Field, in *Espírito Santo* Basin, which consists of three small steel-jacket platforms, 1 three-legged (PCA-01) and 2 four-legged (PCA-02 and PCA-03) connect by two catwalks as seen in [32].

Figure 4.11: Platforms of Cação Field (PCA-01, PCA-02, and PCA-03) in Brazil. [32]

To deal with the incoming growth of the decommissioning industry, Brazil has developed a new decommissioning regulation that was approved in early 2020 by ANP. The challenges that the country will face are going to be analyzed in this dissertation in Section 6, focusing on the new regulation and how it deals with different aspects of the decommissioning

4.4 International Regulations

In general, a regulatory framework follows a hierarchy with domestic regulations, being elaborated based on international conventions. Since the decommissioning issues and technology changed with the continuous development of the industry, the regulations had to adapt to those changes. The matter of the waster disposal, for example, stopped being considered by the regulations only a source of environmental impact, evolving to an issue to be managed by the companies which had to prioritize the waste reuse and recycling [36].

4.4.1 International Guidelines and Conventions

Decommissioning regulations and guidelines have been evolving since the middle of the last century. They formally began in 1958 with the Geneva Convention and were consolidated in the following decades by the London Convention (1972) and IMO (1989). Regionally, the Barcelona Convention, the Kuwait Protocol, the Oslo Convention, and the Paris Convention had a significative impact, however not in the extend of the OSPAR Convention held in 1992. These regulators and conventions existed before the Brent Spar became a public issue in 1995; however, this incident caused the industry and regulators to understand that decommissioning was a multi-disciplinary process with different stakeholders and concerns, not just an isolated company's engineering project that leads to the development of different legal requirements for offshore decommissioning [22].

UNCLOS

The United Nations Convention on the Continental Shelf (or 'Geneva Convention') was created in 1958 and regulated the safety zones (Article 5 (3)), interference with navigation, fishing attention for other users of the sea (Article 5 (1)), and protection of the marine biome (Article 5 (7)). It brought in Article 5 (5) the requirement for the complete removal of any abandoned or disused installation [15, 3]. In 1982, the Third United Nations Convention on the Law of the Sea (UNCLOS) was established with a relaxation on the installation requirement for total removal (Article 60 (3)), allowing the partial removal. The Convention also designated that a competent organization should carry further removal standards [3].

London Convention

In 1972, The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (or 'London Dumping Convention') regulated the sea dumping, i.e., "any deliberate disposal at sea of vessels, aircraft, platforms or other man-made structures at sea" as described in the convention's Article III(1)(a)(ii). The convention considered that dumpings could be approved by local authorities. The 2006's Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (or 'London Protocol') updated the London Convention, adopting a list of acceptable materials for dumping [15, 37].

IMO

In 1985, the Oslo Commission requested that the international community oversee the standards for installations removal. By letter, the commission solicited the International Maritime Organization (IMO) to develop the international disposal standards [22]. IMO, then, developed guidelines and standards for removals, permitting the partial option for deep-water installations [3]. In 1989, IMO Assembly Resolution A.672 (16) adopted the 'Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone'. The countries analyzed in this dissertation – Brazil, the UK, Norway, and the USA – are member states of IMO [38].

These guidelines would only be applied to international waters, leaving the decom guidance within the territorial sea for the local governments [7]. However, the requirement for total platform removal still held for any platform weighing less than 4,000 tonnes in shallow waters (< 75 m). After 1998, the threshold went up to 100 m water depth, and the installations should be designed for that if possible. The partial removals required at least 55 m of unrestricted water column for safety navigation [36, 7].

4.4.2 Regional Conventions

The Convention for the Protection of the Marine Environment of the North-East Atlantic (or 'OSPAR Convention') regulates the North-East Atlantic, an area that includes Greenland, the Arctic, and the north European Union region [37, 3].

The OSPAR Commission (1992) followed the meeting of the Oslo and Paris Conventions of 1972 with the proposal of consolidating the previous conventions and discussing the increasing degradation in sea and coastal zones, aiming for environmentally sustainable management and use of the sea. After the Brent Spar incident, the OSPAR Commission changed its position, from a more lenient policy that permitted partial removals to a more rigorous, prohibiting the dumping of whole or partial offshore installations which became known as the 'OSPAR Decision 98/3' [7, 5].

The decision banned the disposal at sea of offshore installations allowing the *in-situ* disposal as an exception, only in specific circumstances which could be sanctioned in a case-by-case scenario, leading to the derogation principle, i.e., a waiver of the total removal rule. Exceptions regard large fixed concrete and steel jacket platforms installed before 1999 [7, 15, 37], for example, the Ekofisk-tank and Frigg TCP2 concrete platforms in the Norwegian Continental Shel (NCS) which were left in place [27].

4.5 Environmental Aspects

The decommissioning process involves the removal of materials aiming to bring the production area back to its prior state before the field development or close to the original, conserving the natural resources. The environmental aspects of decommissioning are related to its direct impact on nature, the conservation of resources, and energy.

During the operations, human health and safety and the marine environment and live stocks might be impacted [15]. The planned projects, therefore, require detailed planning and assessment of the best practicable environmental option (BPEO) which minimize possible negative impacts and comply with local regulations and international conventions. Thus, the OSPAR Convention determines that the parties involved in the sea activities must prevent and eliminate pollution, taking protective measures against its negative environmental impacts preserving the marine ecosystems (Article 2). The convention also indicates that the parties must use the best available techniques and environmental practices and restore affected areas.

Different authors, from Prasthofer [36] to Fam et al. [3], indicated an evolution in the environmental international regulation which focuses at first on the waste disposal (direct impact) and later on the material management (resources conservation). Regulations also aim at the recovery of waste and material reusing/recycling, creating a preferable order of practices on the management that emphasis first the reduction and recovery and ends with treatment and disposal of the waste.

The sea disposal was one of the key controversies regarding Shell's Brent Spar decom project. The company's analysis indicated sea disposal for the platform as the BPEO since the residual contaminants of the platform would have minimal impact in the deep-sea environment. The operator assessment indicated that the sea disposal would keep a low offshore impact, not taking the impact inshore while removing the spar to an onshore site for disassembling could cause contamination of shallow waters. The UK Natural Environment Research Council (NERC) study confirmed the deep-sea platform disposal as a viable decommissioning option [7, 5]

After the Spar incident, the disposal of the offshore platforms and their residues became an increasing dispute between the environmentalists, regulators, and oil companies. The environmental challenge became the definition of criteria to determine the BPEO, contrasting the recycling onshore, reuse, and offshore disposal options. Pollett [39] shows three important environmental criteria that could appear, as a minimum, in risk-based approach regulations and have to be assessed to establish the BPEO: risk of pollution/contamination, impacts on wildlife (fauna and flora), and the presence of Naturally Occurring Radioactive Materials (NORM).

4.5.1 Human Pressures on the Sea

Decommissioning is among the marine activities that provoke environmental problems. However, OSPAR did not consider the offshore O&G industry in the list of highest human pressures on the sea, which are mainly dominated by fishing-related activities [15]. Alternatively, the European Environment Agency (EEA) indicates that the main pressures are "fishing, seafloor damage, pollution by nutrient enrichment and contaminants, the spread of non-indigenous species" [40]. The seabed damage and pollution can be part of offshore exploration, production, and decommissioning activities. So, for the EEA, the offshore decommissioning do have an impact on the land, sea, and air, altering the environment by sea dumping, land disposal, energy use, and/or gas emissions [7].

Depending on the chosen decom solution, the companies should also account for the environmental effect on the biodiversity in the region surrounding the platforms, since the removal of rigs might impact the fauna and flora of the field's area. The complete platform removal, for instance, is likely to reduce the variety of species that make the platform region their habitat. Depending on the facilities' structures, partial removal options could ease the negative environmental impact [16].

4.5.2 Energy Use

Energy use is typically divided into 'direct energy consumption' – offshore and onshore operations, marine support, transportation, etc. – or 'indirect energy consumption' which includes the materials' lifecycle – materials replacement, mining, scraping and transporting ores and coal, building and fueling machinery, disposing and recycling [41, 16].

The different possible options will influence the energy use requirement that can be evaluated to determine a suitable solution for the field's platform. As indicated by Sommer et al. [16], any of the structure's material can be arranged into an energy use level hierarchy from the least to the most energy-intensive option. The decommissioning option with the least energy usage is the reuse because the energy for transport is limited, there is no need for recycling and new materials creation. Then, the recycling option which requires energy use for material re-processing. The worst option would be sea disposal, because of the high energy cost of replacing the raw material lost in the abandonment [41].

Thus, disregarding the possibility of recycling parts of the structures, removing the platforms partially or completely would demand a higher direct energy consumption and emissions when compared to leaving the installations in place [16].

4.5.3 NORMs

Naturally Occurring Radioactive Materials (NORM) are radioactive minerals scales deposited in the platforms that could be harmful to the human being and the environment. They are associated with radioactive elements of natural origin deposited inside production and processing equipment, tubular, and lines. This natural occurrence is a reference to the radionuclides in the material derived from physical, chemical, or thermal processes in the platform plant [42]. The primarily radioactive elements that compose the NORM deposits are uranium (U), thorium (Th), and radium (Ra), but other elements like lead (Pb), radon (Rn), and polonium (Po) can be found in gas production and processing. The concentration of the isotopes of these elements can be up to a thousand times higher than naturally found in surface seawater [43]. Thus, the decom project must include the hazards and the NORM management, along with other hazardous substances, e.g. asbestos and heavy metals [44].

4.5.4 Fishing Activities

To define the optimal facilities' destination and after removal, the fishing activities must also be considered in the decom program. The fishing industry, especially in the North Sea, represents an important stakeholder with several opinions about the best solution to be applied. For instance, trawlers vessels are benefited by an unobstructed seabed, but net setters prefer the residual structures to be left in the site to aggregate fish. Anglers, trappers, and long-line and net fishermen are also affected by the decom activity [15]. The fish's biodiversity is sensible not only to different approaches such as total or partial platform removal but also to the structures' location, depth, physical characteristics, and direction in which the platforms are disposed of in the seafloor. Sommer et al. [16] indicate that distinct biological communities inhabit natural reefs, operating, and reefed platforms. For instance, fish assemblages differed from an operating to a reefed platform, i.e., vertically, and horizontally placed platforms.

4.6 Economics

This section shows details of the decommissioning economics: how the costs of decommissioning increases with different challenges, what are the main costs grouping of the program, and which activities are included in these grouping. It also shows the cost estimates of the decommissioning regions discussed in this dissertation which coincides with the three higher decom cost estimates worldwide. Finally, this section indicates essential information about the necessity of financial provision to perform the decommissioning activities and the financial securities that some governments require to assure that a company will fulfill its obligations or, in case not, to have a financial guarantee to be used.

4.6.1 Cost of Decommissioning

The North Sea has a low percentage of the world's offshore oil and gas platforms, but it could represent more than 60% of the worldwide decommissioning costs, because of the weight and complexity of the platforms and the region's harsh weather conditions that increase the removal and disposal operations time and difficult and, therefore, the costs [36]. The costs depend directly on the engineering project developed by the operator, having a great range across the adopted solution spectrum, from the total removal to shore to the offshore disposal. For example, towing a steel-jacket platform for onshore scrapping is usually more expensive than toppling the jacket *in-situ* (see Figure 4.4). So, the companies make efforts to create value from decommissioning, yet the materials of the structure have limited recycling value and the best solutions still involve re-using the structures or selling them to another company which is not often possible [5].

The decom costs are also associated with job creation, fiscal terms, transporting, recycling, legal/regulatory exigences, and environmental impact. In the UK, e.g., the decommissioning costs can overload the National Treasury because the government and, therefore, the taxpayers carry part of the cost by the means of tax relief. This tax relief is calculated based on the company's taxable profits, the basin maturity, and the decommissioning expenditure. However, government exposure tends to lower as the industry continues to reduce costs [26].

4.6.2 Cost Groupings

The Oil and Gas UK (OGUK), a British O&G association, developed a guideline [45] pointing out some major costs groupings for the offshore platform decommissioning:

- Project management and operational costs;
- Topsides, equipment, and substructure preparation, cleaning, removal, and recycling;
- Site remediation and monitoring.

The Seaway Heavy Lifting [8] and the Decom North Sea & ABB Limited [46] present the importance of understanding the availability of vessels, the extra costs inherent to offshore working, the productivity and effects of offshore conditions, and show some other costs that need to be considered in the project:

- Decontamination and waste disposal;
- Cleaning, burial or removal of pipelines, if needed;
- Support vessels (lifting, removal, powering, housing, etc.) and alternative transporting (helicopter).

The platform type and the different projected decom solutions might bring extra costs such as cutting and lifting the topside in small or large pieces, total removal to shore for disposal, towing the jacket to shore, or in the deep sea [15].

4.6.3 Regions' Cost Estimates

Wood Mackenzie – an international global energy research and consultancy group – expects that worldwide the amount of US$85 B (around £66 B) will be spent on decommissioning activities over the next decade, with the United Kingdom representing 28% of this value, followed by the USA (13%), Brazil (11%), and Norway (9%), as shown in Figure 4.12 [26]:

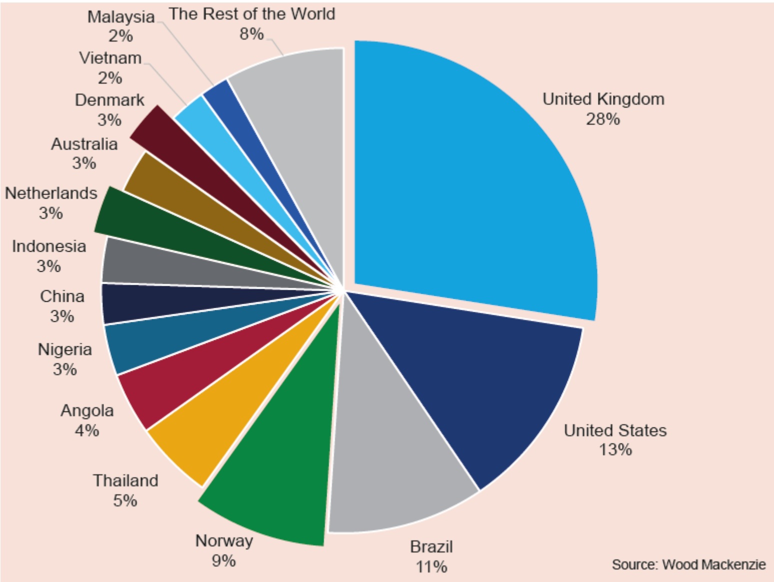


Figure 4.12: Global Decommissioning Expenditure from 2019 to 2028. UK, USA, Brazil, and Norway have higher estimation costs than other countries. [26]

It is possible to see the historical evolution of the value in time. The decommissioning of all structures in the UKCS region was estimated to be equal to £8.4 B in 2001 and £8.8 B in 2002. In 2005, the estimated the costs of total removal of structures in the North Sea in a range between £13 B and £20 B [15].

By 2017, the UKCS had a decommissioning estimative of over £50 B with a government tax relief representing 50 to 75% of that value, which made the UK's Oil and Gas Authority (OGA) and the industry implement practices and guidelines that would maximize the economic oil recovery [47]. The UK is expected to be accounted for more than one-fourth of the global investment [26].

In 2019, OGA's estimated [48] that the total decommissioning cost of the remaining structures in the UK offshore has reduced by 17% in 2019 when compared to 2017 going from £59.7 B to £49 B (Figure 4.13). This reduction is a result of the operators' experience in the previous years, which leads to cost reduction in the platform operational, well plugging and abandonment (P&A), and removal [48].

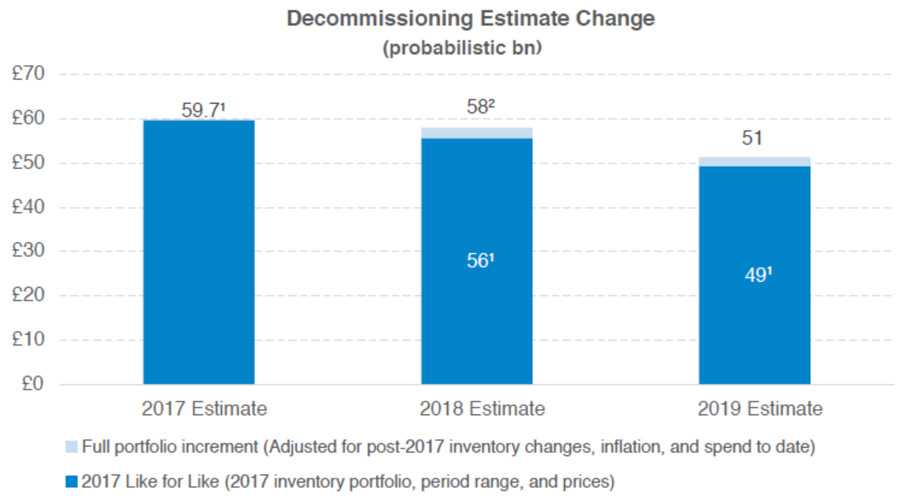


Figure 4.13: OGA's decommissioning estimate in the UK offshore from 2017 to 2019, showing a decreasing estimate change as a result of the operators' increased decommissioning experience. [26]

In the NCS, the regulators expect lower shutdown and disposal costs than in the UK. From 2012 to 2016, the investments for shut down were equivalent to NOK 32.5 B (circa £2.75 B) and for disposal, NOK 8.5 B (£720 M). From 2017 to 2021, the NPD expects costs of NOK 23.4 B (circa £1.97 B) and NOK 12 B (£1 B), respectively. Similar to the UK, the Norwegian state covers the majority of the decommissioning costs, about 80%, through tax deduction and its ownership interests [27]. Even with Norway's lower decom costs, when compared to the UK, it is possible to notice the increment in the decommissioning investments in the last decade as more fields in the NCS are going through shutdown and disposal activities, as seen in Figure 4.14 made in 2017 that shows the decommissioning cost historical evolution from 2010 to 2017 and the forecast from 2018 to 2021:

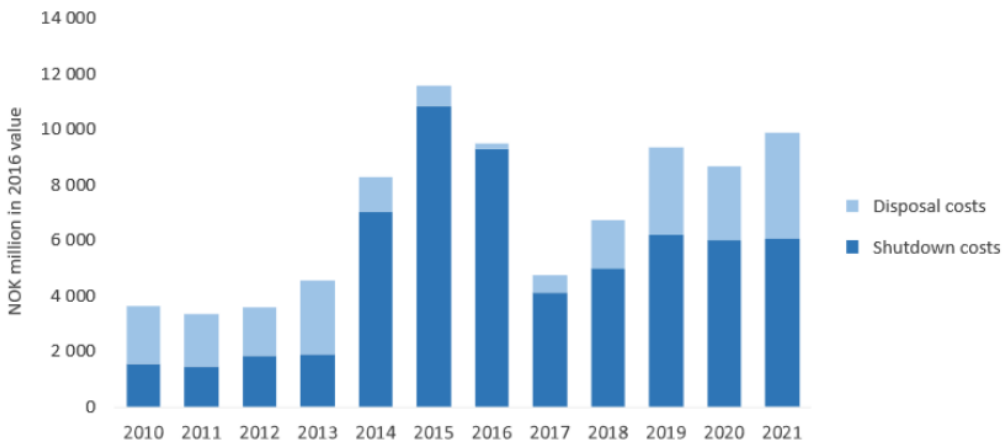


Figure 4.14: NPD's decommissioning costs history and forecast in Norway showing the platforms' costs for shutdown and disposal. [27]

As showed by Prasthofer [36], the economy generated by a more cost-effective solution could result in government investments in other energy sources, for instance, the solar, wind, or geothermal, supplying electricity for thousands of households. For the companies, the capital invested in the field decommissioning, known as 'abandonment and decommissioning expenditure' cannot be recovered by the asset since it has no more production and, therefore, no revenue for the oil and/or gas sales.

In contrast to the UK and Norway, the Brazilian government does not cover the decom costs in a concession contract, expect in fields that have either big production volumes or great profitability and pay the Special Participation Taxes (Article 2), regulated by ANP's Resolution no. 12/2014. There are a dozen of these fields in the country and they can have the special tax partly deducted based on the estimated abandonment cost as described in Article 13 (III) of the resolution [49]. ANP is expecting over R$24.5 B (around £3.5 B) of costs related to decommissioning activities until 2024, as seen in Figure 4.15:

Resultado da Previsão - Investimento por Ano(R$1.000,00)

1 2

Atividades	2020	2021	2022	2023	2024
Completação	11.264.786	8.085.099	6.287.183	8.623.588	2.929.766
Desativação do Campo	4.781.300	6.468.322	4.232.070	4.445.559	4.610.494
Elevação Artificial	226.501	265.076	126.012	186.437	190.602
Estudos e Projetos	2.640.990	2.087.105	1.280.705	805.430	421.367
Levantamento G&G	292.062	1.447.798	1.383.934	1.113.697	980.755
Perfuração	13.589.142	11.910.200	10.919.585	10.496.576	2.123.770
Proteção Ambiental	567.108	101.634	98.725	236.728	135.215
Segurança Operacional	1.219.458	562.655	518.982	514.314	297.148
Sistema de Coleta da Produção	12.712.018	16.173.569	17.475.950	17.063.287	13.010.862
Sistema de Escoamento da Produção	2.655.671	453.814	1.343.942	324.885	38.554

Figure 4.15: Expected investment (in R$) in decommissioning activities in the Brazilian coast from 2020 to 2024, showing the demand in the next few years. [33]

4.6.4 Provision for Decommissioning and Financial Security

As seen in 4.6.3, offshore decommissioning costs can be high and occur in a period where the field has no revenue since it has ceased its production. So, the companies make financial provisions for those costs based on their sizes and the local tax rules [1]. The provision for decommissioning and site rehabilitation varies in different countries. In most countries, the decommissioning liabilities costs should be recognized in the company's financial balance sheet within a reasonable estimation, incorporating the best information available, and the provisions updated with each new balance sheet to reflect any changes in the value [50, 9].

Nevertheless, the balance sheet provision is not enough to assure that the companies will have good financial health to support the decommissioning costs, so for the past decades, the decommissioning financial security has been debated.

In the 1980s, after the oil price dropped from about US$40 (1986) to US$10 (1981), the oil investors worried about the fulfillment of the companies decommissioning obligations. The UK Government, in response, passed the Petroleum Act of 1987, distributing the liability to all field's license partners. By the power of the Act, the Secretary of State could pursue these partners' assets to finance the decommissioning programs. This caused an elevation of the investors' risk exposure, which led them to procure financial security [6]. Currently, OGA can take preventive measures, as allowed by the Energy Act 2016 amendment, to ensure that the companies had the required financial robustness to operate and decommission a field. The regulatory body can impose sanctions should any operator fail to meet its commitment [3].

Some countries have financial security requirements that engage companies to deposit funds into escrow accounts bonded to the government, in which no withdraw is permitted until the satisfying their obligations. However, no financial deduction of the chosen security should be available until they lose ownership of the funds, only being possible to amortize these expenditures with the company meet specific criteria [50]. In other cases, as in the Gulf of Mexico, the financial security comes into the discussion before a property transfer, when larger companies to transfer late-life fields' contracts and responsibilities to smaller and less financially robust operators, which may not be capable of fulfilling their the decommissioning [3].

Chapter 3

5 Decommissioning Challenges

This section presents the challenges that the O&G Industry faces regarding the existing legal, economic, and environmental aspects of the decommissioning projects of offshore platforms. The legal challenges pointed out in this dissertation are faced by both the companies and the authorities, however in different ways, showing the importance of integrating the view of the operators and regulators. The environmental challenges will impact on the final solution for the platforms' disposal and the necessity of having prepared decommissioning yards. Finally, the economic challenges regard the proper way of estimating the costs, how to fund the decommissioning activities, and the necessity of having financial securities to guarantee the fulfillment of the projects.

5.1 Legal Challenges

After the decommissioning of Shell's Brent Spar, the discussion of environmental-friendly alternatives for platform removal and waste management took global proportions, stimulating the international community to develop laws and guidelines with strict measures to ensure minimal environmental impact.

Although the international community had a late start on discussing the decommissioning legal aspects with the Geneva Convention in 1958, the changes of requirements become more dynamic in the next decades. In 1972, the London Dumping Convention was regulating sea dumping. The UNCLOS of 1982 adopted as the primary requirement for the total installation removal, allowing partial removal for specific cases. Only seven years later, IMO developed guidelines and standards for removals to be applied only to international waters. In the North-East Atlantic, the OSPAR Convention (1992) aspired for the good management and use of the sea. Then, after the Brent Spar decommissioning, the OSPAR Decision 98/3, brought a more rigorous profile to the Commission.

The decommissioning is not only governed by international standards and guidelines. The offshore abandonment project must also comply with local regulations which commonly designates the liability of offshore abandonment and site rehabilitation.

As indicated by Jahn, Cook, & Graham [1], each local government has the responsibility of evaluating and approving the decommissioning options proposed by the companies. In most countries, there are specific laws, regulations, and guidelines concerning the decommissioning of oil and natural gas installations.

The legal and regulatory decommissioning issues involve both the industry and the regulatory authorities and unite the desires of these two parties to represent one of the main challenges related to those issues.

5.1.1 Regulator's Standpoint

The regulatory authorities have multiple purposes concerning decommissioning programs. While the cost reduction would be a desirable governmental output, other solutions adopted by the industry might have a positive influence on the national and local economies. On one hand, the onshore disposal could create new jobs in several stages of the decom process, from recycling to scrapping and discarding. On another hand, sea disposal could generate positive social-economic impacts in local fishing and scuba diving in the area surrounding the artificial reefs.

The regulators must analyze and approve a decommissioning program that complies with national laws and international conventions. Commonly, the decom program guidelines created by the authority involve, among others: legal compliance; activities scope; technical practices; safety and hazard levels; risk management; financial security measures; program schedule; the desired output of the decommissioning. To establish a suitable guideline, the regulator must discuss it with multiple parties, analyzing the industry and suppliers' point of view and what they expected from the decommissioning process. The policymakers must also consider what society expects as a decommissioning output for the environmental impact and pollution, job creation, investments, and transparency.

Regarding the regulations approach towards the decommissioning programs, the authorities can take a prescriptive approach and create rules and establish practices and solutions that must be used by the companies, and design enforcement policies to assure that those procedures are followed, aiming for a procedure-oriented decom program; or, they can take a directional approach, designing guidelines of the best practice that can be followed by the industry, aiming for a result-oriented program. Fam et al. [3], name these approaches as 'prescriptive' and 'goal–setting' approach, indicating, for example, that the required depth for removing sub-sea structures in the USA has the first approach and in the North Sea, the latter.

As indicated by [51], there are some elements that the stakeholders understand as fundamental for the governments to analyze before deciding on the nature of the decom programs:

- Consult and engage the stakeholders;
- Delineate a robust legal and regulatory decom framework;
- Monitor the companies' compliance and policies enforcement;
- Establish policies that can provide legal certainty and predictability;
- Fix the accepted and best practices/procedures for the decommissioning;
- Define the financial guarantees that will secure the implementation of the program.

5.1.2 Operator's Standpoint

One of the main challenges that International Oil Companies (IOC) face is the adaptability of their internal rules to the regulatory system in each country. Fam et al. [3] affirm the local regulations might include some aspects of the international conventions and maintain other distinct features, in particular in those countries that have a well-established decommissioning industry. Based on that, along with the company's internal rules, the decommissioning planning should involve discussions between the operators and the local authorities, suppliers, investors, and other stakeholders about many steps of the process. The discussions result in different solutions since distinct stakeholder groups have diverse opinions about the best options. That might even occur within the company's departments where some branches will try to optimize, for instance, either the financial cost-friendly or the ecological-friendly solutions.

Neilson & Gorman [6] indicate the principal spheres interest as the Environmental (Best Practicable Environmental Option (BPEO)), Health and Safety (Best Practicable Safety Option (BPSO)), Financial (Best Practicable Financial Option (BPFO), and Political (Best Practicable Political Option (BPPO), identifying the BPEO as the most accepted strategy among the stakeholders, but the authors demonstrate other possible options that need to be considered. The discussion leads the operator's solution which will be presented to the competent regulatory body for approval and the Best Practicable

Engineered Option (BPEngO) is the solution that can gather the most elements from the previous best options and fulfill the needs of most stakeholders.

The program should display, among others: field's description of inventories; decommissioning methodology; wells P&A program; facilities and equipment cleaning; subsea equipment removal; cuttings methods and depth; pipelines flushing and removal/trenching; platform cutting and lifting; safety, health, and environmental management plan; final waste disposal; cost estimate; navigation routes, etc. [52].

5.1.3 Residual Liability

One of the objectives of decommissioning is the rehabilitate the field area to a condition equal or close to the original since the field's development and decommissioning of a create impacts on the nature that can last for several years and be difficult to remediate. So, a 'residual liability' was established in many countries to deal with the accountability for the decommissioning activities, the remnants of installations, equipment, or lines on the site, and damages to the environment before and after the decommissioning.

In some countries, like the UK, investors and companies retain ownership of these remaining stumps of platforms, equipment, pipelines, and any residues that were placed during the field's development, as determined by the Petroleum Act 1998. Due to this proprietorship, as indicated by Neilson & Gorman [6], these parties have a permanent liability against any legal or regulatory claim arising from such ownership and are responsible for any damage caused by or as a result of the decommissioning process.

The residual liability also appears in the OSPAR Convention and IMO Guidelines. For IMO, Griffin [22] affirmed, it is demanded that a responsible party must be identified by the coastal state for activities involving the structures that remain related to maintenance, navigation, and monitoring, in case of necessity. Additionally, the guidelines require that the party will be liable for damages caused by the residues.

The liability also remains with the original operator if the ownership of the contract/field is handed to new entrants or smaller operators, when they may be required to present financial security. If the new operator fails to fully accomplish their decommissioning obligations, the liability can revert to the former operator or any party with economic interests on the field. In some cases, exists a joint liability, a legal trend that determines that any of the interested parties can be individually liable even if others in the partnership default [15]. Therefore, in addition to the legal liability, the field's remains might be a potential financial liability and a liability in terms of reputation for a company.

The residual liabilities are not to be mistaken with the decommissioning liabilities. In the latter, the operators, partners, and investors can be released from it after the program is completed and validated by a third-party or the competent authority. The decom liabilities are related to the activities approved in the program which must follow specific regulations/guidelines and the project closeout report [3]. The residual liability, nonetheless, could only end if agreed to by the Government, usually with external financial security offered to the partnership.

5.2 Environmental Challenges

The offshore decommissioning operations can disperse contaminants on the sea because of the structure's severance, installations and equipment cleaning, waste disposal, fuel consumption, or the platforms and equipment degradation and corrosion. Hence, the chosen removal and disposal option will play an important role in marine contamination and in the possibility of revitalizing the field's area and biodiversity, evaluating the platform disposal and site revitalization essential for the company to achieve the BPEO.

The analysis of the energy consumption during the offshore decommissioning should also be carried to determine the optimal solution, creating a multi-scenario that will help the stakeholders ponder between the different environmental decom solutions.

5.2.1 Platforms Disposal

Clearing the seabed and reverting the marine environment marked by the offshore activities to its original state after the decommissioning activities have several financial and environmental implications. Nevertheless, these activities might the help navigation and shipping, the recovery of the original marine biome, the reduction of contaminants in the sea, and even the future oil and gas extraction activities because, as seen in Section 4.5.1, the human pressures provoked by the offshore industry can alter the marine ecosystems, decrease in fish stocks, and pollute the waters. Thus, although desirable, the total removal of structures is seen differently by each stakeholder.

The offshore oil and gas structures are mostly composed of non-renewable resources that can be recycled onshore, such as steel which, if not recycled or re-used, can only be replaced by extraction of raw materials that can result in a shortage of resources in the future [15]. Thus, offshore recycling emerges as a good option in terms of sustainable development and environmental impact, and the international, regional, and national regulations define the specific rules for partial disposal of structures or leaving them on site. To define the best solution, three issues can be evaluated: the expected clearance of the seabed, the operational costs to achieve the optimal solution, and the overall impact on nature contrast between removal to shore and sea disposal.

First, it is important to know what level of the seafloor post-decommissioning clearance is expected by the authorities, and if this clearance is possible and reasonable. Some regulations require, for instance, concrete mattresses to be removed from the bottom of the ocean while and others do not require that pipelines be removed, having both solutions bringing adverse results to nature and the companies' financial expenditure. However, even considering that the decom program happened in conformity to the regulations, it is probable that the seabed carries vestiges of human interaction, being unlikely to take the environment back to its original state. Once the maritime environment is impacted by the O&G activities, the biota is affected and the possible human interactions to minimize that is limited due to the water depth, sea currents, wave patterns, among other parameters.

Onshore fields have a different response after decommissioning because of the replantation possibility and the reintroduction of species to their natural habitats. In the offshore decom, the bionetwork must recover by itself and cannot depend on the human interaction besides the clearance of the seafloor and the placement of platforms in strategic places. Nonetheless, platforms placed on the seabed can renew the marine biome, revitalizing the area, and increase the variety of species providing habitats to organisms. In these cases, the total removal disturbs the ecosystems' recovery, leaving them in a degraded state, without the possibility of improvement by human intervention.

Flexible legal regimes allow the approval of decisions on a case by case scenario, allowing different decom solutions based on the current state of the technology [6]. These regimes might permit that platforms shall be used in different ways after the decommissioning. Other uses of offshore installations can avert the need to remove the structures to shore and be implemented in some regulations, and comprehend, among other modalities, the creation of offshore artificial reefs. The USA, for instance, has considerable experience in this alternative and a well-defined rigs-to-reefs program which, for the country, has a positive impact on marine biodiversity, proving a habitat from different species.

The rigs-to-reef is an important solution to be considered because the removal to shore also has negative effects in the environment: eliminating a source of living for some marine living groups; greater energy consumption and carbon footprint because of the towing and scrapping; growth of onshore waste discard since the installations are not fully recyclable; bringing to shore NORMs or other contaminants that can be disposed of back in the produced reservoir, etc. In case the platform is removed, the site rehabilitation is needed to bring the area back to a condition that can allow a natural revitalization since the original biota has been damaged or extinguished. Bret-Rouzaut & Favennec [9] presented some rehabilitation exercises and site redevelopments:

- Reforestation in the Madidi National Park, Bolivia;
- Decontamination of groundwater with bioslurping in Argentina;
- Restoration and implementation of anti-erosion in a pipeline in Myanmar.

For a good site rehabilitation, it is crucial to have the environmental baseline before the commence of the field's development which will help determine the initial state of the area, set the goal for the rehabilitation, and determine the responsible party for any damage or contamination caused by the development, production, and abandonment activities. To understand the necessary recovery to be done, a habitat equivalency analysis (HEA) can be performed by the company and/or regulators. The HEA is a framework that provides an approximation of the required site restoration and can produce reliable results for oil spills and simple contamination cases, helping in the estimates of the needed resource compensation from oil spills or hazardous-substance contamination and providing guidance to recover the natural resources. [53].

5.2.2 Rigs-to-reef and Fishing

Another alternative for the decommissioning of installations is the rigs-to-reef program, transforming installation in a reef instead of taking it totally or partially to a that is not only a lower cost option but also helps to revitalize the sea biome in the region near the platform. This option can be done in the same location where the platform was initially placed or in a region where it can have a less negative impact and the need of restocking the sea life that has been damaged by creating underwater habitats for fish and reefs restocking different fish species, coral, algae, bacteria, and sponges (Figure 5.1):

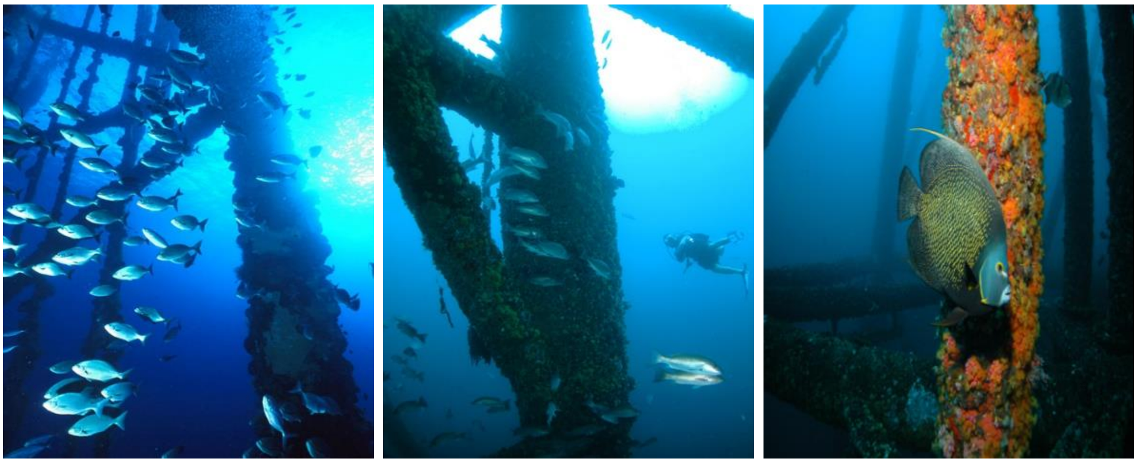


Figure 5.1: Picture of a fixed platform disposed on the sea to create an artificial reef as a part of the rigs-to-reef program in the GoM with a variety of fish species near the area and corals attached to the jacket. [54]

The Gulf of Mexico has settled the Rigs-to-reefs policy in the mid-1980s, after the increasing number of decommissioned platforms when removal rates exceeded 100 structures per year. According to BOEM, the program was developed to help maintain the ecosystems established by the structures after decommissioning [55] and by April 2018, 532 platforms had already been converted to permanent artificial reefs in the Gulf of Mexico [54].

Although until this moment, Brazil and the North Sea have not implemented a direct policy regarding the rigs-to-reefs program, other offshore areas have been utilizing this alternative, as seen in Table 5.1:

Table 5.1: Rigs-to-reefs projects worldwide. [56]

Location	Details
Australia	First rigs-to-reef conversion in 2018 in North West Shelf.
Brunei	First rigs-to-reef conversion in 1988.
Gulf of Mexico	Activities in coastal areas of Alabama, Florida, Louisiana, Mississippi, and Texas.
Indonesia	Two structures identified for rigs-to-reef on a trial basis.
Malaysia	The Baram-8 platform was left *in-situ* after collapse until 2004; then, it was raised, cleaned, towed, and sunk in Kenyalang Reef.
Indonesia	Two structures identified for rigs-to-reef on a trial basis.

This alternative involves mostly fixed platforms because the jackets of these installations provide the necessary arrangements to form artificial reefs, and their topsides are removed for disposal. The creation of artificial reefs made by floating units is limited to the hulls of spar platforms which can create environments like those provided by the fixed platforms jackets. Moreover, the reef area must provide enough water clearance from the top of the severed jacket to the waterline, allowing a clear path for safe navigation and shipping [14].

Figure 5.2 shows platform reefing methods and waterline clearance. The first method (a) consists of taking the jacket and placing it in a determined area designed for reefing or disposal without impacts. The second method (b) consists of knocking the jacket and laying it down in place. The last is the severance of the jacket and placing it in the desired location. The last method (c) can be done by placing the top of the jacket on the seabed or removing it for onshore disposal. These methods commonly use explosives or mechanical tools to severe the fixed jacket legs and an HLV to pull, tow, or lay the structures [57].

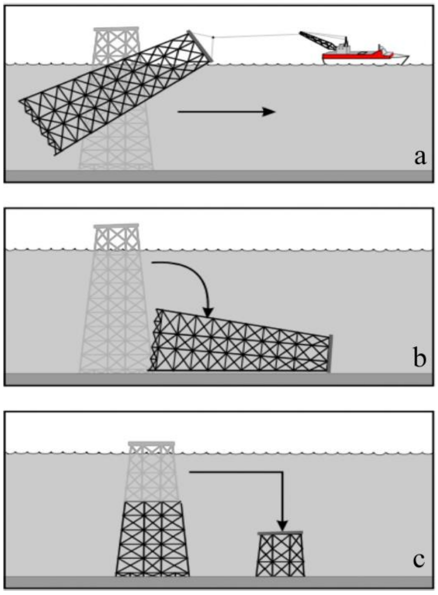


Figure 5.2: Reefing methods of fixed platforms that can be performed by the operators: (a) tow-and-place, (b) topple-in-place, (c) partial removal/'topping'. [57]

Other challenges in decommissioning from an environmental perspective are those related to energy use and gas emissions which are intrinsic to all options and have both direct and indirect impacts on nature. Because of that, the energy performance and the volume of contaminating gases emitted during the operations should be evaluated to define the final solution.

The energy expenditure of the decommissioning programs is significant and might increase the costs of the operations, especially regarding the consumption of fossil fuels to power the vessels. Phillips Petroleum Company Norway, for instance, estimated in 1999 that the energy consumption required to remove and recycle the Ekofisk platforms in Norway was 40% of the annual electricity consumption of a small city [16].

However, energy usage and gas emissions need to be evaluated on a case-by-case basis. The decom project determines the types and duration of the operations and, therefore, the energy demand which can be analyzed and approved by the authorities. It is important to keep in mind that direct energy use might incur in higher emission factors than recycling and material production, as stated in Section 4.5.2. Also, to ponder the options concerning the carbon footprint and the possibility of recycling some of the platforms' material. Jones [56], for example, states that leaving concrete gravity base in place can be both advantageous or prejudicial since it could reduce the carbon emissions of the offshore operations for removal but increase the carbon accounting due to the manufacturing of new concrete which could be recycled to a certain amount.

In some countries, like the UK and Brazil, an Environmental Impact Assessment (EIA) of the decommissioning activities is required, helping in the environmental evaluation of the impacts of the decommissioning program without considering the ecosystem developed during the field's production phase. Besides that, guidelines can facilitate the calculation of energy requirement levels and gas emissions for each probable offshore decommissioning solution which is the case of the 'Guidelines for the Calculation of Estimates of Energy Use and Gaseous Emissions in the Decommissioning of Offshore Structures' published by the British Energy Institute, formerly known as the 'Institute of Petroleum', in February 2000. With these tools, a multi-criteria decision analysis (MCDA) can be performed to assess the impacts of decommissioning options.

5.2.3 NORMs

The OSPAR guidelines and other regulations also cover hazardous and radioactive substances and require the operators to characterize what substances exist in the offshore platforms, how they may be dispersed during and after operations, the environmental exposure to these contaminants, and the programed disposal of the materials. Among these contaminants, the disposal of NORMs (Section 4.5.3) represents a challenge in the decom industry.

The NORM scales are produced during the platform operation and can reside in different parts of the plant, specially separators, hydro-cyclones, pipes, and valves and after the platform cleaning and preparing for decommissioning, the radioactive substances have to be taken to a decommissioning yard/landfill site for proper disposal in compliance with regulatory demands. By 2014, there was only one landfill site in the UK that can take hazardous NORM waste which showed to have sufficient capacity to deal with problems at the time but this limited number might struggle with the growth of demand from the decommissioning projects in the following years. ARUP [58] estimated that the UK produces approximately 800,000 kg of NORM per year, with less than 20% being properly addressed.

Since yards or landfills specialized in radioactive waste are still a rare option in the decommissioning industry for onshore deposition. Disposal costs for the waste, asbestos, and other types of scale, must be considered during planning [14]. In the lack of specialized yards, another solution for the disposal of NORMs could be the reinjection of the materials into a disposal well together with other hazardous waste [44]. Other methods can be used [43]:

- Encapsulation and downhole disposal;
- Nearshore discharge of grinded NORM to sea;
- Reinjection of dissolved NORM or solid NORM slurry;
- Seaward disposal of produced water and from de-scaling operations.

Regulations indicate the appropriate management and disposal of those radioactive substances and depending on the amount and level of radiation the discard on the sea is allowed because small portions of NORMs barely affect the marine biota. However, it is important to evaluate the amount of radiation and the environment where the materials are going to be discarded. The reinjection is the optimal solution for the NORM present in the produced water and solid slurries since it uses fewer resources of the operators and returns the radioactive substances to its origins. Nevertheless, if the substances are required to be taken onshore for disposal, a specialized facility should be the preferred destination [43]. It is important to determine the NORM disposal routes both at sea and onshore to minimize the contamination in places where the hazardous substances will be carried. A risk-mitigation scenario from prevention to disposal must be elaborated by the companies to reduce the negative impacts during decommissioning.

5.3 Economic Challenges

The main decommissioning economic challenge is related to the companies developing ways to reduce the operating expenditures (OPEX) with the appliance of new techniques, usage of modern equipment, and improvement of the efficiency or reducing the complexity of the programmed activities [1]. However, there are other challenges derive from the decommissioning planning that concerns the funding of the programmed activities and the cost estimates, and the financial securities which is an economical question that derives from regulatory or legal demands. This section is going to focus on the decommissioning funding, cost estimates and its precision, and financial securities requirements and models which can impact the field's cash flow or the financial strength of a company.

5.3.1 Decommissioning Funding

Since the offshore decommissioning costs can be higher than the companies' expectations, they must have enough financial strength to execute the approved program, and, for that, some companies might use the revenue provided by other oil and gas fields that are still producing to pay for decommissioning. Smaller companies, otherwise, might have only the income from the field to be decommissioned without the opportunity to use other assets to comply with their obligations. Thus, authorities may require that a decommissioning fund be created before the cessation of production with provisions made by the operator throughout the field's life but not before the financial breakeven point. These provisions normally depend on the size of the company and field, regulations, the decommissioning estimates, the maturity of the field, and the country's tax rules [1].

For an operator to have sufficient provisions to decommissioning the field, the authorities should specify the legal obligations to be done by the operators since those may implicate in more costs for the investors and company at a time when the assets cannot provide more financial income. The decom obligations may involve onshore platforms disposal, trenching pipelines, removing subsea structures, abandoning the wells with more barriers, performing sea analysis, monitoring the field's area for an extended period after the decommissioning, etc. Based on that, the companies should provide the cost estimates for the decom program and if it is proved that the operator cannot fulfill its abandonment obligations, the liable parties must comply with legal demands and perform the necessary activities to remove the structures and revitalize the field’s area.

In case the investors are not able to afford the decommissioning costs, the government will be accountable for performing the decom program. Hence, it is important to have a proper cost estimation of the program and to set aside financial allowances in advance to fund the abandonment costs while the field still has a positive cash flow.

5.3.2 Cost Estimates

According to ICF Incorporated [14], the difference from the cost estimate and the actual cost of a fixed platform in the Gulf of Mexico can vary from -50% to +300% which is impacted by many factors, like the chosen solution for the removal. For instance, the ICF points that cutting the structures into small pieces and removing them can lead to an increase of 50% to 100% when compared to heavy lifting, a more traditional approach.

It is important to have a good cost estimation of each activity in the decom program so that the companies can evaluate the availability of the resource and understand if the solution is technically feasible within the designed schedule. That happens because the costs of the offshore activities depend on the resources, corporate structure, type and size of the platform, water depth, transportation, and legal obligations involving the removal and disposal of the platform. Moreover, the location of the field, the mobilization and demobilization of the resources, and the possibility of cooperation of operators in the same offshore area will impact in the cost estimate.

To have a good estimate, the regulators and the industry must work together to develop cost estimation guidelines that can assist both parties to reach an agreement about the cost estimation in the decommissioning program. The OGUK, for instance, developed the ‘Guidelines on Decommissioning Cost Estimation’ in 2013 that aimed to provide a template for the operators to better estimate the costs, means to compare estimates, and a common basis for decommissioning data, among other objectives. Also, to improve the precision of the estimates, the decommissioning must be evaluated since the field’s development plan for the company to develop the field focusing on the late life cycle and the decom activities.

The OGUK [45] report indicates the necessity of having accurate data for the cost estimation which will be used for estimates during four stages of the field life cycle: development, production, asset sale/transfer, and cessation of production (pre-decom stage). By the end of the production, the gathered data – inventory, drilling records, as-built drawings, construction reports, maintenance records, and inspection reports – together with field inspections of the platform and equipment integrity will serve as the basis for the engineering plans and determination of resources availability and cost estimates [14].

Table 5.2 presents an estimation of component costs that might be used to estimate the costs of the decommissioning activities in the Gulf of Mexico. By extension, they might also be used in other areas like the Brazilian coast.

Table 5.2: Typical costs for different activities and platforms types used for the decommissioning estimates. Adapted from [14].

Activity	**Typical Cost**
Engineering/Project Management	8% of costs with mob/demob
Work Provision	15% of costs without mob/demob (except 10% for wet tree well P&A)
Weather Contingency	20% of costs without mob/demob
Well P&A	Dry Tree (50 to 400 ft): US$350 k/well Dry Tree (over 400 ft): US$480 k ~ $1.8 M/well Wet Tree: US$8 M to US$16 M/well
Conductors	US$160 k to US$600 k/conductor
Fixed Platforms	Depth ≤ 500 ft: less than US$10M Depth > 500 ft: US$10 M + US$7 M/100 ft
Spar Platforms	Preparation: US$54/ton Mooring lines: US$47/ft of water depth US$31 M ~ US$39 M
TLPs	Preparation: US$100/ton Tendons: US$86/ft of water depth US$11 M in total
SSs	Preparation: US$54/ton Mooring lines: US$40/ft of WD US$15 M in total
Site Clearance/Verification	US$400 k sensitive to mob/demob costs Up to 1% of the total costs

It is important to highlight that the maturity level of the decommissioning project also influences the cost estimate since the more studies and evaluations are done and more data is gathered and evaluated, the more precise are the cost previsions. The AACE International [59], an association of cost engineering, in its 'Recommended Practice No. 18R-97' provided general principles of project cost estimates and defined estimate classes corresponding to the maturity level of the project which can be applied to different processes, as seen in Table 5.3.

Table 5.3: AACEI cost estimate classification matrix determining the accuracy of the estimate based on the level maturity of the project. Adapted from [59].

Estimate Class	Primary Characteristic	Secondary Characteristic		
	PROJECT MATURITY	**END USAGE**	**METHODOLOGY**	**ACCURACY**
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: - 20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: - 15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	65% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

As noted, at the beginning of the decom planning can carry costs estimate with errors varying from -50% to +100% (Class 5) but after project maturity progresses, the errors can be decreased to ±3% (Class 1). Since they will influence the provisions for the program funding, the financial liability of the decommissioning, and the necessity of financial securities, the decommissioning cost estimates must be as precise as possible.

5.3.3 Financial Security

After defining the cost estimates and how the decommissioning is going to be funded, some measures can be taken by the regulator to prevent any unwanted output of the decom, such as discussing the project forecast with the company, ceasing the production, terminating the contract, transferring the field to another operator, or any suitable action to either maximize the production or assuring that the legal obligations are going to be observed. If, however, a company does not have the necessary capital to pay for the abandonment activities, the costs should not be redirected to the governments which are, commonly, not willing to bear the expenses of these activities.

To prevent that, financial securities can be required and executed if the obligations are not fulfilled as a failsafe system that helps the authorities to ensure that the programs are financially covered. However, there are costs for the companies in maintaining a perpetual structure do deal with latent decommissioning issues that may not come emerge for decades or ever, which makes this solution not to be practical.

Neilson & Gorman [6] indicate some mechanisms of financial guarantee:

- Third-Party Guarantee: a third party, normally banks, serves as a guarantor in the amount of the investor's share of costs through bonds or letters of credit, requiring collateral. The fees can increase closer to the decommissioning;
- Parent Company or Corporate Guarantee: the licensed company has a financially strong parent that could support the liability. Similar to the investor in the Third Party Guarantee, the parent company's borrowing powers are affected;
- Trust Fund: it provides security to the government and the investors and covers the costs of the decommissioning. The fund needs to specify the total value and frequency of provision based on the costs and the remaining field revenues;
- Mutual Guarantee Fund: in this mechanism, all companies engage in a national decommissioning fund. If a company fails to meet its obligations, the fund covers the costs. The provisions are made based on the decom costs and not the possibility of investor default which means that the companies with larger fields are required to deposit more capital, resulting in subsidizing smaller companies;
- Government Grant: the government pays a share of the decommissioning costs proportional to the taxes collected during the life cycle of the field. This could replace a system of tax reliefs for the decommissioning, like the one applied in the UK. The Government Grant mechanism is applied in Norway;
- Decommissioning Levy: the government introduces a special decommissioning charge, sufficient to bear the decommissioning costs. Then, the government would be responsible for the implementation of decommissioning activities. Overall, the governments did not show any interest in this concept;
- Insurance: it can be done by an investor against the lessee to cover for his share of the costs. It also can be an endowment fund established particularly for decommissioning obligations. However, considering the decommissioning costs, the premium would be very expensive.

However, as stated by Bret-Rouzaut & Favennec [9], the security requirement may be a costly obligation for the company and may reduce its possibilities of doing further investments in the field to delay its decommissioning and maximize the oil recovery. Hence, a follow up of the field's cash flow helps determine the necessity of requiring extra securities for the company and the model to be applied.

It is important to highlight that these mechanisms of financial security, in exception of the Government Grant and Decommissioning Levy should not supersede the company's legal obligation towards the execution of the decommissioning program. Even if regulatory authorities request a financial guarantee, the activities should be funded by the project's revenue, making it economically robust by having a positive cash flow throughout its lifecycle [50].

The UK and USA implemented in their regulations the necessity of companies to provide financial securities or bonds which is based on the company's profile [3] and Brazil regulators have drafted a new regulation framework to discuss the securities [60]. It is desirable for the industry that the regulators establish clear rules for the financial securities, e.g., when they will be required, value to be covered/assured, the security mechanisms accepted, the possibility of updating the value or changing the type of security, period that the company must maintain the security, possibility of closure or transfer it to a new operator, etc.

Chapter 4

6 Discussion

This chapter has the objective of presenting the challenges presented in Section 5 in the Brazilian context, pointing what was adopted by the country, what solutions could be applied for those challenges that the local industry and regulators have yet to face, and how suitable is the new Brazilian regulation in comparison to the policies adopted in the North Sea and the Gulf of Mexico. To design a suitable national regulation, the legal challenges were discussed among the regulators, operators, and other stakeholders but the residual liability goes between the authority of the O&G regulator and must be discussed with the Brazilian Congress. The environmental challenges, although mapped in the new regulation, still demand discussions on a case-to-case basis to define the best strategies for removal and disposal of the platforms. At last, the economic challenges still need to be better worked in Brazil which is presenting a draft for a financial security regulation but lacks a guideline for cost estimation.

6.1 Brazilian Regulatory Challenges

ANP, the Brazilian O&G regulatory body, has published in April 2020 a new decommissioning regulation – *Resolução* ANP n.º 817/2020 – which indicated that the previous legal requirements for the activities needed to be updated and simplified, bringing clear standards for the regulators and less prescriptive solutions [61]. The regulatory body indicates that the new regulation is a more robust and can provide legal certainty and predictability to the companies, and other aspects that Rawa et al. [51] showed to be fundamental for the decommissioning programs (Section 5.1.1). Before the regulation was published, the regulators discuss the possible framework with different stakeholders, involving the industry, academics, the Brazilian Navy, the Brazilian Environmental Institute and others stakeholders, passing the regulation through public scrutiny and debating about 370 contributions to the final document [61], representing a unification of the procedures required by the O&G regulatory body, The Navy, and the Environment Institute.

When compared to the previous regulation – *Resolução* ANP n.º 27/2006 – the new model focus on, first of all, maximizing the hydrocarbons recovery the further development of the field previously to the decommissioning (Art. 3rd), mitigate risks to human safety, other species, and the environment (Art. 4th), and management system aiming in social responsibility, sustainability, and the use of the best practices of the industry (Art. 5th). Overall, the new document stands more as a guideline than a law since it provides the major operator's responsibilities and decommissioning goals and does not discourse about which technical solutions must be utilized to achieve those ends [62].

The program submitted to the authorities is expected to have a risk analysis of the planned activities and the decision about what solutions were chosen by the operators must be based on a multi-scenario evaluation (Item 2.2). This assessment must consider five criteria: technical, environmental, social, economic, and safety. However, the regulation demands that no criteria should be decisive by itself, having the companies to analyze the scenarios entirely (Item 3.2.1).

On one hand, aiming for a regulation that requires goals instead of ready-made solutions will help the operators and the authorities to have a continuous discussion about the more up-to-date solution in the industry and the regulation becomes more dynamic. Additionally, focusing on the management of risks might help the operators to find different solutions for the activities, reducing costs and becoming more efficient without diminishing the importance of the discussions with the regulators and approval by the competent authorities. On the other hand, not having a determined set of possible solutions can lead to prolonged discussions between the stakeholders about the decom program. In this way, a solution that can be applied at a certain period might not be capable to happen after months of discussions due to the lack of technical or financial resources, changes in the company's dynamics, altering of the ocean waves pattern, etc.

To limit the time required for the analysis and approval of the decom, ANP fixed deadlines within the regulation for the program submission (Article 10), the requirement of further information (Article 16), and the program approval and indicated the possibility of holding public scrutiny meeting (Article 14). Nevertheless, that might not guarantee that the initial schedule compromised between the regulators and the operators will be followed because of the suspension of deadlines when the operators need to give additional information or until the completion of the public meetings (Article 17). Thus, the program's approval time will depend on the level of communication and the transparency between the regulators and the operators.

When compared to the legal aspects of the North Sea and the Gulf of Mexico, the Brazilian regulation presents itself as a modern and flexible guideline, providing the necessary room for debates without undermining the authority and opinion of the regulators, or drifting away from international regulations.

The Norway Petroleum Act (Chapters 5 and 6), for instance, have more strict regulations with removal requirements mostly based on the OSPAR Convention and the UNCLOS that can be noticed in the following NPD statement: “facilities must be removed in their entirety; only in extremely limited cases they can be abandoned on the field after ended use. [63]” The UK Petroleum Act 1998 (Part IV) and Energy Act 2016 (Chapter 6) are laws that are driven also by cost-effective solutions. Article (2A)(b) of the Petroleum Act, for instance, demands that the program must “ensure […] that the cost of carrying it out is kept to the minimum that is reasonably practicable in the circumstances.” However, the Acts determines that the OGA must consider and advise on alternatives to the installation and can allow platforms to be left in place or partially removed if a provision is given (Article (4)(c)).

The flexibility of the Brazilian decom regulation, however, does not reach the residual liability challenge since the environmental damages due to petroleum E&P are included in the National Constitution which in the Brazilian legal hierarchy is far above a common law or a regulation. The Constitution (Article 225, §2nd and §3rd) establishes that any person or company that explores mineral resources are obliged to repair the damaged environment as required by the regulators under a possibility of criminal and administrative sanctions [64]. Thus, every company and investor are severally responsible for the decommissioning, like in Norway (Section 10.8 of the Norwegian Petroleum Act) and the UK where, by demand of the Department for Business, Energy & Industrial Strategy (BEIS), the owner of a facility bears the residual liability of the decommissioning (UK Petroleum Act 1998).

Thus, as discussed in previous chapters, it is possible to notice that Brazil has a modern regulation that aims for a goal-oriented approach and opening discussions with the operators and other stakeholders, which makes the guideline more modern and dynamic. Although no decommissioning has been carried after the publication of the regulation, the *Cação* Field decommissioning (Section 4.3.3) will help ANP to establish the approach was well-design by the authorities. Concerning the residual liability, not covered by the regulation, even if it could drive some IOCs away from investing in Brazil, the country is following international rules about this challenge.

A solution for this question might not come soon time since the international community is still maintaining the residual liability with the operators and investors after the decommissioning. Brazil could establish a point in its regulations where the operators could be released from the residual liability after some years of post-decom monitoring, requiring a third-party to certify the fulfillment of activity after a risk-analysis is done, or upon a tax/payment to a decommissioning fund that can be used to cover an incomplete field decommissioning or any future liability. This could disburden the companies' balance sheet and allow future investments in other O&G fields.

6.2 Brazilian Environmental Challenges

The Brazilian decommissioning regulation determines as the main rule that any offshore installation should be fully removed from the field's area (Item 3.1) and prohibits intentional unapproved sea dumping, abandonment, or toppling of platforms (Item 3.1.1). Nevertheless, following international conventions, the regulators can allow that the platform is partially removed or left in place if the operators can justify it and follow the required standards for these types of disposal (Item 3.1.2), based on a multi-criteria analysis that will be approved by ANP [62]. This means that ANP could permit the implementation of the rigs-to-reefs policy on a case-to-case basis, which contrasts with the requirements of the previous regulation and can be more cost-effective for the companies and less harmful to the environment (Sections 4.5.4 and 5.2.2). If the proper cleaning and disposal of the platform are carried out, the rigs-to-reefs can restock the marine life in the field's area, provide a region for fishing and diving activities, having a positive influence on the country's economy. However, it is important to define the criteria to allow the creating of reefs and the regions to place the platforms without harm to the environment and where they can bring benefits to marine life.

In a more technical aspect, the Brazilian regulation determines that the platforms which are left in place or partially removed do not interfere in the navigation or other uses of the sea or do not have negative pressure in the sea nature (Item 3.3). Among the few prescriptive demands of the regulation are: platforms placed in water depths equal or below 100 m must be severed 3 m under the seabed (Item 3.4 (b)); structures must leave a free water level of at least 55 m (Item 3.4 (c)), as IMO compels; the seafloor must be fully cleaned, removing any materials or non-bio residues bigger than one meter in a radius of at least 100 m around the platforms.

The NORMs have also been discussed in the Brazilian regulation which demands that the operators create a management system for the treatment and disposal of radioactive materials during decommissioning (Item 2.4.1) without getting into details on the treatment, disposal of the materials, or collection points. To aid the operators about this concern, the Brazilian Petroleum, Gas and Biofuels Institute (*Instituto Brasileiro de Petróleo, Gás e Biocombustíveis* – IBP) elaborated a guideline about NORMs explaining their origin, characteristics, forms of presentations, points of accumulation in the platforms, risks to health and safety, and risks to the environment. Moreover, the Institute presented guidelines for better management of the materials, indicating how to protect human life, the necessary measuring and control equipment, transport and disposal of the NORMs, and document management [65].

Although this guideline filled some points that the regulation did not cover, it also fails to address the decommissioning sites that could receive, treat, and dispose of the NORMs. IBP only points towards the Brazilian Commission of Nuclear Energy (*Comissão Nacional de Energia Nuclear* – CNEN) which has its regulation about the radioactive material. The collection and storage of radioactive waste is an exclusive activity of CNEN that serves those facilities that generate radioactive waste that need proper disposal. Radioactive waste is stored in temporary regional deposits. The Commission was planning on building a permanent facility until 2018 to store the waste, so far that has not happened [66]. Figure 6.1 shows one of CNEN's temporary regional deposits in Brazil.

Figure 6.1: CNEN regional deposit in Brazil where radioactive material is stored in appropriate containers after collection from different sources. [66]

Brazil industry has little experience in decommissioning and no specialized yards to deal with the incoming demand, unlike the North Sea and the GoM. In contrast, in 2014, the North Sea had already 6 yards with decom experience that could be used for decommissioning activities and 17 other yards that could service the decommissioning industry [58]. However, similarly to those countries, the potential yards are the fabrication sites that can be the best alternative to handle the structures onshore decommissioning and, after receiving the large structures, can redirect the scrapped or reconditioned material to smaller.

In summary, the creation of artificial reefs is possible in the Brazilian waters, as the regulation is not strict about the platforms' disposal, if approved by the regulators which must analyze if this option is cost-effective, the environment is less negatively affected and the biodiversity can increase with the reefs. The goal of the regulators must evaluate this option with the operators and pointing out if this option is feasible and in which regions the platforms can be placed. After the first reefs are artificially created, it is important that ANP and the operators monitor the disposal areas and determine with the policy is beneficial.

Concerning the NORMs, the exclusive responsibility for the collection and storage of radioactive of CNEN might harm the decom activities either by reducing the options of having more cost-effective suppliers or the availability of storage. A feasible solution is to CNEN certify other companies to handle the collection and the storage or for the national Congress to remove the exclusivity of the commission for transport and store radioactive materials, allowing that the companies fill the gap develop the local industry. It is also important that CNEN constructs the permanent facility planned to begin in 2018 and design it to deal with NORMs and other radioactive material that comply with international regulations.

With the upcoming decommissioning demand in Brazil for the next decade (Figure 4.15), the regulatory agency should also work with the industry to define the suitable sites for the decommissioning activities and verify if the existing facilities can support the stipulated forecast. In case the current sites cannot keep up with the industry's need, the government should take the necessary measures to ensure appropriate yards that can perform decom activities such as lifting, scrapping, and recycling, will be planned and constructed. The new facilities should be able to handle the hazardous materials that come with the platforms and store them until CNEN personnel can collect them.

6.3 Brazilian Economical Challenges

The decommissioning in Brazil is an obligation that is presented in the concession contract and must be carried in the field even if it only had an exploration phase. In Brazil, the decom costs are not substantial when evaluating investments for the field's development because they happen at the end of the project's cash flow, decades after the first oil, and the evaluation considers an annual discount rate between 8% to 15% [67]. Nevertheless, as pointed out in Section 5.3.1, the impact of these costs at the late-life of a field can even lead the companies with poor financial strength to bankruptcy.

How the funding of the activities must be made is not described in the newest Brazilian contracts which, on the other hand, only indicates the necessity of presenting financial securities for well abandonment and field's decommissioning at the first oil date. Among the accepted securities indicated in the E&P contracts are the third-party guarantee, letter of credit, and trust fund, but ANP does not limit the possibility of any other mechanism if it proves to be enough to ensure the decom obligations without further detail [68]. These securities should be based on the field's decommissioning estimates done at the field's development plan and the field should be developed with the decommissioning planning in mind to facilitate the execution of activities after cessation of production.

The estimation process is not simple because, many times, the full development of the field cannot be understood in the early life of the asset which still has several years of production and data gathering before the decommissioning activities start. Also, the predictability of the services is a necessary condition to attract qualified suppliers and services and to reduce costs, but this is not feasible decades before the activities. As indicated in Section 4.3.3, Petrobras has been developing field since before the creation of the regulatory agency and it is the company that carried most of the offshore decommissioning events in the country, considering both the wells abandonment and floating platform removal. Thus, the offshore decommissioning in the country does not have enough scale to bring the suppliers that predictability which would help planning and cost estimation.

The Brazilian O&G contract does not have further details on how the securities must be presented or constituted which makes it even more challenging to the industry. To correct that, in 2020, ANP provided to the companies the resolution draft that regulates procedures for the presentation of financial securities for decommissioning. The document included other mechanisms such as the oil and gas pledge security and the parent company or corporate guarantee and defined the model of how the deposits to be done to a trust fund. The regulators also defined a secondary contract to arrange the provided security [60].

In the UK, the industry has proposed to make financial deposits into a fund to cover for the liabilities and possible future costs, ensuring that the government would not pay for these expenses [6] but this idea was not accepted by the British authorities. In contrast, the company Maersk Energia Ltda. ('Maersk') wanted to sell its participation in the Brazilian Polvo Field in 2014 and had to guarantee its share of the decommissioning costs estimated to have the regulators' approval for the sale [69]. Although this act was allowed by the regulators, it is not clear if a possible residual liability is going to reach that company and, if so, how the authorities are going make Maersk accountable for the field's decommissioning.

A question remains about the decom costs since they might the lower or higher than expected, having a negative impact either on the company or the regulators and if the guarantee will also cover any possible future liabilities. In Brazil, even if the company complies with its obligations and the decommissioning program is fully accomplished regarding the necessary regulations that do not mean that the company does not have its residual liability removed, what might happen to Maersk.

As the National Constitution indicates (Section 6.1), the liability is perpetual, even for the contracts between the operators and the authorities are terminated. So, a company should maintain its financial security albeit not demanded by the regulators to cover for possible future issues. However, that does not seem practical or reasonable from a company's point of view, since the guarantee is costly and need to be presented in the balance sheet, which can drive possible investors away from the company and its liabilities.

To minimize the risks and the necessity of maintaining perpetual security to deal with the residual liability originated from the decommissioning, Tularak et al. [52] proposes having a post-decom monitoring program for a determined period after the end of operations would ensure the regulators that the operations are done are unlikely to cause environmental impacts or other hazards. After this period, the parties could be released from the residual liability which, in Brazil, would require a change in the constitution.

Another problem concerning the financial securities is the total value of the guarantee which is normally based on the estimation costs performed by the company. Even though they might the proportional or similar, the market/supplier costs commonly differ from the operator's costs which might have their rigs, equipment, and teams to perform several stages of the decommissioning. The decommissioning costs also depend on the number and conditions of wells, the cooperation between suppliers, the mobilization/demobilization costs, and the climate. These factors can alter the estimates but are measured near the decommissioning and could make the estimated cost to be less than expected during the first years of production. Thus, having the operators maintaining financial security in the out-of-date market value harms the companies' cash flow.

So, ANP and the Brazilian industry and supplier should create a joint guideline for cost estimations such as the OGUK guidelines (Section 5.3.2). That will assist the operators to predict and reduces the cost of operations. It would also help the regulators to determine the best financial security for each company based on the cost estimate and the financial health of the company. The cost estimate should be evaluated periodically and change with time as the field moves towards the cessation of production.

The argument that is favorable for maintaining the security in the initial market value is that in case the parties do not fulfill their obligations the government will have to carry the decommissioning and post-decom monitoring. For that, the authorities will have to engage with the suppliers and attend to the market's prices, since the government does not have practical technical experience in the area, rigs, teams nor equipment that can be used to perform the operations.

7 Summary and Conclusion

Decommissioning is the process related to the removal, disposal, scrapping, re-use/repurpose of installations and equipment, and to the revitalization of the field's area. The operator must comply with international and local regulations set by each country, involving requirements about the technical application, health and safety, environmental impacts, waste management, and post-decommissioning site monitoring.

The O&G industry faces its biggest challenges of decommissioning in the offshore environment, a process that involves many stakeholders which include legal requirements, multidisciplinary studies, stakeholder involvement, and proper technical application. Three different offshore decommissioning regions with different decommissioning stages were analyzed focusing on legal, environmental, and economic aspects. The Gulf of Mexico has the most experience in decommissioning, the North Sea with strict legal aspects, and expensive decommissioning projects, and Brazil has an infant decom industry and new regulation.

The regulatory framework follows a hierarchy having the domestic regulations to be based on the international which evolved based on the existing demands. Although decommissioning regulations and guidelines exist since the middle of the last century, they became more emphatic after the Brent Spar incident in 1995. Among the more noteworthy international and regional regulations are the UNCLOS, IMO, London Convention, and OSPAR Convention.

For the analysis, the decommissioning challenges were divided into three groups corresponding to the legal, environmental, and economic aspects. The legal challenges involve both the industry and the regulatory authorities and need to unify the standpoint of these parties which can be distinct in some points. The regulators aim the investment in the field, creation of new jobs and other positive social-economic impacts while focusing on the need for the operator to comply with national laws and international conventions that the country is a signatory. The operators, on adapting their internal procedures to the regulatory system of different countries, safeguarding the investors, and minimizing the costs of the decommissioning.

The regulators need to delineate a robust legal and regulatory decom framework and establish policies that can provide legal certainty and predictability for all parties and discussing its policies with the stakeholders and the society to have greater transparency. For the operators, there is the necessity of presenting a solution with technical, complying with regulations, and sharing information with other companies and the regulators.

Another legal challenge concerns the residual liabilities of the remaining stumps of platforms, equipment, or other residues since a responsible party must be triggered in case there is any problem with the field after the decommissioning for an undetermined time. Brazil has a very strict position about the residual liability since the damages to the environment due to petroleum E&P are included in the National Constitution, making every company and investor jointly responsible for the program.

The environmental challenges presented are those related to the platform disposal, the rigs-to-reefs policy, and the NORMs management. The chosen solution for the disposal can disperse more contaminants on the sea and make it more difficult to revitalize the area, fish stocks, and biodiversity, and harm the navigation and fishing. The rigs-to-reef program, transforming installation in an artificial reef, might lower decommissioning costs and help to revitalize the sea biome in the region near the platform.

Other environmental issue regards the radioactive substances and the disposal of NORMs which can be carried by specialized yards or the material be reinjected into a disposal well. Regulations should indicate the appropriate management and disposal of those radioactive substances, which was not properly done in the Brazilian decommissioning regulation that only demands that the operators create a management system for the treatment and disposal of radioactive materials during decommissioning. The country, however, does not have a permanent facility to store the radioactive waste, depending on temporary regional deposits which may not be enough with the increment of demand generated by the decom activities. Additionally, Brazil has no yards with decommissioning experience, relying on the fabrication sites.

The economic aspects presented indicated that decommissioning costs can be higher than the companies' expectations. To fund the decom activities, some companies use the revenue provided by other fields which may not be an option for the smaller companies and if the operator does not fulfill its abandonment obligations, other liable parties must comply with legal demands. The decommissioning estimates will, however, influence the funding provisions, liability inherent to the decommissioning process, and the necessity of financial securities. The securities are a failsafe system that will help the authorities to ensure that the decom programs have been financially covered.

Brazil must face all these challenges in its decommissioning industry and has recently published a new regulation. The document is more robust and can provide legal certainty and predictability to the companies and involved different stakeholders in the discussions, even when compared to the North Sea and the Gulf of Mexico, providing guidelines for the operators and the requirement to build a decom management system. On one hand, this makes the regulation more modern and dynamic, helping the operators to find different solutions and to reduce costs; on the other hand, it might lead to extensive discussions between the stakeholders.

The total platform disposal in Brazil is the primary rule, nevertheless, regulators can allow it to be left in place or partially removed which can permit the implementation of the rigs-to-reefs policy on a case-to-case basis. The platforms left *in-situ* or partially removed must provide sufficient waterline and may not interfere in the navigation or other uses of the sea or do not have negative pressure in the sea nature.

The funding of the decommissioning activities is not described in the Brazilian contracts which only demands from the operators' financial security based on the field's decommissioning estimates, without going into details. Nonetheless, presenting the necessary financial securities or fulfilling the decommissioning obligations does not remove the company from its residual liability. To minimize the risks and the necessity of maintaining perpetual security, the companies should perform a post-decom monitoring program for a determined period. After that, the parties could be released from the residual liability. In 2020, ANP created a resolution draft about the securities to open the discussions with the operators and other stakeholders.

It is recommended that the Brazilian regulatory body and offshore industry follows the next fields' decommissioning performed in the country and build a database to define how the new regulation is dealing with the incoming issues, to design the best platforms disposal strategies, and to handle the estimation of the decom costs. The database can improve cooperation and promote information sharing between the stakeholders, increasing the knowledge.

Another recommendation is that ANP focuses on the draft of the financial security regulation which must be appropriately discussed with the stakeholders or else it can lead to high costs to the industry and higher without giving the proper guarantee that the decommissioning will be properly accomplished. The operators also have an important part in the cost reductions by better managing the assets and complying with regulatory requirements to ensure safe and environmentally acceptable outcomes of the operations. The supply chain must be diversified, providing new services, technologies, or techniques, lowering activities costs, and presenting different solutions for decommissioning projects.

References

[1] Jahn, F., Cook, M., and Graham, M., (2003). *Developments in Petroleum Science 46: Hydrocarbon Exploration and Production*, 1st. ed. Elsevier. ISBN: 0-444-82883-4

[2] Bureau of Safety and Environmental Enforcement (BSEE), (s.d.). *Decommissioning FAQs*. Available at: https://www.bsee.gov/subject/decommissioning-faqs (Accessed 10 June 2020).

[3] Fam, M. L., Konovessis, D., Ong, L. S., and Tan, H. K., (2018). A review of offshore decommissioning regulations in five countries – Strengths and weaknesses. *Ocean Engineering*, **160**, pp. 244 - 263. Available at: https://doi.org/10.1016/j.oceaneng.2018.04.001.

[4] Veselis, T., (2018). Global Decommissioning Challenges and Opportunities. Houston, TX: The Society of Naval Architects and Marine Engineers.

[5] Rice, T., and Owen, P., (2003). *Decommissioning the Brent Spar.* Taylor & Francis e-Library. ISBN: 0-203-22205-9.

[6] Neilson, J., and Gorman, D.G., (1998). *Decommissioning Offshore Structures.* London, United Kingdom: Springer. ISBN-13: 978-1-4471-1SS4-0.

[7] Anthony, N., Ronalds, B., and Fakas, E., (2000). Platform Decommissioning Trends. *SPE Asia Pacific Oil and Gas Conference and Exhibition*, 8. Brisbane, Australia: Society of Petroleum Engineers.

[8] Seaway Heavy Lifting, (2011). *A Global Decommissioning*. Available at: https://www.seawayheavylifting.com.cy/uploads/media/Decommissioning_booklet.pdf (Accessed 10 June 2020).

[9] Bret-Rouzaut, N., and Favennec, J.P., (2011). *Oil and Gas Exploration and Production: Reserves, costs, contracts*, 3rd ed. Paris, France: IFP Publications. ISBN: 9782710809753.

[10] Fanchi, J.R., and Christiansen, R.L., (2017). *Introduction to Petroleum Engineering.* Hoboken, NJ, USA: John Wiley & Sons, Inc. ISBN: 9781119193647

[11] Kaiser, M.J., (2019). *Decommissioning Forecasting and Operation Cost Estimation: Gulf of Mexico Well Trends, Structure Inventory and Forecast Models.* Cambridge, USA: Gulf Professional Publishing. ISBN: 978-0-12-818113-3

[12] Green, D.W., and Willhite, G.P., (2018). *Enhanced Oil Recovery*, 2nd ed. Richardson, TX, USA: Society of Petroleum Engineers. ISBN: 978-1-61399-494-8

[13] Nuclear Energy Agency (NEA), (2010). *Cost Estimation for Decommissioning: An International Overview An International Overview Practices and Reporting Requirements.* Organisation for Economic Co-operation and Development (OECD).

[14] ICF Incorporated, (2015). *Decommissioning Methodology and Cost Evaluation.* Bureau of Safety and Environmental Enforcement. Available at: https://www.bsee.gov/research-record/tap-738-decommissioning-methodology-and-cost-evaluation (Accessed 17 June 2020).

[15] Ekins, P., Vanner, R., and Firebrace, J., (2005). *Decommissioning of Offshore Oil and Gas Facilities: Decommissioning Scenarios: A Comparative Assessment Using Flow Analysis.* Policy Studies Institute (PSI).

[16] Sommer, B., Fowler, A., Macreadie, P., Palandro, D., Aziz, A., and Booth, D. (2019). Decommissioning of offshore oil and gas structures – Environmental opportunities and challenges. *Science of The Total Environment*, **658**, pp. 973-981.

[17] Wood Group Mustang, (2013). Deepwater Solutions & Records For Concept Selection. *Offshore Magazine* (May 2013). Available at: https://www.offshore-mag.com/resources/maps-posters/whitepaper/14034340/wood-group-mustang-2013-deepwater-solutions-records-for-concept-selection (Accessed 10 June 2020).

[18] DOF Subsea, (s.d). Vessels. Available at: http://www.dofsubsea.com/capabilities/vessels/ (Accessed 13 June 2020).

[19] Leffler, W.L., Pattarozzi, R., and Sterling, G., (2011). *Deepwater petroleum exploration and production: A Nontechnical Guide*, 2nd ed. Tulsa, OK, USA: PennWell. ISBN: 978-1-59370-253-3

[20] Griggs, G., (2017). *Coasts in Crisis: A Global Challenge.* Oakland, CA, USA: University of California Press. ISBN: 9780520966857

[21] Mount, P.B., and Voskanian, M.M., (2005). Offshore California Facility Decommissioning: Past, Present, Future. *SPE/EPA/DOE Exploration and*

Production Environmental Conference, 7-9 March. Galveston, TX, USA: Society of Petroleum Engineers.

[22] Griffin, W., (1999). Evolution of the Global Decommissioning Regulatory Regime. *SPE Production & Facilities,* **14** (02), 83-87.

[23] Bureau of Ocean Energy Management (BOEM), (2020). *BOEM Data Center*. Available at: https://www.data.boem.gov/Platform/PlatformStructures/Default.aspx (Accessed 15 June 2020).

[24] Bureau of Ocean Energy Management (BOEM), (2020). Official Protraction Diagrams (OPD) And Leasing Maps (LM) & Supplemental Official OCS Block Diagrams (SOBD). Available at: https://www.boem.gov/renewable-energy/mapping-and-data/official-protraction-diagrams-opds-and-leasing-maps-lms (Accessed 10 June 2020).

[25] Oil & Gas Authority (OGA), (2019). *OGA Overview 2019/20.* Available at: https://www.ogauthority.co.uk/news-publications/publications/2019/oga-overview-201920/ (Accessed 03 July 2020).

[26] Oil and Gas UK (OGUK), (2019). *Decommissioning Insight Report.* Available at: https://oilandgasuk.co.uk/product/decommissioning-insight-report/ (Accessed 02 July 2020).

[27] Norwegian Petroleum Directorate (NPD), (2017). *Resource Report - 2017 - Fields and discoveries: Big Opportunities.* Available at: https://www.npd.no/en/facts/publications/reports2/resource-report/resource-report-2017/ (Accessed 01 July 2020).

[28] OSPAR Commission, (s.d.). OSPAR Inventory of Offshore Installations. Available at: https://odims.ospar.org/documents/1623 (Accessed 12 June 2020).

[29] OSPAR Commission, (2020). Data & Information Management System (ODMIS). Available at: https://odims.ospar.org/layers/geonode:ospar_offshore_installations_2017_01_001 (Accessed 12 June 2020).

[30] Morais, J., (2013). *Petróleo em águas profundas: uma história tecnológica da Petrobras na exploração e produção offshore.* Brasília, DF, Brazil: Instituto de Pesquisa Econômica Aplicada (IPEA).

[31] Furtado, A., Barnabé, P., & Loureiro, A.B., (2018). Descomissionamento Offshore no Brasil. *TN Petróleo*, **122**, pp. 42 - 49. Available at: www.tnpetroleo.com.br/revistas/ (Accessed 09 June 2020).

[32] Moura, R.N., (2019). *Extensão de Vida Útil e Descomissionamento no Brasil: Desafios, Oportunidades e a Regulação do Setor.* Available at: http://www.anp.gov.br/arquivos/palestras/apresentacao-descomissionamento-oportunidades-desafios.pdf (Accessed 10 June 2020).

[33] Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP), (2020). *Painel Dinâmico de Produção de Petróleo e Gás Natural.* Available at: http://www.anp.gov.br/exploracao-e-producao-de-oleo-e-gas/painel-dinamico-de-producao-de-petroleo-e-gas-natural/ (Accessed 05 July 2020).

[34] Coelho, M., (2020). *Impactos e Oportunidades do Descomissionamento no Brasil.* Available at: http://www.anp.gov.br/arquivos/palestras/descomissionamento/cf-coelho.pdf (Accessed 11 June 2020).

[35] Mimmi, F., Nunes, R.D., Silva, M.M., and Souza, G.L., (2015). Offshore Fixed Platforms Decommissioning: Mapping of the Future Demand in the Brazilian Context. *OTC Brasil*, **18**. Rio de Janeiro, Brazil: Offshore Technology Conference.

[36] Prasthofer, P.H., (1998). Decommissioning Technology Challenges. *Offshore Technology Conference*, p. 8. Houston, TX, USA.

[37] Paterson, J.B., (2016). Decommissioning Offshore Installations: international, regional and domestic legal regimes in the light of emergent commercial, political, environmental and fiscal concerns. In AMPLA Yearbook 2015. pp. 344-362. AMPLA. Available at: https://ampla.wheelers.co/browse/series/442997 (Accessed 12 June 2020).

[38] International Maritime Organization, (s.d). Member States. Available at: http://www.imo.org/en/About/Membership/Pages/MemberStates.aspx (Accessed 13 June 2020).

[39] Pollett, B., (2020). Risk-Based Offshore Decommissioning Standards and Regulations. *Offshore Technology Conference*, **5**. Houston, TX, USA: Offshore Technology Conference.

[40] European Environment Agency (EEA), (2018). Marine environmental pressures. Available at: https://www.eea.europa.eu/themes/water/europes-seas-and-coasts/marine-environmental-pressures (Accessed 24 June 2020).

[41] Curtis, T., Steinar, N., and Picken, G., (2001). Guidelines for Energy and Emissions Calculation in Offshore Decommissioning. *SPE/EPA/DOE Exploration and Production Environmental Conference*, **9**. San Antonio, TX, USA: Society of Petroleum Engineers.

[42] Smith, A., (2010). NORM The Lessons To Be Learnt, New Challenges And Innovative Thinking With Decommissioning And Radioactive Waste. *SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production*, **19**. Rio de Janeiro, RJ, Brazil: Society of Petroleum Engineers.

[43] Valeur, J., (2010). Environmental Impacts of Different NORM Disposal Methods. *Middle East Health, Safety, Security, and Environment Conference and Exhibition*, 12. Manama, Bahrain: Society of Petroleum Engineers.

[44] Green, M., Crowley, C., Spiteri, J., and Allford, L., (2019). Managing Process Safety in a Decommissioning Project. *SPE Offshore Europe Conference and Exhibition*, **17**. Aberdeen, UK: Society of Petroleum Engineers.

[45] Oil and Gas UK (OGUK). (2013). *Guidelines on Decommissioning Cost Estimation - Issue 3.* London, UK: Oil and Gas UK. ISBN: 1-903-004-07-1.

[46] ABB Limited, (2015). *Offshore Oil and Gas Decommissioning.* Decom North Sea (DNS). Available at: https://library.e.abb.com/public/d689c2f70f0c447586610ac566c9aa7e/ABB-Offshore-Oil-and-Gas-Decommissioning-2015.pdf (Accessed 27 June 2020).

[47] Esson, R., (2017). Transforming Decommissioning Planning. *Offshore Technology Conference*, 9. Houston, TX, USA: Offshore Technology Conference.

[48] Oil & Gas Authority (OGA), (2019). *UKCS Decommissioning Estimate - 2019.* Available at: https://www.ogauthority.co.uk/news-publications/publications/2019/ukcs-decommissioning-cost-estimate-2019-report/ (Accessed 29 June 2020).

[49] Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP), (2020). Participação especial. Available at: http://www.anp.gov.br/royalties-e-outras-participacoes/participacao-especial (Accessed 07 July 2020).

[50] Parente, V., Ferreira, D., dos Santos, E.M., and Luczynski, E. (2006), Offshore decommissioning issues: Deductibility and transferability. *Energy Policy,* **34** (15), pp. 1992-2001.

[51] Rawa, A., Mayorga Alba, E., Sheldon, C., Aramburu, R., and Rodriguez, F., (2010). Working with Stakeholders to Develop a Toolkit to Guide Planning and Implementation of Decommissioning and Closure Schemes in Resource-Rich Countries. *SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production*, **12**. Rio de Janeiro, RJ, Brazil: Society of Petroleum Engineers.

[52] Tularak, A., Khan, W., and Thungsuntonkhun, W., (2007). Decommissioning Challenges in Thailand. *SPE Asia Pacific Health, Safety, and Security Environment Conference and Exhibition*, **7**. Bangkok, Thailand: Society of Petroleum Engineers.

[53] Dunford, R., Ginn, T., and Desvousges, W., (2004). The use of habitat equivalency analysis in natural resource damage assessments. *Ecological Economics,* **48** (1), pp. 49-70.

[54] Bureau of Ocean Energy Management (BOEM), (s.d.). *Rigs to Reefs*. Available at: https://www.bsee.gov/what-we-do/environmental-focuses/rigs-to-reefs (Accessed 18 July 2020).

[55] Kaiser, M.J., and Siddhartha, N., (2018). *Gulf of Mexico Decommissioning Trends and Operating Cost Estimation.* US Department of the Interior. Bureau of Ocean Energy.

[56] Jones, J.C., (2017). *Offshore Oil and Gas Decommissioning*, 1st ed. Bookboon. ISBN: 978-87-403-1922-4.

[57] Bull, A., and Love, M., (2019). Worldwide oil and gas platform decommissioning: A review of practices and reefing options. *Ocean & Coastal Management,* **168**, pp. 274-306.

[58] ARUP, (2014). *Decommissioning in the North Sea: Review of Decommissioning Capacity.* Decom North Sea (DNS). Available at:

http://decomnorthsea.com/uploads/pdfs/projects/Decommissioning-in-the-North-Sea-Demand-vs-Capacity_low-res.pdf (Accessed 22 July 2020).

[59] AACE International, (2019). *Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction For The Process Industries.* Available at: https://web.aacei.org/resources/publications/recommended-practices (Accessed 27 July 2020).

[60] Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP), (2020). *Garantias Financeiras de Descomissionamento.* Available at: http://www.anp.gov.br/fase-producao/5750-garantias-financeiras-de-descomissionamento (Accessed 27 July 2020).

[61] Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP), (2020). *Publicada resolução sobre desativação de instalações.* Available at: http://www.anp.gov.br/noticias/5745-publicada-resolucao-sobre-desativacao-de-instalacoes (Accessed 28 July 2020).

[62] Imprensa Nacional - Diário Oficial da União, (2020). Resolução nº 817, de 24 de abril de 2020. Available at: http://www.in.gov.br/web/dou/-/resolucao-n-817-de-24-de-abril-de-2020-254001378 (Accessed 28 July 2020).

[63] Norwegian Petroleum, (2020). Cessation and Decommissioning. Available at: https://www.norskpetroleum.no/en/developments-and-operations/cessation-and-decommissioning (Accessed 29 July 2020).

[64] Constituição da República Federativa do Brasil 1988. Brasil. Available at: http://www.planalto.gov.br/ccivil_03/constituicao/constituicaocompilado.htm (Accessed 27 July 2020).

[65] Instituto Brasileiro de Petróleo, Gás e Biocombustíveis (IBP), (2019). *Diretrizes para Gerenciamento de Materiais Radioativos de Ocorrência Natural (NORM).* Rio de Janeiro, RJ, Brazil: IBP.

[66] Comissão Nacional de Energia Nuclear (CNEN), (2020). Perguntas Frequentes. Available at: http://www.cnen.gov.br/perguntas-frequentes (Accessed 28 July 2020).

[67] Instituto Brasileiro de Petróleo, Gás e Biocombustíveis (IBP), (2017). *Regulação do Descomissionamento e seus Impactos para a Competitividade do Upstream no Brasil.* Available at: https://www.ibp.org.br/observatorio-do-setor/regulacao-do-

descomissionamento-e-seus-impactos-para-a-competitividade-do-upstream-no-brasil/ (Accessed 29 July 2020).

[68] Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP), (2019). *Edital e Modelo do Contrato: 16ª Rodada de Licitações de Blocos.* Available at: http://rodadas.anp.gov.br/pt/concessao-de-blocos-exploratorios-1/16-rodada-de-licitacao-de-bloco/edital-e-modelo-do-contrato-de-concessao (Accessed 29 July 2020).

[69] Estadão, (2015). Economia & Negócios. *PetroRio: ANP Divulga Resolução de Diretoria Relativa à Cessão de 40% do Campo de Polvo*. Available at: https://economia.estadao.com.br/fatos-relevantes/pdf/18190541.pdf (Accessed 30 July 2020).