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TRABALHO DE CONCLUSÃO DE CURSO

COMPARATIVE ASSESSMENT IN SUBSEA PIPELINES DECOMMISSIONING: A CASE STUDY BETWEEN BRAZIL AND UNITED KINGDOM

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Trabalho de Conclusão de Curso (TCC) desenvolvido no *ThermoPhase – Fluid and Complex Systems Research Group* e apresentado ao Curso de Bacharelado em Engenharia de Petróleo, da Universidade do Estado de Santa Catarina, como requisito parcial para a obtenção do título de Bacharel em Engenharia de Petróleo.

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RESUMO

Os dutos submarinos desempenham um importante papel na produção *offshore* de óleo e gás, sendo os responsáveis por escoar e conduzir os fluidos produzidos ou injetados. Desde o projeto até o final da vida útil, os dutos submarinos estão sujeitos a diversos esforços e degradações, afetando diretamente a última etapa de seu ciclo de vida, o descomissionamento. O descomissionamento pode ser entendido como o conjunto de atividades que abrangem a cessação da produção, o abandono de poços, a remoção ou abandono de estruturas e a recuperação e monitoramento da área afetada. É esperado que este processo ocorra quando não for mais possível produzir de forma segura e/ou economicamente viável. Os dutos submarinos possuem diversas alternativas possíveis para descomissionamento, que vão desde o abandono das tubulações no local sem remediações a remoção total destas, passando por opções com intervenções intermediárias como a remoção parcial e a cobertura com rochas. A escolha da melhor opção é complexa tendo em vista a diversidade de alternativas, a condição das tubulações e os interesses por vezes conflitantes dos múltiplos *stakeholders*. Desta forma, torna-se fundamental a utilização de ferramentas de apoio à tomada de decisão, que possuem como base critérios e subcritérios bem definidos e contam com a avaliações técnicas de especialistas nos assuntos abordados. A Análise Comparativa (AC) é a ferramenta mais utilizada pela indústria devido a sua simplicidade, flexibilidade e por ser mandatória em países como o Reino Unido e Brasil como técnica para nortear e embasar a tomada de decisão. Neste sentido, o presente trabalho tem como objetivo fazer uma comparação entre casos reais de Avaliações Comparativas do Reino Unido e do Brasil. Para a escolha dos campos a serem analisados, foram utilizados os PDIs e Reports disponibilizados publicamente pelos órgãos do Brasil e Reino Unido. O estudo de caso comparando as ACs realizadas para o campo de Brent e para os campos de Bijupirá/Salema (BJSA) permitiu evidenciar alguns pontos, como determinação das alternativas, definição de subcritérios e dos métodos de ponderação, que podem estar diretamente atrelados ao resultado obtido para cada um dos campos. Para Brent diversas opções foram apontadas como recomendadas, para BJSA a alternativa recomendada foi o abandono permanente das tubulações. Os fatores apontados por este estudo devem ser analisados com maior profundidade de modo a permitir a otimização das metodologias utilizadas, o estabelecimento de diretrizes e melhorias regulatórias.

Palavras-chaves: Descomissionamento, Dutos Submarinos, Análise Comparativa, Brasil, Reino Unido.

ABSTRACT

Subsea pipelines play an important role in offshore oil and gas production, being responsible for draining and conducting the produced or injected fluids. From design to end of life, subsea pipelines are subject to various stresses and degradations, directly affecting the last stage of their life cycle, decommissioning. Decommissioning can be understood as the set of activities that include the cessation of production, the abandonment of wells, the removal or abandonment of structures, and the recovery and monitoring of the affected area. This process is expected to occur when it is no longer possible to produce safely and/or economically viable. Subsea pipelines have several possible alternatives for decommissioning, ranging from abandoning the pipelines in place without remediation to their total removal, going through options with intermediate interventions such as partial removal and covering with rocks. Choosing the best alternative is complex given the diversity of alternatives, the condition of the pipelines, and the sometimes conflicting interests of multiple stakeholders. Thus, it is essential to use tools to support decision-making, which are based on well-defined criteria and sub-criteria and rely on technical evaluations by specialists in the subjects addressed. The Comparative Assessment (CA) is the most used tool by the industry due to its simplicity, flexibility and for being mandatory in countries like the United Kingdom and Brazil as a technique to guide and support decision making. This work aims to make a comparison between real cases of Comparative Assessment in the United Kingdom and Brazil. To choose the fields to be analyzed, the PDIs and Reports made publicly available by the agencies in Brazil and the United Kingdom were used. The case study comparing the CAs carried out for the Brent field and the Bijupirá/Salema (BJSA) fields made it possible to highlight some points, such as the determination of alternatives, definition of sub-criteria and weighting methods, which may be directly linked to the result obtained for each of the fields. For Brent, several options were indicated as the recommended option, for BJSA the recommended alternative was permanent abandonment. The factors pointed out by this study should be analyzed in greater depth in order to allow the optimization of the methodologies used, the establishment of guidelines and regulatory improvements.

Keywords: Decommissioning, Subsea Pipelines, Comparative Assessment, Brazil, United Kingdom.

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LIST OF ABBREVIATIONS AND ACRONYMS

AHP	Analytic Hierarchy Process
ANP	*Agência Nacional do Petróleo, Gás Natural e Biocombustíveis* (Brazil)
BEIS	Department for Business Energy & Industrial Strategy
BJSA	Bijupirá/Salema
CA	Comparative Assessment
DECC	Department of Energy & Climate Change
EEZ	Exclusive Economic Zone
EJD	Estudo de Justificativas de Descomissionamento
ELECTRE	*Élimination et Choix Traduisant la Realité*
FAR	Fatal Accident Rate
FPSO	Floating Production Storage and Offloading
GBS	Gravity-based Structure
IBAMA	*Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis* (Brazil)
IMO	International Maritime Organization
IRPA	Individual Risk Per Annum
JIP	Joint Industry Project
MB	*Marinha Brasileira* (Brazil)
NORMs	Naturally occurring radiative material
OGUK	Oil & Gas U.K.

OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PDI	Programa de Descomissionamento de Instalações
PEHD	High-density Polyethylene
PLET	Pipeline End Termination
PLL	Potential Loss of Life
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
RAG	Red-Ambar-Green
SGIP	*Sistema de Gerenciamento da Integridade de Poços* (Brazil)
SGSO	*Sistema de Gerenciamento de Segurança Operacional* (Brazil)
TDP	Touch Down Point
THS	Tubing Head Spools
TLP	Tension Leg Platform
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UK	United Kingdom
UNCLOS	United Nations Convention on the Law of the Sea

SUMMARY

1 INTRODUCTION

1.1 FORMULATION OF THE PROBLEM

Decommissioning is defined as the process of closing the activities of an oil and/or gas producing field, in which occur the plug and abandonment of wells, the abandonment or removal of equipment and structures, and the recovery of the area (MADI, 2018). Decommissioning is expected to occur when, considering the technical and economic aspects, the alternatives for maximum recovery of hydrocarbons in a field are exhausted and/or when a production unit reaches the end of its useful life (BITTAR; MODESTO, 2019).

In Brazil, discussions about decommissioning began to gain strength in the last 10 years, due to the aging of production units. More than 50 years after the beginning of offshore oil production in Brazil, many basins have reached their productive maturity and many facilities have reached the end of their useful life (STEENHAGEN, 2020). According to the data provided by ANP (2022) 54 platforms are older than 25 years, equivalent to about 32% of the units in operation, most of them located in the Campos and Potiguar basins.

According to IHS Markit (2021) forecast, Brazil should become the third-largest decommissioning market in the world, being responsible for 9% of the activities, only behind the United Kingdom (21%) and the United States (17%). Investments of around R$ 30 billion are expected between 2021 and 2025. Wells plug and abandonment activities are responsible for most of the estimated value, around R$ 20 billion, followed by equipment withdrawal, with R$ 9 billion expected (ANP, 2022a).

On the other hand, the United Kingdom, due to the maturity of the North Sea oil and gas basins, has presented considerable investments in decommissioning since 2004, which became even more expressive from 2010 onwards. The North Sea became an incubator for significant experience in decommissioning, making services and goods, regulations and guidance from the UK demanded worldwide and serving as an example for the definition of strategies and regulatory frameworks in several countries (OGUK, 2021).

In addition to the multidisciplinarity involved and the interests of multiple stakeholders that make decision-making regarding the final destination of structures and facilities quite complex, subsea pipelines have other characteristics that contribute to increasing the associated difficulty. After a long productive life, subjected to various efforts and the severity of the marine environment, their integrity may be severely affected. The accumulation of NORMs (Naturally

Occurring Radioactive Material), the presence of marine ecosystems, and the variety of possible decommissioning alternatives increase the number of factors to be considered in the decision-making (MICHALOWSKI; NETO; ANDRADE, 2020).

1.2 JUSTIFICATION AND RELEVANCE

The Comparative Assessment has a strategic role in the planning and execution of decommissioning activities since its results guide the decommissioning project. Its use brings rationality and clarity to the decision-making, allowing to technically assess each factor involved and weigh the interests (MUNIZ, 2020).

The need to present a Comparative Assessment to support decision-making, bringing greater clarity, traceability and impartiality, is quite recent in Brazil and is due to the publication of ANP Resolution nº 817/2020 (ANP, 2020). The resolution, however, does not prescribe the details of the methodology to be used (STEENHAGEN, 2020). There is still much learning to be acquired to optimize methodologies, guidelines, and resolutions. However, mirroring success stories and incorporating lessons learned in other countries can accelerate this process. The United Kingdom has established itself as an excellent benchmark given its experience in carrying out and analyzing comparative assessments, in addition to having well-established guidelines for their execution.

From an academic point of view, the accomplishment of this work allows the development of critical thinking, using as a basis the knowledge acquired during graduation. In addition, it brings decommissioning, a topic widely discussed by the industry, closer to the academic environment, in which the discussions are still scarce and limited.

1.3 OBJECTIVES

1.3.1 Main objective

This work aims to make a comparison between real cases of Comparative Assessments in the United Kingdom and Brazil to identify opportunities to improve the methodologies used and even the regulatory framework.

1.3.2 Specific objectives

To reach the main objective of this work the following steps will be performed:

- To make a background of the basic concepts about submarine pipelines;
- To gather the necessary information for a better understanding of the decommissioning process and its respective decision-making, especially regarding subsea pipelines;
- To perform a comparison between a Comparative Assessment carried out for a field in Brazil and one in the United Kingdom.

2 THEORIC FUNDAMENTALS AND LITERATURE

This section presents the main concepts about subsea pipelines, to provide the necessary background for a better understanding of the systems discussed in Chapter 3.

2.1 PIPELINES IN THE OIL AND GAS INDUSTRY

A subsea pipeline is an indispensable part of the development and production of oil and gas in offshore fields. It is the fastest, safest, and most economical and reliable means of transporting oil and gas continuously (FANG; DUAN, 2014).

Subsea pipelines are responsible for connecting wells to manifolds and the stationary production unit, conducting injected and/or produced fluids (BIRAL, [s.d.]). In addition, subsea pipelines are also used to transport and export production, connecting two or more production units or even conveying the oil and gas directly to onshore terminals (QUEIROZ, 2011).

The Mero field's development of phase 3, located in the pre-salt Santos Basin, represents an actual example of a subsea pipeline system. To develop this project will be required 80 km of rigid risers and flowlines, 60 km of flexible service lines, and 50 km of umbilicals. The costs involved in the manufacturing, installation, and pre-commissioning of these pipelines, as well as in the installation of the FPSO mooring lines and hookup, are estimated between US$500 and US$750 million (SUBSEA7, 2021).

The next subsections bring fundamental information about subsea pipelines to better understand the systems analyzed in the Section 3.

2.1.1 Classification

The different types of subsea pipelines can be classified according to their structure, location, and function, as described in the following sections.

2.1.1.1 Regarding its structure

2.1.1.1.1 Rigid pipelines

Rigid pipelines (Figure 1) are made of carbon steel and, when necessary, special alloys are used to inhibit problems such as corrosion (BIRAL, [s.d.]). Additional layers can be added for purposes such as maintaining thermal insulation or providing more weight to the pipe.

Despite the structural simplicity they have high collapse resistance at great depths (GUO et al., 2014).

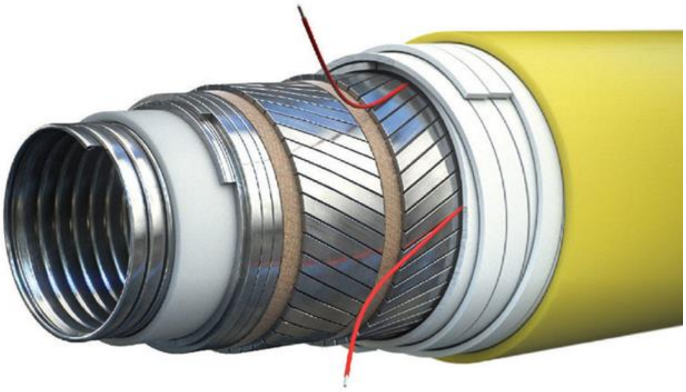
Figure 1 – Rigid Pipelines

Source: Cortez Subsea, 2020.

2.1.1.2 Flexible pipelines

Flexible pipelines are formed by interspersed layers (Figure 2) of metallic and polymeric materials. Each of these layers has a specific function and their quantity and arrangement are designed according to the necessity. Steel layers guarantee the flexibility of the pipes while the polymeric layers guarantee the tightness and corrosion protection of steel layers (DORNELLAS, 2018).

Figure 2 – Flexible Pipelines



Source: Journal of Petroleum Technology, 2016.

As stated by Biral ([s.d.]) generally, flexible pipelines have the following layers from the inside out:

a) **Interlocked Casing:** Usually made of stainless steel, it provides resistance to collapse that can be caused by external pressures or tensile armor.
b) **Internal Pressure Sheath:** Provides tightness to driving fluids. It is used in its manufacture polymeric material, commonly polyamide, due to its high resistance to hydrocarbons, high temperatures, and high pressures.
c) **Zeta Layer (Pressure Armor):** Carbon steel layer that provides the tube with resistance to radial forces resulting from internal and external pressures due to its configuration.
d) **Anti-abrasive layer:** A high-density polyamide or polyethylene (PEHD) layer is used to reduce the friction between the zeta layer and tensile reinforcement thus preventing wear.
e) **Tensile Armor:** It is divided into internal and external armor, constituted of two layers of 35° angled carbon steel wires, one to the right and another to the left, to obtain the highest tensile strength. Between the armors, adhesive tape is used to support the layers until the next layer is fabricated.
f) **External Plastic Layer:** Responsible for joining and protecting the other layers from the effects of the marine environment such as abrasion and corrosion. Among the materials used are polyamide and PEHD.

Flexible pipelines are often used for production in fields that have floating production units, given that, despite being anchored, these units are more exposed to the efforts resulting from the vessel's movements (MUNIZ, 2020).

When compared to rigid pipelines, flexible pipelines present greater flexibility in terms of piping layout and vessel movements and less sensitivity to accidents on the seabed (free spans, undulation, etc.) Another advantage is the simpler and faster installation process. However, rigid pipelines, in addition to having a lower manufacturing cost, are more resistant to high pressures, favoring their use in deep and ultra-deep waters (QUEIROZ, 2011).

2.1.1.3 Regarding its location

2.1.1.3.1 Riser

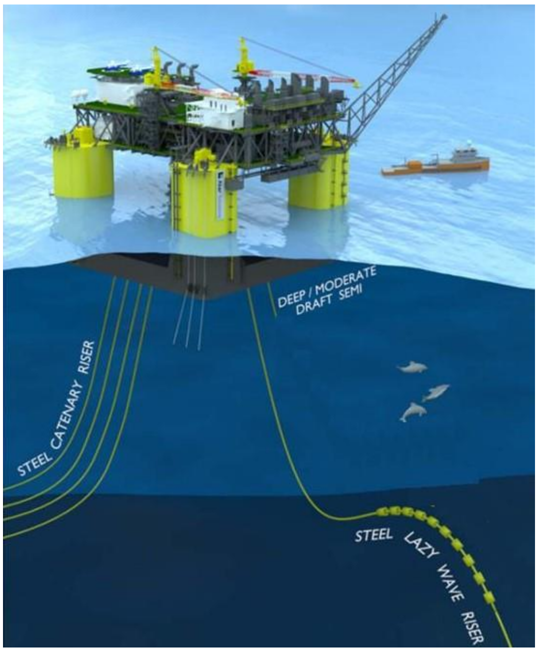
Riser is the suspended section of the subsea pipe that connects the production unit, whether fixed or floating, to the wells or manifolds. Its function is to drive the produced or injected fluids. The risers can be rigid, flexible, or even hybrid, a junction of the two previous categories (BIRAL, [s.d.]).

According to Biral ([s.d.]) risers are critical components as they are subjected to high tensile and fatigue forces from the marine currents' action, wave effects, platform movement, and due to their weight. To suit these efforts, specific configurations may be used, they are:

a) **Vertical:** in this configuration a tractive force is applied to the top of the riser to keep it tensioned, avoiding buckling. It is especially used on SPAR and TLP platforms. An alternative is the use of additional weight in one section and floats in another, generating traction at the ends of the riser without the need for tensioners or motion compensators.
b) **Simple Catenary:** the riser is freely extended in catenary form from the platform to the marine floor, the full weight of the pipeline is supported by the point of connection to the platform. This configuration is quite simple and inexpensive but may not be the best alternative in high water depths due to excessive top traction and Touch Down Point (TDP) buckling.
c) **Complex Catenary:** to compensate for excess traction due to weight, characteristic of the simple catenary, floats are added to a section of the duct.

Figure 3 illustrates a Simple Catenary (left) and Complex Catenary (right) risers.

Figure 3 – Simple Catenary and Complex Catenary Risers

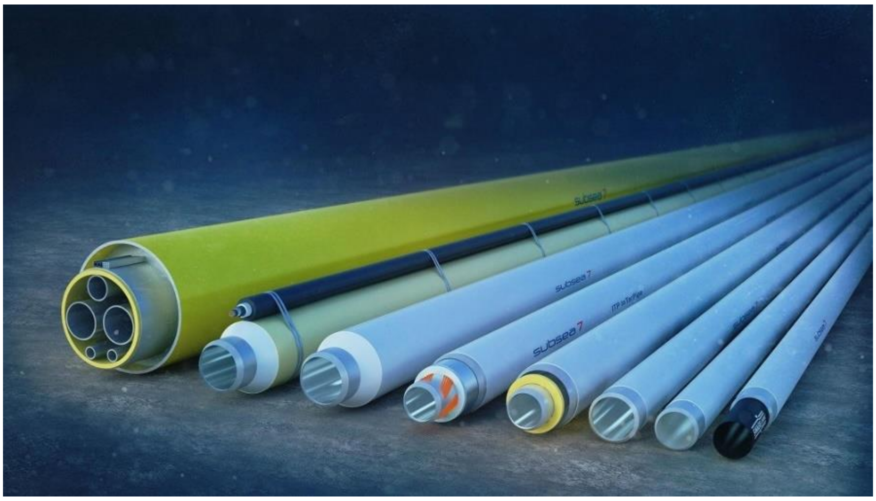


Source: Offshore Energy, 2020.

2.1.1.3.2 Flowline

Is called flowline the rigid or flexible section of subsea pipelines that, after installation, remain supported on the seabed and connect the underwater equipment to the riser. Flowlines (Figure 4) have a static behavior as they are not subject to cyclic movement and mechanical stress when already positioned on the seabed. However, during the launching procedure, they suffer tensile, compressive, and flexural efforts (BALDAN; MACHADO, 2010).

Figure 4 – Flowlines



Source: Subsea7, [s.d.].

2.1.1.4 Regarding its function

2.1.1.4.1 Pipe

Pipes are responsible for conducting produced or injected fluids in the subsea system (BAI; BAI, 2010).

2.1.1.4.2 Umbilical

Umbilical (Figure 5) is a duct consisting of hydraulic and electrical cables, fiber optics, or a combination of these (BAI; BAI, 2010). It is used for chemical injection, remote operation of valves and subsea equipment, and monitoring of operational parameters such as temperature and pressure (BIRAL, [s.d.]). Integrated Production Umbilicals (IPU), besides the characteristic purposes of umbilicals, also allow to produce fluids, that is, acting as flowlines (HEGGDAL et al., 2001).

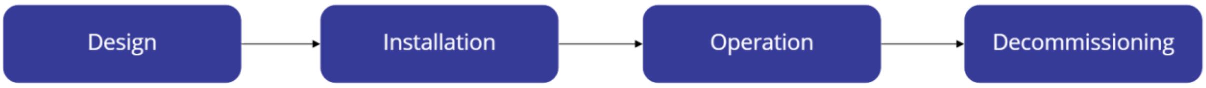
Figure 5 – Umbilical

Source: Petrobras, 2015.

2.1.2 Pipelines lifecycle

Although each type of duct has its characteristics and functions, they have in common the stages of their life cycles. Figure 6 summarizes the main stages of a pipeline lifecycle for a petroleum field.

Figure 6 – Stages of a Pipeline Lifecycle



Source: Elaborated by the author, 2020.

The stages shown in Figure 6 are described in more detail below:

a) **Design:** this stage is quite complex but fundamental to ensure that the pipelines can perform their functions safely and efficiently. According to Guo et al. (2014), before designing an offshore pipeline, it is necessary to understand the environments and the conditions in which the pipeline will be installed and operated. A complete pipeline design may include pipeline sizing (diameter and wall thickness) and material grade selection based on analyses of parameters such as stress, hydrodynamic stability, span, thermal insulation, and corrosion. Once the design variables have been defined, the manufacturing process begins, varying according to the type of pipe to be produced.

b) **Installation:** after being manufactured, pipelines are transported by barge to the installation site. Several methods can be used for pipeline installation including S-lay, J-lay, reel barge, and tow-in methods (GUO et al., 2014). The choice of the appropriate installation method must consider the type of pipeline to be installed and environmental factors such as the depth of installation.

c) **Operation:** when the installation is concluded, it is necessary to clean and test the pipelines to assure they are safe and ready to operate. During the productive life, flow assurance and pigging operations are performed to maintain the integrity of the pipelines. Flow assurance issues such as hydrates, paraffin, asphaltenes depositions, and corrosion are the main responsible for compromising pipeline conditions (GUO et al., 2014).

d) **Decommissioning:** This stage will be covered in detail in section 2.2.

Understanding the stages and processes to which the pipelines are subjected during their useful life, as well as their different types, is essential to understand the complexity of the variables involved in the last stage of pipelines lifecycles, called decommissioning.

2.2 PIPELINES DECOMMISSIONING

The operation stage ends when the pipelines are no longer able to operate safely and need to be replaced, or when the production of a field is no longer viable, either technically or economically, and it is necessary to give the correct destination to all equipment. Then, the decommissioning stage begins.

Often, words such as dismantling, deactivation, or abandonment are used as synonyms for decommissioning, but caution is necessary, as these words do not encompass the full meaning of the word decommissioning.

ANP (2020) defines decommissioning as:

> The set of legal actions, technical and engineering procedures applied in an integrated manner to an offshore system to ensure that its deactivation or cessation of production reaches safety conditions, environmental preservation conditions, reliability, and traceability of information and documents.

Subsea pipelines are a critical and complex part of the decommissioning programs. It happens since their integrity may be compromised due to the severe environmental conditions, the accumulation of naturally occurring radioactive materials (NORMs), and the presence of the marine ecosystem (MICHALOWSKI; NETO; ANDRADE, 2020).

Considering this, the decommissioning alternatives for subsea pipelines must be carefully analyzed and compared, seeking to avoid and/or minimize all kinds of negative impacts.

2.2.1 Decommissioning regulations

International and national regulations aim to ensure the safe execution of decommissioning activities, minimizing risks to people, the environment, and other uses. Understanding these regulations is critical in the decision-making process of decommissioning options.

These resolutions are not specific to subsea pipelines, however, given their interconnection with other subsea equipment and with production units, they are often affected by what is established by them.

2.2.1.1 International

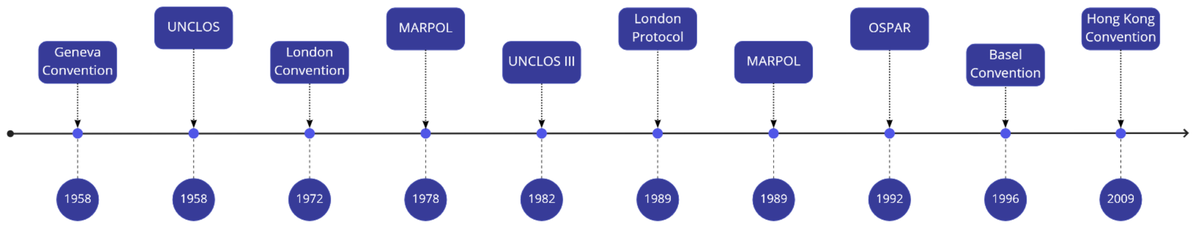
The first international regulation about decommissioning of offshore structures came from Geneva Convention (1958) that establish that any installations which are abandoned or disused must be entirely removed. Some years later, in 1982, The United Nations Convention on the Law of the Sea (UNCLOS III) suggested more flexibility compared to the previous convention, for leaving structures in situ if they do not offer any risk to other sea users (M’PUSA, 2017).

In 1989, the Guidelines and Standards for the Removal of Offshore Installations and Structures were adopted on the Continental Shelf and in the EEZ (Exclusive Economic Zone) from the International Maritime Organization (IMO). These guidelines state that abandoned or disused offshore installations or structures on any continental shelf or in any EEZ are required to be removed, except where non-removal or partial removal is consistent with the stated guidelines and standards (IOGP, 2017).

The international regulatory framework is complemented by lots of conventions, such as the London Convention (1972) and Protocol (1996), Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (1989), and The Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships (2009).

The main international regulations are represented in the timeline shown in Figure 7.

Figure 7 – International Regulatory Framework Timeline



Source: Elaborated by the author, 2020.

2.2.1.2 Brazil

Decommissioning activities in Brazil are considerably recent, Petrobras, the operator of the main mature fields, just started the process of decommissioning the first field, Cação, located in the shallow waters of the Espírito Santo basin. Therefore, the national regulatory framework still is in the process of developing, adaptation, and updating (BORGES, 2018).

The main bodies responsible for regulating the deactivation and decommissioning of offshore structures in Brazil are National Petroleum Agency (ANP), the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), and the Brazilian Navy (MB) (MADI, 2018).

According to the resolution 17/2017 from CNPE:

> Art. 1st Establish as a Policy for Exploration and Production of Oil and Natural Gas the maximization of the recovery of in situ resources of the reservoirs (...).
>
> Art. 3rd The ANP (...) shall observe the guidelines established in art. 1st, as well as the following:
>
> VIII – to stimulate the extension of the useful life of the fields, simultaneously promoting the culture of preservation of the safety conditions and respect for the environment.
>
> IX – ensure the proper decommissioning of facilities at the end of the field's life, avoiding premature occurrence.

According to Law nº 9.478/97, ANP aims to promote the regulation, hiring, and inspection of the economic activities of the oil and gas industry.

ANP, in the use of its powers, established over the years several resolutions to promote operational and environmental safety, as well as establishing procedures for decommissioning, return of areas, disposal, and reversal of assets. These resolutions constitute the Brazilian regulatory framework for decommissioning and are described hereunder:

1. Resolution ANP nº 27/2006 – Technical Regulation of Deactivation of Installations in the Production Phase (This resolution has been revoked and replaced by Resolution ANP nº 817/2020);

2. Resolution ANP nº 28/2006 – Establishes the procedures regarding the Disposal and Reversal of Assets belonging to Production Systems and the Return of Concession Areas in the Production Phase and in the Concession Agreement (This resolution has been revoked and replaced by Resolution ANP nº 817/2020);

3. Resolution ANP nº 43/2007 – Operational Safety Regime for Oil and Natural Gas Drilling and Production Facilities;

4. Resolution ANP nº 02/2011 – Technical Regulation for Onshore Pipelines for Movement of Oil, Derivatives, and Natural Gas

5. Resolution ANP nº 25/2014 – Technical Regulation for Return of Areas in the Exploration Phase (This resolution has been revoked and replaced by Resolution ANP nº 817/2020);

6. Resolution ANP nº 41/2015 – Technical Regulation for Operational Safety Management System for Subsea Systems (SGSO);

7. Resolution ANP nº 46/2016 – Technical Regulation for Well Integrity Management System (SGIP);

8. Resolution ANP nº 817/2020 – Technical Regulation for Decommissioning of Oil and Natural Gas Exploration and Production Installations;

9. Resolution ANP nº 854/2021 – Regulates the procedures for submitting financial guarantees and terms that ensure the financial resources for the decommissioning of production facilities in the oil and natural gas fields.

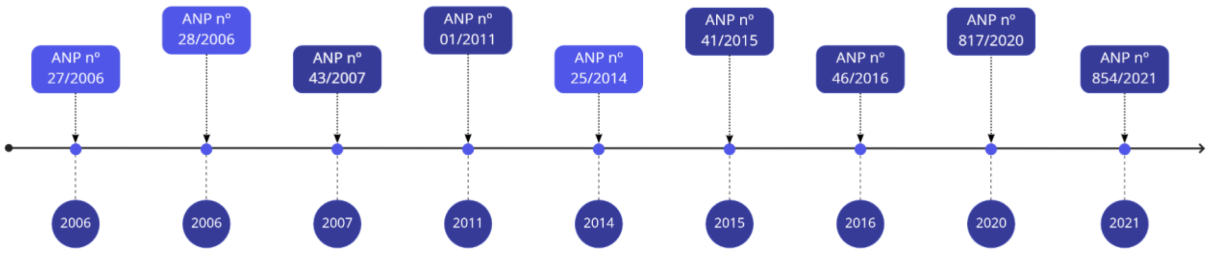
Resolution ANP nº 817/2020 is considered the main resolution of the decommissioning regulatory framework. It entered into force on April 27th, after a long period of studies, hearings, and public consultations. It was the result of joint work between IBAMA, Brazilian Navy, and ANP that unified their processes. The purpose of this new resolution was to update the regulatory framework, standardizing procedures, contemplating the best international practices, and ensuring greater predictability. It replaces three previously existing resolutions, ANP nº 27/2006, ANP nº 28/2006, and ANP nº 25/2014, which also guarantees administrative simplification (ANP, 2022b).

Among the advances brought about by the resolution is the unique Facility Decommissioning Program (PDI), presented to the three institutions, optimizing, and simplifying the approval process. It also established the presentation of a Study of Justification for the Decommissioning of Production Facilities (EJD), to ensure the maximum use of national reserves, as already adopted by other countries such as the United Kingdom and following the resolution nº 17/2017 from CNPE (ANP; FGV ENERGIA, 2021).

Another important point addressed in Resolution ANP nº 817/2020 was the need to present a comparative assessment as a technical justification for cases in which total removal is not technically recommended and the definition of the criteria that must be considered in this assessment (ANP; FGV ENERGIA, 2021).

Figure 8 summarizes, in chronological order, the main ANP's resolutions that address aspects of decommissioning. Resolutions highlighted in lighter color were repealed by Resolution ANP nº 817/2020.

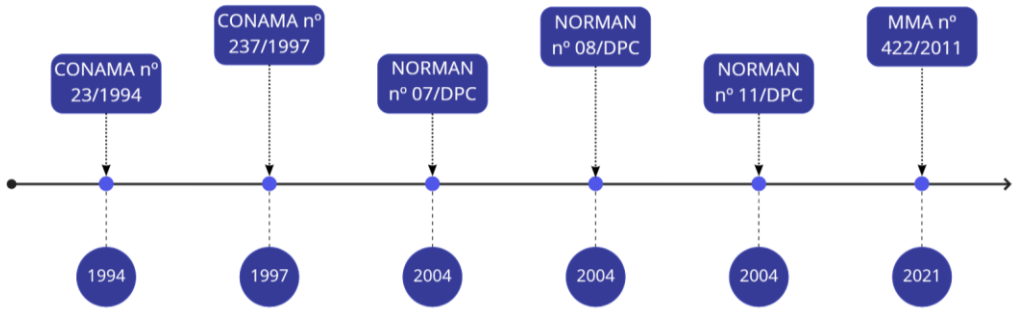
Figure 8 – Brazilian Regulatory Framework Timeline - ANP Resolutions



Source: Elaborated by the author, 2021.

The regulatory framework is complemented by the resolutions CONAMA nº 23/1994, CONAMA nº 237/1997 and Ordinance MMA nº 422/2011, from IBAMA and NORMAM-07/DPC, NORMAM-08/DPC and NORMAM-11/DPC, from Brazilian Navy (ANP, 2022b). These supplementary resolutions are represented in Figure 9.

Figure 9 – Brazilian Regulatory Framework Timeline - Supplementary Resolutions



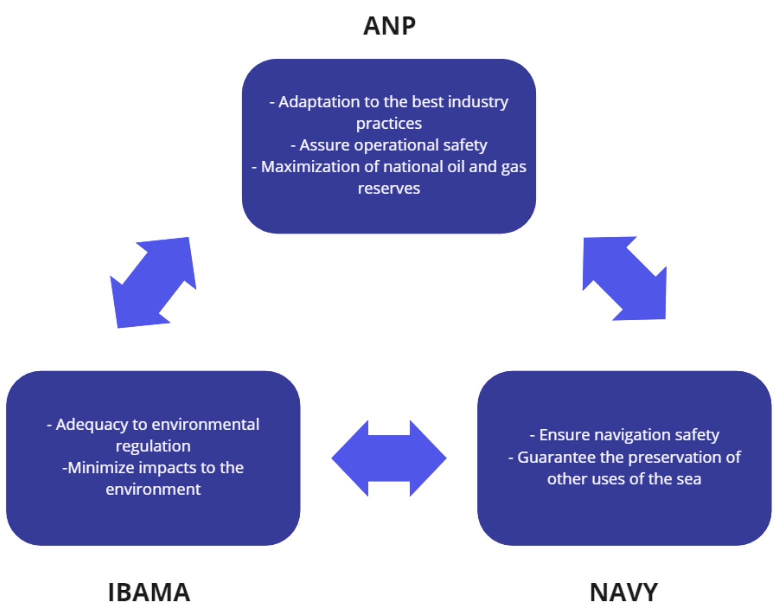
Source: Elaborated by the author, 2021.

In 2021, the Matrix of Decommissioning Rules was published to compile all resolutions, laws, and ordinances involved in decommissioning activities, as well as defining the main points to be fulfilled by operators in each of them.

In summary, as illustrated in

Figure 10, IBAMA analyzes the decommissioning solution from an environmental point of view; ANP under the technical aspect of the proposed solutions (adaptation to the best industry practices) to guarantee operational safety and the best use of national oil and gas reserves; and Brazilian Navy observes whether issues affecting the safety of navigation and other uses of the sea are guaranteed (TRIBUNAL DE CONTAS DA UNIÃO, 2021).

Figure 10 – Competences of each Regulatory Body

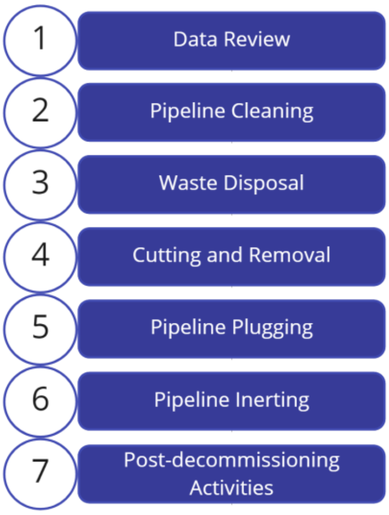


Source: Adapted from Tribunal de Contas da União (2021).

2.2.2 Decommissioning action plan

Philip et al. (2014) point out that a complete action plan, that meets the legal obligations, must include the items presented in Figure 11.

Figure 11 – Decommissioning Action Plan



Source: Elaborated by the author, 2020.

Each step of the action plan is discussed below:

1. **Data review:** the availability of sufficient and accurate data is critical to the development of a decommissioning program. Information as operating history, repairs and modifications reports, and inspections data will help to establish the pipeline cleaning requirements. This data review also is fundamental to determine the technical feasibility of the decommissioning options.
2. **Pipeline cleaning:** independent of the decommissioning option adopted, pipelines must be cleaned to the required level stated by the regulation. Usually, the first step is to make pipelines hydrocarbon-free by purging or flushing and then cleaning them internally using cleaning pigs.
3. **Waste disposal:** the environment must be protected from pipelines contents leakage. Fluids used for flushing, purging, and cleaning should always be treated as hazardous and must be safely disposed of. It also includes the precaution and measures taken regarding the NORMs.

4. **Cutting and removal:** cutting and removal of the pipeline or pipeline sections may be required depending on the decommissioning option selected. This step should be realized only after the pipeline is properly cleaned and safe.
5. **Pipeline plugging:** Plugging is required when cleaning is not feasible, constituting a seal that prevents the contact of hydrocarbons and residues with the marine environment.
6. **Pipeline inerting:** When it is planned to re-use a pipeline in the future, it is necessary to fulfill it with an inert fluid to avoid corrosion.
7. **Post-decommissioning activities:** The condition of the seabed after the decommissioning works should be defined in the action plan. Verifications are advised to guarantee that there are no obstructions. It is necessary to monitor the conditions and integrity of the pipelines and equipment remnants to assure it offers no hazard to third parties and the environment.

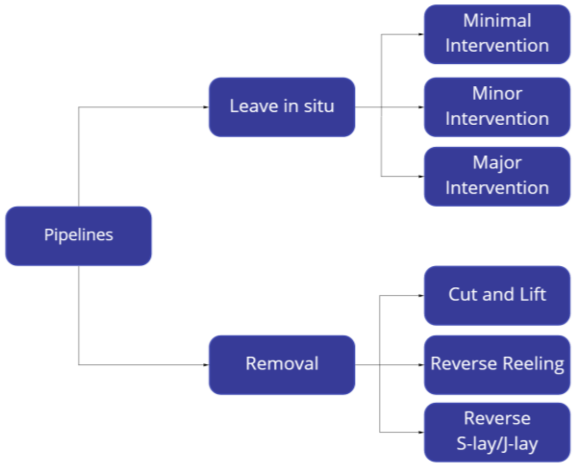
2.2.3 Decommissioning options

Barbosa (2013) affirms that the evaluation of the alternative to pipelines decommissioning should seek to minimize environmental impacts, risks to the health and safety of workers and communities, but also consider the feasibility of execution and costs.

It is important to note that the choice of the best option should be done case by case and it depends on the data provided about the pipelines and their current conditions such as size, weight, material, corrosion, and deterioration.

In terms of subsea pipelines, there are several options for decommissioning, however, these can be categorized into two large groups, leave *in situ* and removal, as proposed by Manouchehri (2017). Figure 12 illustrates this categorization.

Figure 12 – Pipelines Decommissioning Options



Source: Elaborated by the author, 2020.

The following paragraphs explain each decommissioning option based on the group it belongs to.

2.2.3.1 Leave in situ options

BEIS (2018) in their guidance notes states that may be candidates for in situ decommissioning the following pipelines:

- Those which are adequately buried and trenched, and which are not subject to development of spans and are expected to remain so.
- Those which were not buried or trenched at installation, but which are expected to self-bury over a sufficient length within a reasonable time and remain so buried.
- Those where burial or trenching of the exposed sections is undertaken to a sufficient depth and is expected to be permanent.
- Those which are not trenched or buried but which nevertheless are candidates for leaving in place if the comparative assessment shows that to be the preferred option.
- Those where exceptional and unforeseen circumstances due to structural damage or deterioration or other cause mean they cannot be recovered safely and efficiently.

Leave in situ options are classified by the level of intervention and are described below:

2.2.3.1.1 Leave in situ with minimal intervention

Suitable pipelines for this option are those that were trenched and buried at installation and remained buried over their lifetime and those that self-bury over time, generally large diameter pipelines. After cleaning, a pipeline is usually left filled with seawater to prevent corrosion and with the ends left open to the sea (OGUK, 2013).

2.2.3.1.2 Leave in situ with minor intervention

In some cases, minimal interventions could not be enough to assure that there are no potential hazards to the environment and other users of the sea, being necessary selected removal or remedial trench or burial of short sections of the pipeline (OGUK, 2013). Rock dumping could be used in the exposed section, delivering the required protection and stability to the line (MANOUCHEHRI, 2017).

Where a pipeline is trenched, the depth is determined aiming to remove any hazards to other users of the sea, considering factors such as seabed and soil conditions. A typical target depth suggested by the DECC is 0.6 meters to the top of the pipe (OGUK, 2013).

2.2.3.1.3 Leave in situ with major intervention

The interventions are similar to the option above, but they are applied for relatively long sections of the pipelines. Partial removal of some sections may be considered as an option in conjunction with leaving in situ. These sections may be removed by utilizing the cut and lift or reverse installation methods which would present similar risks in terms of safety and technical challenges (BRITISH PETROLEUM, 2011).

Monitoring devices may be demanded to check pipelines' conditions after interventions (MANOUCHEHRI, 2017).

2.2.3.2 Removal options

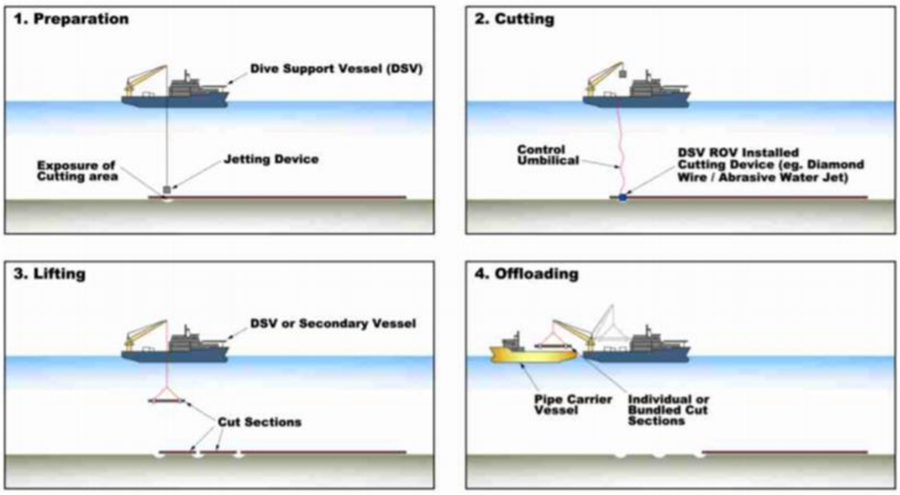
Small diameter pipelines, including flexible flowlines and umbilicals, which are installed on the seabed and not trenched or buried, are expected to be entirely removed (BEIS, 2018).

The most used methods are:

2.2.3.2.1 Removal by Cut and Lift method

This method does not require a dedicated lay vessel. The line is cut on the seabed into manageable sections, lifted to the surface, and transported to shore by a vessel, where it can be recycled, as shown in Figure 13. There are many cutting techniques available, such as abrasive water jetting, wire or rotating cutters, explosive, thermic lance, oxy-arc, or shear cutters. Several of these techniques (mostly the cold-cutting methods) have been developed for subsea remote operations (BRITISH PETROLEUM, 2011). It can be used for any diameter or length of the pipeline but is usually the preferred removal option for short sections of the pipe (OGUK, 2013).

Figure 13 – Cut and Lift Removal Method



Source: BP, 2020.

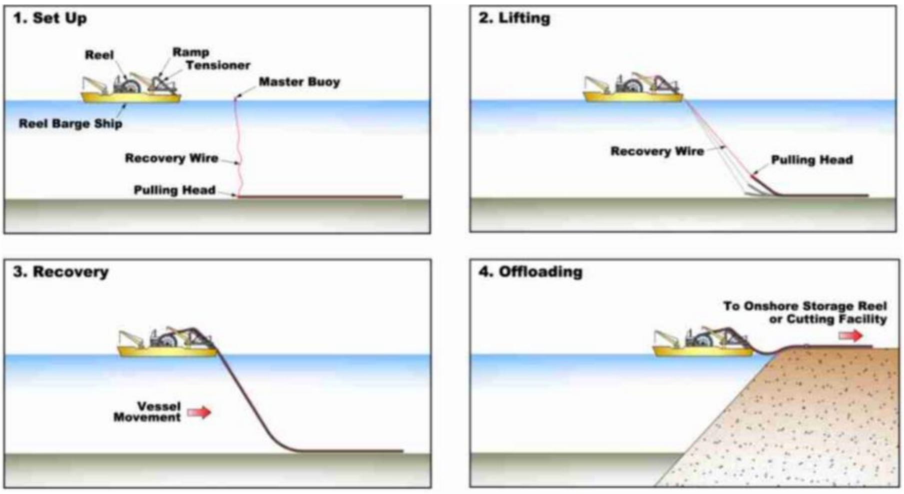
2.2.3.2.2 Removal by reversed reeling method

This is the simplest way to recover pipelines, and it is possible to be used for ducts with a diameter of 16 inches or less, which are not concrete coated.

It can be performed on rigid and flexible ducts. However, due to the nature of the rigid ducts, they are unlikely to be reused later once the multiple cycles of plastic deformation suffered by the duct wall will potentially compromise their integrity (OGUK, 2013).

One end of the pipeline is picked up by a vessel and, as it moves backward, the pipeline is progressively wound onto a very large reel on board. Once the pipeline is fully recovered onto the reel or the maximum reel capacity is reached, the vessel follows to shore where the pipeline can be recycled (BRITISH PETROLEUM, 2011). Figure 14 illustrates the Reverse Reeling Removal process.

Figure 14 – Reverse Reeling Removal



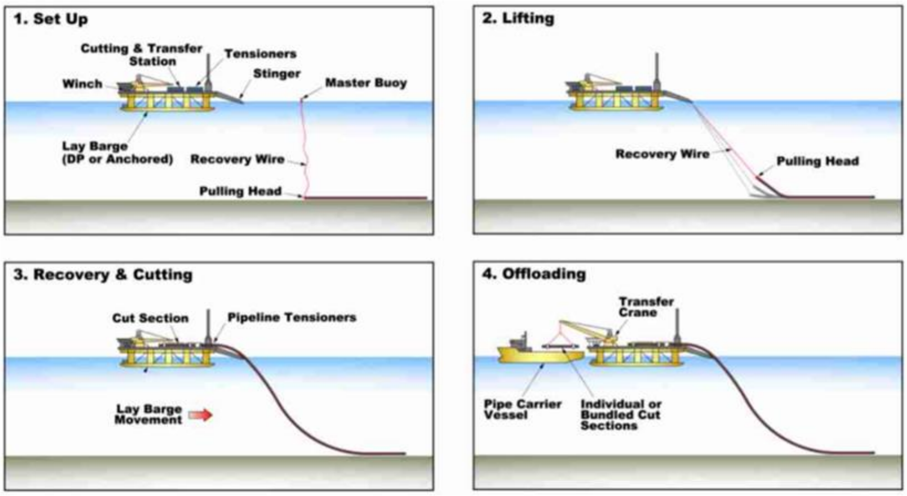
Source: British Petroleum, 2011.

2.2.3.2.3 Removal by reversed S-lay or J-lay method:

It is possible to apply the same concept of reverse reeling to vertical (J-Lay) and horizontal (S-Lay) pipeline laying. These methods are generally considered to larger diameters (over 16 inches) pipelines. For larger water depths, J-Lay is the most suitable, since it bears greater top traction.

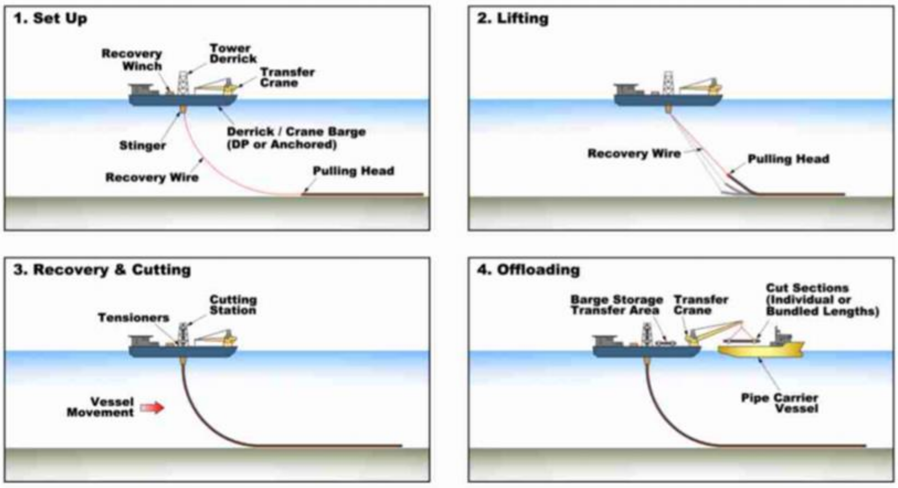
In these methods, one end of the pipeline is picked up by a specialist lay vessel and progressively pulled onboard over a ‘stinger’. In the vessel, pipelines are cut into sections and then transferred to a suitable transportation barge for onshore recycling (SHELL U.K. LIMITED, 2AD). Figure 15 and Figure 16 represent the removal procedures by the S-Lay and J-Lay methods, respectively.

Figure 15 – Reverse S-Lay Removal Method



Source: British Petroleum, 2011.

Figure 16 – Reverse J-Lay Removal Method



Source: British Petroleum, 2011.

2.3 DECISION-MAKING SUPPORT TOOLS

Choosing the most appropriate decommissioning option is a complex process that involves multidisciplinary areas and multiple stakeholders that frequently have conflicting interests. In this sense, decision-making support tools are methods used to assess the available options and find the best outcome (PALANDRO; AZIZ, 2018).

ANP (2020) states that, by standard, all subsea structures must be removed from the seabed. Leave in situ or partial removal are only allowed as an exception, provided that the applicable regulatory requirements are met and upon appropriated technical justification. In this sense, the tools should be used as a basis for decision-making, evidencing the existence of significant reasons for an option to be preferable to the others.

A wide variety of support tools allow the use of different approaches in decision-making. Generally, these tools, also called methods, consist of the following process, as stated by Fowler et al. (2014).

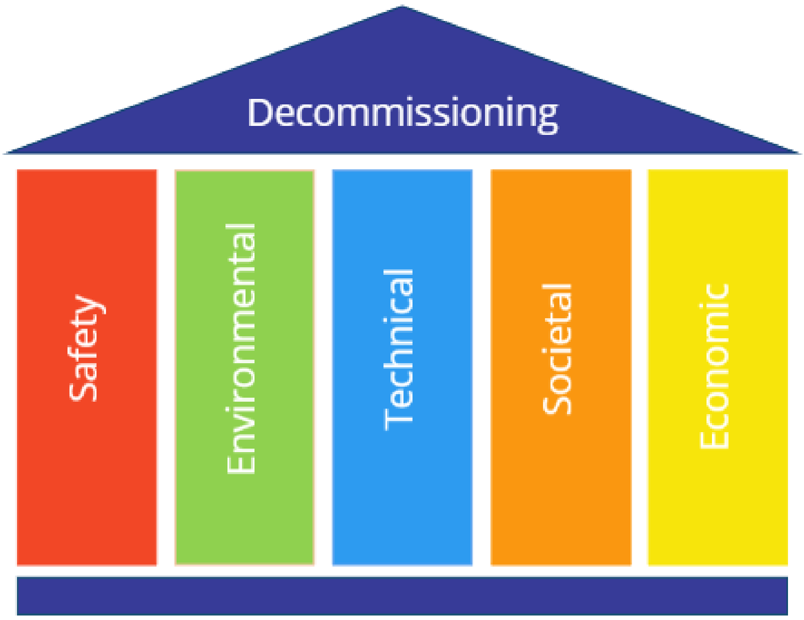
1. Definition of the objectives;
2. Criteria selection is made considering the objectives;
3. Identification of the alternatives;
4. Evaluation of each option for each criterion;
5. Criteria are weighted according to their importance;
6. Evaluations and criteria's weights are combined into an overall performance estimated for each alternative;
7. Alternative selection based on overall performance.

2.3.1 Analysis criteria

The choice of evaluation criteria is made seeking to reconcile the interests and objectives of stakeholders and to cover all the parameters that permeate decommissioning. They, together with decommissioning options and the regulatory framework, form the basis of the decision-making process.

BEIS (2018) states five main criteria that are globally used by the operators and academia, they are Safety, Environmental, Technical, Societal, and Economic. They are considered the pillars of decommissioning (Figure 17) and were reinforced by Resolution ANP nº 817/2020 that determines the alternatives must be evaluated in the light of these criteria and establishes the aspects that must be considered in each one of them.

Figure 17 – Five Decommissioning Pillars



Source: Elaborated by the author, 2020.

Based on these five criteria, each operator defines more precisely what is encompassed in which criterion through the definition of its sub-criteria. As there is no established standard, operators adopt different approaches to this definition, some more direct and technical, and others more comprehensive and subjective. Often operators use different names for the same sub-criteria or do not explicit the description of each sub-criterion, making it difficult to understand which parameters were analyzed (MICHALOWSKI; NETO; ANDRADE, 2020).

As claimed by Bittar and Modesto (2019), although there is no definition as to the weights established for each criterion, safety and environmental frequently receive higher weights. Economic is not a decisive criterion but should be balanced with the others. ANP (2020) highlights that no criterion, alone, should be considered decisive in the decision-making.

Each criterion is explained furtherly in the subsections below.

2.3.1.1 Safety

According to ANP (2020), it must be considered the risk assessment of alternatives to workers in the maritime and terrestrial environments, to other sea users and third parties.

Generally, the analysis of these risks is done considering the immediate operational risks arising from activities such as diving and lifting or exposure to harmful substances, and the long-term risks caused by exposed pipeline ends or steep-sided rock dump profiles, for example

(OGUK, 2013). The risks considered cover not only workers involved in decommissioning activities but all the parties that may be affected. Table 1 brings examples of sub-criteria often adopted in reports of Comparative Assessments and scientific papers.

Table 1 – Safety Sub-criteria

Criterion	Sub-criteria
Safety	Risk to Offshore Personnel
	Risk to Onshore Personnel
	Legacy Risks
	Risk to Other Users of the Sea
	High Consequence Events
	Risk to Onshore Public
	Exposure to Toxic Materials
	Exposure to NORM
	Work Under Hyperbaric Conditions
	Work at Height
	Confined Space
	Exposure to Drilling Mud
	Risk to Divers During Decommissioning Operations

Source: Elaborated by the author, 2020.

BEIS (2018) recommends that the general principles of risk management used within the industry should be applied to assess and compare the risks and when it is possible, to use quantitative techniques. Typical mechanisms include using Potential Loss of Life (PLL), Individual Risk Per Annum (IRPA), and Fatal Accident Rate (FAR) criteria.

It is noteworthy that alternatives that provide unacceptable safety risks should not even be considered in the process of comparing options and in the final decision, they should be discarded in the preliminary stages (BITTAR; MODESTO, 2019).

2.3.1.2 Environmental

ANP (2020) states that this criterion must consider the assessment of the risks and environmental impacts of alternatives in the marine and terrestrial environments.

BEIS (2018) suggests that this assessment should be carried out following the widely recognized techniques and standard methodologies for such evaluations.

Generally, it is considered in this criterion any operational impact and associated legacy impacts on the environment, both at the offshore location and at the onshore dismantling and disposal site. Energy and resources consumption, as well as discharges to the sea and atmosphere, should be also assessed (BITTAR; MODESTO, 2019).

The environmental criterion has the greatest diversity of sub-criteria. Often, risks are assessed not by their nature, but by their impact on marine organisms. This diversity can be observed in Table 2 which shows examples of sub-criteria frequently adopted in reports of Comparative Assessments and scientific papers.

Table 2 – Environmental Sub-criteria

Criterion	**Sub-criteria**
Environmental	Operational Marine Impacts
	Atmospheric Emissions
	Legacy Marine Impacts
	Discharges to Sea
	Waste Management
	Resource Consumption/ Recycle Value
	Disturbance to Seabed / Land
	Accidental Spills
	Noise Underwater and Onshore
	Impacts to Onshore Environment
	Risk of Invasive Species Dissemination
	Production of Exploitable Biomass
	Effect on Water Column
	Alteration of Trophic Webs

Criterion	Sub-criteria
	Alteration of Hydrodynamic Regimes
	Facilitation of Disease
	Proportion of Material Landfilled
	Protection from Trawling
	Conservation Sites
	Conservation Species
	Chemical Discharge
	Hydrocarbon Release from Pipelines
	Contamination
	Impacts of Endpoints
	Bentons of Consolidated Substrate
	Bentons of Unconsolidated Substrate
	Nectondemersal
	Necrotelagic
	Plankton
	Endangered Species
	Legally Protected Areas
	Sediment Quality and Physical Disturbance
	Marine Benthic Ecology
	Marine Fish Ecology
	Marine Birds
	Terrestrial Habitat Value
	Coastal Habitat Value
	Marine Fish Production

Source: Elaborated by the author, 2020.

2.3.1.3 Technical

ANP (2020) indicates that the evaluation of the technical feasibility of the alternatives should be carried out considering the characteristics of the facilities and the existing technologies.

Risk Assessment techniques, engineering, and operations analysis should be combined to provide comprehensive and robust information, whether qualitative or quantitative (BEIS, 2018).

Table 3 shows examples of sub-criteria frequently adopted in reports of Comparative Assessments and scientific papers.

Table 3 – Technical Sub-criteria

Criterion	**Sub-criteria**
Technical	Project Technical Risk
	Technical Complexity and Challenges
	Technical Feasibility
	Vulnerability to Weather Problems
	New equipment
	Vulnerability to Installation Condition Problems
	Equipment Reliability
	New Procedure
	Planning
	Ease of Recovery from Excursion
	Weight Management
	Logistics Requirements
	Structural Integrity
	Risk of Major Project Failure

Source: Elaborated by the author, 2020.

2.3.1.4 Societal

ANP (2020) determines that must be evaluated the impacts of alternatives to communities and other sea users and the perspective of variation in jobs.

BEIS (2018) highlights that the engagement of interested stakeholders is fundamental to assess and take account of the views of different interest groups.

Table 4 shows examples of sub-criteria often adopted in reports of Comparative Assessments and scientific papers.

Table 4 – Societal Sub-criteria

Criterion	Sub-criteria
Societal	Fishing Industry
	Other Groups
	Employment
	Stakeholder Reaction
	Tourism
	Impact on Communities
	Local Content
	Taxation Concessions
	Economic Stimulus
	Cultural Impingements
	Diving Opportunities
	Unobstructed Ocean View
	Public Sentiment
	Public Access
	Clear Seabed

Source: Elaborated by the author, 2020.

2.3.1.5 Economic

According to ANP (2020), this criterion should encompass an estimative of project costs for each alternative.

Must be considered not only the costs for the execution of decommissioning activities (cleaning, cutting, lifting, and waste disposal, for example) but also the costs such as insurance, inspection, monitoring, and remediation (PHILIP et al., 2014). Table 5 brings examples of sub-criteria frequently adopted in reports of Comparative Assessments and scientific papers.

BEIS (2018) highlights that it is unlikely that the economic criterion alone will be accepted as the deciding factor in arriving at the preferred option unless all other criteria show no significant difference.

Table 5 – Economic Sub-criteria

Criterion	**Sub-criteria**
Economic	Operational & Legacy Costs
	Uncertainties
	Comparative Cost
	Liability for Property Damage
	Liability for Personal Injury
	Replacement of Construction Materials
	Landfill
	Onshore Processing
	Personnel
	Mobilization of Support Vessels
	Residual Liability Including Monitoring and Remediation

Source: Elaborated by the author, 2020.

These criteria and sub-criteria are a fundamental part of the use of decision support tools.

2.3.2 Comparative assessment

Comparative Assessment (CA) is a planning tool largely used in various sectors and adapted to oil and gas decommissioning. It enables the decision-maker to analyze different options for each scenario, considering criteria and sub-criteria (BITTAR; MODESTO, 2019).

According to the authors, CA started to be used initially in the U.K., where it became a mandatory requirement and since then became the most used decision-making support tool by the operators. One of the reasons for its popularity is its simplicity and flexibility, especially when compared to other tools, in addition to the possibility of using quantitative and qualitative data.

As stated in the U.K. Guideline, to optimize the evaluation process, the CA should be carried out in two stages. The first one consists of a screening in which the operator analyzes all possible options against evaluation criteria and reduces them to a shortlist of feasible options. In the second stage, each of the options on this short-list should be subjected to a more detailed comparative assessment (BEIS, 2018).

Martins et al. (2020) summarized the three methods for evaluation described in the U.K. Guideline. The first is a qualitative method that includes a red-amber-green (RAG) chart to compare impacts, as shown in Figure 18. The second and the third are both qualitative and quantitative, but the last includes weighting factors to the criteria according to the stakeholders' perceptions.

Modesto and Bittar (2019) exposed a case study based on the “MacCulloch Decommissioning Programme: Comparative assessment Report for Subsea Infrastructure” from Conoco Phillips (U.K) Limited, to determine the best pipeline decommissioning alternative, concluding that complete removal is the most appropriated and the cheapest choice.

CA is the most present tool in the operators' reports (MARTINS et al., 2020). The most remarkable application is the Brent Field Decommissioning: Comparative Assessment Procedure, from Shell, which is the most extensive study and is widely used as a benchmark in the decommissioning process (MICHALOWSKI; NETO; ANDRADE, 2020).

Other examples are Hunter & Rida Comparative Assessment ((PREMIER OIL UK LIMITED, 2020); Anglia Comparative Assessment (ITHACA ENERGY UK LIMITED, 2020); Comparative Assessment Report for the Viking VDP2, and VDP3 Pipelines and Associated Mattresses (CONOCOPHILLIPS, 2018); and Ann & Alison Decommissioning Comparative Assessment (CENTRICA ENERGY, 2016).

Figure 18 – RAG Chart

		DECOMMISSIONING OPTIONS			
ASSESSMENT CRITERIA	**Matters to be considered**	Complete removal to land	Partial removal to land	Leave wholly in place	Disposal at sea *
Safety	risk to personnel				
	risk to other users of the sea				
	risk to those on land				
Environmental	marine impacts				
	other environmental compartments (including emissions to the atmosphere)				
	energy/resource consumption				
	other environmental consequences (including cumulative effects)				
Technical	risk of major project failure				
Societal	fisheries impacts				
	amenities				
	communities				
Economic					
	HIGH	MEDIUM		LOW	

Source: BEIS, 2018.

2.3.3 Analytic hierarchy process (AHP)

According to Borges (2018), AHP is not just a decision-making support tool, but also is a math model with well-defined steps that can be easily applied. It allows to carry out simulations and analyses of uncertainties, verifying the robustness of the decision and making it possible to improve the decision-making process.

The AHP aims to quantify relative priorities for a given set of alternatives on a ratio scale (MILLET; HARKER, 1990). To construct a hierarchy, the criteria are pairwise compared considering their importance to the goal and the alternatives are also pairwise compared by the light of each criterion. These comparisons generate scales of the relative importance that are synthesized using weights and adding processes, to determine the best alternative (SAATY, 2002).

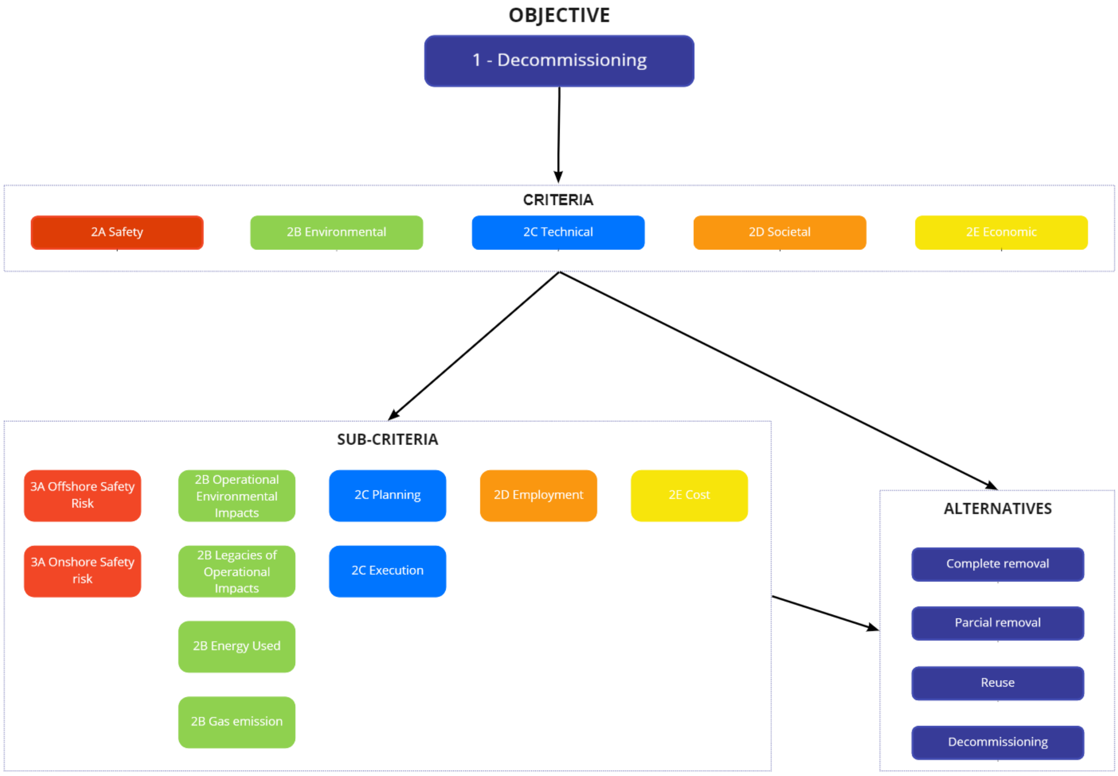
In agreement with Borges (2018), the main differential of AHP is the possibility of converting empirical data into a mathematical model, allowing them to be processed and compared.

Saaty (2005) and Saaty (2008) structure the method as follows:

1. **Hierarchy:** structure the decision hierarchy from the top with the goal of the decision, followed by criteria and sub-criteria, and then a set of the alternatives.
2. **Comparison:** construct a set of pairwise comparison matrices. The comparison between two elements (whether they are criteria or alternatives) can be done using the Saaty Scale assigning values between 1 and 9 to determine the relative importance of one concerning the other. Each element in an upper level is used to compare the elements in the level immediately below concerning it.
3. **Adding Process:** the components of the normalized eigenvector of the matrix correspond to the relative importance of each element. These priorities are now used as weighting factors for the eigenvectors generated at the next lower level in the hierarchy until all levels are completed.
4. **Consistency Test and Sensitivity Analysis**: eigenvalue is used to check the consistency of assessments provided to each other. A sensitivity analysis can be done to examine how robust the choice of an alternative is about changes in the way the analysis was carried out (BORGES, 2018).

Borges (2018) used AHP to glimpse the choice of alternatives for subsea structures decommissioning to an ultra-deep waters field in Rio de Janeiro. The 5 criteria established by the DECC were adopted and subdivided into sub-criteria. The alternatives were defined individually for each equipment to be decommissioned and the evaluations were made by experts. An example of the hierarchical structure formed by the criteria, sub-criteria, and alternatives can be seen in Figure 19.

Figure 19 – Hierarchical Structure



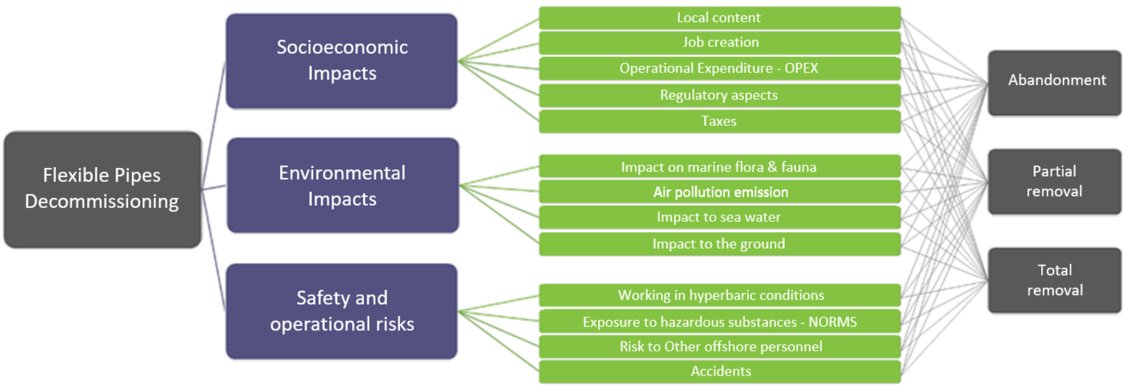
Source: Adapted from Borges, 2018.

The author concluded that for the service lines, production lines, umbilicals, and jumpers the most recommended alternative was the Abandonment and the least, Complete Removal using a guillotine. It was also found that, when varying the weights assigned to each criterion, there was no change in the recommended alternative.

Barreto (2019) used AHP to assess the alternatives to flexible subsea pipelines decommissioning and develop a model using this tool that can be applied in the future to other subsea structures. In his study, he adopted three groups of decommissioning possibilities: Total Removal, Partial Removal, and Abandonment (leave in situ). The evaluation criteria were also grouped into three groups: Environmental Impacts, Socioeconomic Impacts, and Safety and Operational Risks. Each criterion was broken down into sub-criteria.

Figure 20 synthesizes the relations between criteria, sub-criteria, and decommissioning alternatives.

Figure 20 – Criteria Tree with Alternatives



Source: Adapted from Barreto, 2019.

The matrices with the experts' evaluations were normalized and the eigenvectors were calculated, indicating the relevance of each criterion within each matrix and, finally, consistency analysis was carried out using the eigenvalues.

At the end of the study, it was observed that Environmental Impacts and Socioeconomic Impacts had a greater weight in the choice of the most impacting alternative, each obtained almost 43% of the total in relevance. The alternative with the worst negative impact in the flexible pipelines decommissioning was the total removal. Partial removal and abandonment were the preferable alternatives, with very similar results.

Marfatia (2019) compared AHP with TOPSIS and Pairwise Functions to determine the ideal method, once this is critical in the decision-making process. The analysis showed that AHP is the best suited, due to its hierarchical structure that prevents weighting inter-dependencies when options and criteria were deleted or edited.

2.3.4 Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)

PROMETHEE is a ramification from another method, ELECTRE, and belongs to the class of outranking methods. It has a more advanced mathematical modeling; however, it increases the necessity of accurate information. Such as AHP, PROMETHEE also is based on the pairwise comparison. In this method, the decision-maker must attribute weights and a preference function to each criterion.

Souza (2018) realized a case study using the data provided by Shell regarding the decommissioning of the Brent field and implemented the PROMETHEE method. Subsequently, he compared the results of his study with the results obtained by Shell. It was concluded that the worst global alternative is the same in both cases, but the other alternatives diverged.

He compared the different preference functions used in the PROMETHEE: linear, usual, u-shape, and level. It was noted that linear and usual functions generated more homogeneous results, with a smaller difference between the alternatives. Otherwise, u-shape and level resulted in a greater discrepancy between the alternatives and pointed out that the best alternative was the one with the greatest technical feasibility.

Borges (2018) also applied this method along with AHP in her study and concluded that the best and the worst alternatives to the pipelines decommissioning were the same in both methods. The other alternatives had no significant variation between the methods. This comparison was made using the linear function as the preference function in PROMETHEE.

In addition to the methods discussed in this work, other tools are used, especially in academic papers, for decision making regarding pipelines and/or platforms, among them are ELECTRE, NEBA, BPEO, MAUT and TOPSIS (MICHALOWSKI; NETO; ANDRADE, 2020).

3 CASE STUDY BETWEEN BRAZIL AND UNITED KINGDOM

To choose the decommissioning projects to be considered as objects of analysis in this section, the PDIs available on the ANP website and the Reports available on the UK government website were considered.

First, those that addressed the decommissioning of their submarine pipelines and those that did not present sufficient information about the Comparative Assessment processes were eliminated. Subsequently, those who presented more detailed information and the same operator were prioritized, resulting in the choice of the following decommissioning projects: Bijupirá/Salema (Brazil) and Brent (UK). Brent Comparative Assessment is already consolidated as an international benchmark and Bijupirá/Salema PDI presents more than 900 pages, between the document and its annexes, providing a more complete and detailed discussion. In both fields, Shell is one of the operators and responsible for carrying out the Comparative Assessment, allowing to evaluate the conduct of the same company under different regulations and guidelines.

Through the Bijupirá and Salema fields, Shell became the first international company to produce oil commercially in Brazil, after opening the national market. These two fields are often treated as one since they have the same production unit, the FPSO Fluminense, and interconnected subsea systems.

The Brent field was considered one of the largest fields in the North Sea and was responsible for generating thousands of jobs, contributing billions in tax revenue, and providing the UK with a substantial amount of its oil and gas. The field was served by four large platforms – Alpha, Bravo, Charlie, and Delta.

Table 6 summarizes the main information about the fields covered in this study.

Table 6 – Fields' Characteristics

	Brent	**Bijupirá/Salema**
Type of Installation	Steel Jacket, Concrete Gravity and SPAR	FPSO
Location	East Shetland Basin, North Sea	Campos Basin, Brazil
Start of Operation	1976	2003
Average Water Depth (m)	140	700/550*

	Brent	Bijupirá/Salema
Distance from Shore (km)	186	250
Pipelines' length (km)	103	66

* These numbers represent the average water depth for Bijupirá and Salema respectively.

Source: Elaborated by the author, 2022.

The differences between the Brazilian and British fields, in aspects such as water depth, distance from shore, start of operation, must be kept in mind during the comparison. In general, as mentioned by M'Pusa (2017), the panorama of decommissioning in Brazil and the United Kingdom differs in some aspects, such as the maturity of the service and supply chain, diversity of operators and average water depth of the basins. All these factors affect, albeit indirectly, the outcome of the decision-making regarding decommissioning.

It is noteworthy that all the information presented in the following sections has been taken from Comparative Assessment reports and their complementary documents made available for public access.

This work is not intended to determine the best methodology, but rather to identify similarities and differences between these, pointing out aspects that must be studied more deeply to optimize decision making.

3.1 COMPARATIVE ASSESSMENT METHODOLOGY

3.1.1 Bijupirá/Salema

According to the PDI of Bijupirá and Salema fields (SHELL BRASIL PETRÓLEO LTDA., 2020), the Comparative Assessment followed the methodology developed by a Joint Industry Project (JIP), coordinated by DNV-GL, presented in the document "Guidelines for Risk-Based Comparative Assessment of Options for Decommissioning of Subsea Installations in Brazil".

The Comparative Assessment consisted primarily of two workshops. The first one aimed to define the assumptions for the evaluation itself and found in the revision and confirmation of the categories and groups of submarine equipment; verification of the decommissioning alternatives to be evaluated; definition of borders between categories; and definition of evaluation factors to be applied to each sub-criterion.

The second workshop consisted of evaluation sessions of alternatives according to each of the criteria and for each field. The sessions had qualified professionals in each of the topics covered so that they could effectively contribute to discussions.

The guidelines established by the JIP propose two main methods to develop a comparative evaluation: qualitative and quantitative. For the BJSA subsea system, the qualitative method was selected, which implies the ranking of component elements of the sub-criteria based on their risks and impacts. The qualitative analysis was substantiated by quantitative data and additional studies, such as the definition of greenhouse gas emissions, amount of waste generated, dispersion studies of solid particles, and marine environmental impact study.

3.1.2 Brent

In accordance with Brent Field Pipelines Decommissioning Technical Document (SHELL U.K. LIMITED, 2AD), the Comparative Assessment for Brent pipelines was performed following the DECC Guidance Notes and the Shell BDP Comparative Assessment Procedure (SHELL U.K. LIMITED, 2017), with appropriate modification for the pipelines and the options under consideration.

Based on DECC Guidance Notes (BEIS, 2018) that states the types of pipelines that would normally be expected to be removed, and therefore would require a less complex comparative assessment, Shell used a decision tree to determine the pipelines that would be submitted to a complete and complex comparative assessment and those that wouldn’t.

Twenty-eight Brent pipelines were reviewed and as a result, for fourteen of them, the recommended options were clearly indicated by the DECC Guidance Notes. For the remaining fourteen pipelines, this initial screening using the decision tree indicated that a full comparative assessment would be required since the technically feasible options were often numerous, varied, and complex or the clear recommended option was not immediately apparent. These pipelines were submitted to a quantitative Comparative Assessment substantiated by numerical data and scores resulted from experts’ judgments.

3.2 DECOMMISSIONING ALTERNATIVES

3.2.1 Bijupirá/Salema

According to the final comparative evaluation report for the BJSA, after extensive discussions during the first workshop, the pipelines and subsea facilities were categorized into 10 groups: 4 for each field (Bijupirá and Salema) and 2 common to both fields (Gas Export Pipeline and Mooring Lines), they are:

- Group 1 – Risers, Flowlines and Umbilicals
- Group 2 – Jumpers and Flying Leads
- Group 3 – Manifolds of production, injection of water and gas lift and PLETs
- Group 4 – Subsea Christmas Trees (including Tubing Head Spools - THSs)
- Group 5 – Gas Export Pipeline
- Group 6 – Mooring Lines

After grouping the pipelines, the decommissioning options applicable to each of the groups were defined in a workshop. These options are summarized in Table 7. Groups 3, 4, and 6 were not included in the table since they are formed by components of the subsea system other than pipelines.

Table 7 – Groups and their Respective Options

Group	Options
Group 1 – Risers, Flowlines and Umbilicals (including pipelines already disconnected)	**Option 1** – Complete Removal: Laydown of the FPSO lines and removal after departure from the FPSO (base case). **Option 2** – Partial removal: remove the risers and the dynamic part of the Umbilical (with the FPSO on location) and permanently abandon the remainder, including legacy risers and flowlines. **Option 3** – Partial removal of unburied lines without the presence of corals: laying the FPSO lines and removing parts of the riser, flowline, and umbilicals without the presence of corals and not buried. Leave the rest permanently in place. **Option 4** – Laydown and leave permanently.
Group 2 – Jumpers and Flying Leads	**Option 1** – Complete removal (base case). **Option 2** – Partial Removal: unburied lines and no coral - assume 50% removal. **Option 3** – Permanent dropout (jumpers and flying leads remain connected).
Group 5 – Gas Export Pipeline (21km stretch)	**Option 1** – Complete removal by reverse reel. **Option 2** – Complete removal by lifting and cutting on deck. **Option 3** – Partial Removal - 50% removed. Subsea cutting and deck elevation (40-meter section).

Group	Options
	Option 4 – Partial Removal **-** 50% removed. Underwater cutting and deck elevation, considering the presence of corals. **Option 5** – Permanent abandonment.

Source: Adapted from Shell Brasil, 2020.

The groups were evaluated separately for the Bijupirá and Salema fields, except for Group 5 (Gas Export Pipeline) and Group 6 (Mooring Lines), which cover both fields.

3.2.2 Brent

As for the Brent field, the pipelines were divided into two large groups: Qualitative Lines, which had relatively simple and more obvious decommissioning options, and Quantitative Lines, which required more detailed examination and additional data to determine the recommended option.

The pipelines which were categorized as Qualitative Lines have fewer feasible decommissioning options than the quantitative pipelines. These options can be essentially summarized into two results: One is to leave the pipeline in situ within the existing trench or under the existing rock dump and carry out additional remediation at the exposed end(s) – such as rock dump – to mitigate potential snagging risks. The other is to remove the line completely, either by a reverse of the installation procedure or some other method of recovery.

For Quantitative Lines were identified a total of nine feasible options were, seven of which applied to most of the pipelines. These options are compiled in Table 8, as well as their applications.

Table 8 – Options Applicable to Quantitative Lines

Option	Application	Description
Option 1: Leave in Situ with no Further Remediation Required	Only applicable to those pipelines which are tied in at both ends to Brent platforms.	It is estimated that the Brent Alpha jacket footings might exist for up to 500 years and the GBS caisson might last perhaps 1,000 years therefore the pipeline tie-ins to these platforms would also exist for as long as the pipeline remains intact
Option 2: Leave Tied-in at Platforms; Remote End Trenched and Back-filled	Only applicable to those pipelines which are tied in at one end to a subsea structure that must be removed by OSPAR Decision 98/3.	In this option, the tie-in spool to any subsea structure would be removed by cut and lift for recycling or disposal onshore and the cut end would be trenched and backfilled. The other pipeline end would remain tied into the

Option	Application	Description
		platform which would reduce the snagging hazards presented by the pipeline ends while the tie-in spools remain intact.
Option 3: Leave Disconnected on the Seabed and Rock dump Pipeline Ends	Only applicable to those pipelines which are tied in at one end to a subsea structure that must be removed by OSPAR Decision 98/3.	As with Option 2, the tie-in spool pieces connecting the pipeline to a subsea structure would be removed for onshore recycling or disposal. At the remote end of the pipeline, 30m of rock-dump (rather than trenching and backfill) would be used to reduce the snagging risk for fishing gear
Option 4: Disconnect from Platforms/Subsea Infrastructure and Trench and Backfill Whole Length of Pipeline		The pipelines would be disconnected from the platform or subsea structures at each end and the tie-in spools removed by cut and lift for onshore recycling or disposal. The main section of the pipeline would be trenched and backfilled over the whole length, except the trench transitions into and out of the seabed.
Option 5: Disconnect from Platforms/Infrastructure and Rock dump Whole Length of Pipeline		The pipelines would be disconnected from the platform or subsea structures at each end and the tie-in spools removed by cut and lift for onshore recycling or disposal. The main section of the pipeline would be left on the seabed and then covered by a profiled rock berm along its entire length.
Option 6: Remove Whole Length of Pipeline by Cut and Lift		The pipeline would be cut into short sections and the sections lifted to a vessel for transportation to shore for recycling or disposal as appropriate.
Option 7: Remove Whole Length of Pipeline by Reverse S-lay (Single Joint)		The tie-in spools would be recovered by cut and lift. The entire pipeline would be removed using reverse single joint S-lay (i.e. reverse installation) using a pipe-lay vessel. In this procedure, the pipeline would be pulled onto the vessel and cut into single joints of pipe (i.e. sections 12m long) which would be stored on board for transportation to shore for recycling or disposal.
Option 8: Partial Trench and Backfill of Pipeline with Isolated Rock dump	It’s specific to pipeline PL001/N0501, which is the 35.9 km long, 30-inch oil export line from the Brent Charlie platform to the Cormorant Alpha platform.	The tie-in spools would be recovered in this option by cut and lift. All lengths of the pipeline which are not trenched to >0.6m to top require remediation.
Option 9: Partial Rock dump of Pipeline	It’s specific to pipeline PL001/N0501, which is the 35.9 km long, 30 inch oil export line from the Brent Charlie platform to the Cormorant Alpha platform.	The tie-in spools would be recovered by cut and lift. All sections of the pipeline where the top is trenched to <0.6 m would be covered with profiled rock-dump, covering the top of the pipe to a depth of 0.5 m. Unlike Option 8, this form of remediation could be used on every section of the pipeline regardless of its length and it would not have to be applied to those sections which are already well trenched.

Source: Elaborated by the author, 2022.

After defining the alternatives, they had their feasibility evaluated for each pipeline, the result is shown in Figure 21. The DECC Guidance Notes state that all feasible decommissioning options should be considered and covered by a comparative assessment.

Figure 21 – Summary of Feasible Decommissioning Options for each Brent Quantitative Line.

Pipeline	Option								
	1	2	3	4	5	6	7	8	9
PL001/N0501	✓					✓	✓	✓	✓
PL002/N0201		✓	✓	✓	✓	✓	✓		
PL017/N0601		✓	✓		✓	✓			
PL044/N0405	✓			✓	✓	✓	✓		
PL045/N0303	✓			✓	✓	✓	✓		
PL046/N0304	✓			✓	✓	✓	✓		
PL047/N0404	✓			✓	✓	✓	✓		
PL048/N0302		✓	✓	✓	✓	✓	✓		
PL049/N0301		✓	✓	✓	✓	✓	✓		
PL050/N0401	✓			✓	✓	✓	✓		
PL051/N0402	✓			✓	✓	✓	✓		
PL052/N0403	✓			✓	✓	✓	✓		
N9903A				✓	✓	✓			
N9903B				✓	✓	✓			

Option 1: Leave in situ with no further remediation required	Option 6: Remove whole length by cut and lift*
Option 2: Leave tied-in at platforms; remote end trenched	Option 7: Remove whole length by reverse S-lay (single joint)
Option 3: Leave tied-in at platforms; remote end rock-dumped	Option 8: Partial trench and backfill with isolated rock-dump
Option 4: Disconnect from platforms/subsea infrastructure and trench and backfill whole length of pipeline	Option 9: Partial rock-dump of pipeline
Option 5: Disconnect from platforms/infrastructure and rock-dump whole length of pipeline	* For PL050/N0401 and PL051/N0402 which are Brent Flare pipelines with one end already rock-dumped, this option would require small amounts of rock to be added to existing rock dump at remote end. For PL002/N0201 and PI052/N0403 new rock would also be required in the vicinity of the existing rock-dump.

Source: Shell UK Limited, 2017.

3.3 CRITERIA AND SUBCRITERIA

Both DECC, from the UK, and ANP, from Brazil, establish the same five criteria, largely diffused in the decommissioning industry, and already addressed in subsection 2.3.1. Hence, Brent and Bijupirá/Salema adopted the same criteria, and based on these they defined their sub-criteria, which will be analyzed and compared in the following sections.

- **Safety**

Table 9 – Safety Sub-criteria for each Field

Bijupirá/Salema	Brent
Risk to offshore personnel	Safety risk to offshore project personnel
Risk to other sea users	Safety risk to other users of the sea
Risk to onshore personnel	Safety risk to onshore project personnel
Risk to the onshore public	-

- **Environmental**

Table 10 – Environmental Sub-criteria for each Field

Bijupirá/Salema	Brent
Impacts on the marine environment	Operational environmental impacts
Impacts on the terrestrial environment	Legacy environmental impacts
Risk of dissemination of invasive species	Energy use
Waste generation	Gaseous emissions
Risk of spills for the marine environment	-
Legacy risk left in situ for the marine environment	-

- **Technical Feasibility**

Table 11 – Technical Feasibility Sub-criteria for each Field

Bijupirá/Salema	Brent
Impacts on the technical feasibility of the project	Technical feasibility

- **Societal**

Table 12 – Societal Sub-criteria for each Field

Bijupirá/Salema	Brent
Social onshore impacts	Effects on commercial fisheries

Bijupirá/Salema	Brent
Impacts on fishing	Employment
Impacts on jobs	Impact on communities

- **Economic**

Table 13 – Economic Sub-criteria for each Field

Bijupirá/Salema	Brent
Project Costs	Costs

3.4 ALTERNATIVES EVALUATION

3.4.1 Bijupirá/Salema

In BJSA the sub-criteria were assessed using Evaluation Factors, which are specific conditions expected for each sub-criterion and provide an individual analysis, increasing traceability and viewing of results. Therefore, the performance of the factors is evaluated instead of the performance of the sub-criterion. The performance of each evaluation factor is evaluated with the color code shown in Figure 22.

Figure 22 – Color Code proposed in DNV GL Guidelines for Qualitative Comparative Assessment

Performance	Risk/Corporate impact	Score
Most favorite	Risk/Lowest impact	2
Intermediate	Risk/Moderate impact	1
Less favorite	Risk/Highest impact	0

Source: Adapted from Shell Brasil, 2020.

The report reinforces that in a comparative assessment the relative risks are evaluated and not absolute risks, in this way, relative values should be allocated to differentiate alternatives. For example, a score of "0" does not mean that the option has an unacceptable risk, only that about the other alternatives, it has a larger associated risk. Likewise, a score of "2" does not imply the absence of risks, only that these are relatively smaller.

For the analysis, a list (Figure 23) was defined with all evaluation factors for their respective sub-criteria, as well as the conditions that must be met to base their performance measure (color classification).

Figure 23– Evaluation factors for the sub-criterion "Risk to Offshore Personnel".

1. SAFETY CRITERION			
1.1 RISK TO OFFSHORE PERSONNEL	**Most favorite (Best performance)**	**Moderate**	**Less favorite (Lowest performance)**
1.1.1 Number of heavy lifting operations required	Minimal number of heavy lifting operations required	Moderate number of heavy lifting operations required	Many heavy lifting operations required
1.1.2 Number of material handling operations on deck or on barge during removal	None or minimum material handling on deck or on barge during removal	Some material handling operations on deck or on barge during removal	Multiple material handling operations on deck or on barge during removal
1.1.3 Number of human diving activities required	None or minimal human diving activities required	Increase in human diving activities required for short intervals and for less than 25% of the duration of decommissioning activities	Human diving activities required for the most part of the duration of decommissioning activities
1.1.4 Duration of decommissioning activities	Short duration of decommissioning activities (Less than a month)	Intermediate duration of decommissioning activities (Between a month and a year)	Long duration of decommissioning activities (More than a year)
1.1.5 Number of simultaneous operations (SIMOP) with two or more ships	Low number of vessel's simultaneous operations	Moderate number of vessel's simultaneous operations	Large number of vessel's simultaneous operations
1.1.6 Number of helicopter crew changes	None helicopter crew changes planned	Helicopter crew changes are anticipated, but not in large numbers	A significant number of helicopter crews changes during most decommissioning activities
1.1.7 Number of cargo movement over pipelines/wells in operation	None cargo movement over pipelines/wells in operation	Some cargo movement over pipelines/wells in operation	Many cargo movements over pipelines/wells in operation

Source: Adapted from Shell Brasil, 2020.

After classification of the performance colors of each Evaluation Factor, the average score is calculated for each sub-criterion. The score of each criterion, for each decommissioning option, can be given by the sum or the average of the scores of each sub-criterion.

3.4.2 Brent

Brent Comparative Assessment uses global scales as a way of providing a unitless scale to compare different sub-criteria and a way to compare the performance of the options across all the Brent facilities. This requires the production of quantitative data and qualitative information on the performance of each option in each sub-criterion.

These data were obtained from independent reports, internal technical studies, or external or internal subject matter experts. For eight sub-criteria, the studies provided quantitative data such as estimates of the risk of Potential Loss of Life (PLL), energy use (gigajoules, GJ), and cost (£). For the remaining four sub-criteria the studies required the use of expert judgments on the performance of the options and therefore had no fixed numerical scale against which to score the option. The source of information, the type of data, and the measure units (when applicable) for the twelve sub-criteria are compiled in Figure 24.

Figure 24 – Sub criteria Information

Sub-criterion	Source of Information	Type of Data	Unit
Safety risk to offshore project personnel	Internal study by Shell	Numerical	PLL
Safety risk to other users of the sea	Studies by Anatec	Numerical	PLL
Safety risk to onshore project personnel	Internal study by Shell	Numerical	PLL
Operational environmental impacts	Score provided by DNV GL	Score	
Legacy environmental impacts	Score provided by DNV GL	Score	
Energy use	Environmental Statement	Numerical	Gigajoules
Emissions	Environmental Statement	Numerical	Tonnes
Technical feasibility	Score provided by Shell	Narrative and score	
Effects on commercial fisheries	Study by Mackay Consultants	Numerical	GBP
Employment	Study by Mackay Consultants	Numerical	Man-years
Impact on communities	Score provided by DNV GL	Score	
Cost	Internal study by Shell	Numerical	GBP

For each sub-criterion, the raw data values from every option and every facility were then placed on a ‘data scale’. Considering each sub-criterion in turn, the ‘best’ and ‘worst’ data were then used to fix the top and bottom of the scale. These raw data scales were then transformed into ‘global scales’, each spanning the range 0 to 1. The best or most desirable option on the raw data scale was accorded a score of ‘1’ and the least desirable a score of ‘0’.

Taking the example of safety sub-criteria, the option with the highest PLL is the least desirable and therefore marks the bottom of the global scale and is accorded a score of ‘0’, and the option with the lowest PLL is the most desirable and is therefore accorded a score of ‘1’.

3.5 WEIGHTING METHODS

3.5.1 Bijupirá/Salema

For the Comparative Assessment of the Bijupirá /Salema fields, two different weighting methods were used. The weights assigned to each criterion by both methods are synthesized in Figure 25.

Weighting Method 1 – Equal weights for each sub-criterion. By this method, the score of each criterion is obtained by the sum of the scores of each sub-criterion. The criteria that have a larger number of sub-criteria will have a greater weight in the final evaluation. In this comparative evaluation, there are a total of 16 sub-criteria, with 7 of these associated with the environmental criteria. Consequently, the environmental criterion has 44% of the weight in the final ranking.

Weighting Method 2 – Equal weights for each criterion. By this second method, the score of each criterion is obtained by the average of the scores of each sub-criterion. In this way, each criterion has the same weight, regardless of the number of associated sub-criteria.

Figure 25 – Weight of each criterion according to the weighting method.

Criterion	Number of Sub-criteria for each Criterion	Weighting Method 1 (Sum)	Weighting Method 2 (Average)
Safety	4	25%	20%
Environmental	7	44%	20%
Societal	3	19%	20%
Technical	1	6%	20%
Economic	1	6%	20%

Source: Adapted from Shell Brasil, 2020.

For the three groups under analysis in this work, the best option for each group was the same for the two methods.

In addition to obtaining the results through the two weighting methods, a sensitivity test was performed by removing the economic criterion, with the subsequent recalculation of the scores. However, there was no change in the recommended option for each group.

3.5.2 Brent

The decommissioning alternatives were evaluated in 6 different scenarios. Scenario 1 weighted each criterion equally as well as its sub-criteria. The weighted score for any sub-criterion was calculated by multiplying the score from the global scale by the standard weight for that sub-criterion. The total weighted score for any option was then obtained by summing the weighted scores of all the sub-criteria.

To examine the sensitivity of the CA-recommended option, therefore, were applied five 'selected weighting scenarios' to the transformed scores, to generate new total weighted scores for each option. Thus, scenarios 2, 3, 4, and 5 assign 40% of the weight to Safety, Environmental, Technical Feasibility, and Societal criteria, respectively. On the other hand, scenario 6 eliminates the Economic criterion. Figure 26 presents the weighting attributed to each criterion and its sub-criteria for the different scenarios.

Figure 26 – Weighting Applied to Sub-criteria in Pre-determined Weighting Scenarios.

Sub-criteria	Weighting Scenario					
	1	2	3	4	5	6
Safety risk to offshore project personnel	6.7%	13.3%	5.0%	5.0%	5.0%	6.7%
Safety risk to fishermen (refer to Note 1)	6.7%	13.3%	5.0%	5.0%	5.0%	6.7%
Safety risk to onshore project personnel	6.7%	13.3%	5.0%	5.0%	5.0%	6.7%
Operational environmental impacts	5.0%	3.8%	10.0%	3.8%	3.8%	5.0%
Legacy environmental impacts	5.0%	3.8%	10.0%	3.8%	3.8%	5.0%
Energy use (GJ)	5.0%	3.8%	10.0%	3.8%	3.8%	5.0%
Gaseous emissions (CO_2)	5.0%	3.8%	10.0%	3.8%	3.8%	5.0%
Technical feasibility	20%	15.0%	15.0%	40.0%	15.0%	20.0%
Effects on commercial fisheries (refer to Note 1)	6.7%	5.0%	5.0%	5.0%	13.3%	6.7%
Employment	6.7%	5.0%	5.0%	5.0%	13.3%	6.7%
Communities	6.7%	5.0%	5.0%	5.0%	13.3%	6.7%
Cost	20%	15.0%	15.0%	15.0%	15.0%	20.0%(2)

Source: Shell UK Limited, 2017.

Note that in scenario 6, to preserve the spread of the weightings across the other sub-criteria the sub-criterion 'cost' retains a weighting of 20% but all the options are accorded a cost of 'nil', that is, the cost does not contribute to the overall weighted score of an option.

Were used assessments, sensitivity analyses, and wider business and corporate considerations, to compare the performances of the options for each of the Brent pipelines being assessed by quantitative CAs, to identify the 'Recommended option'.

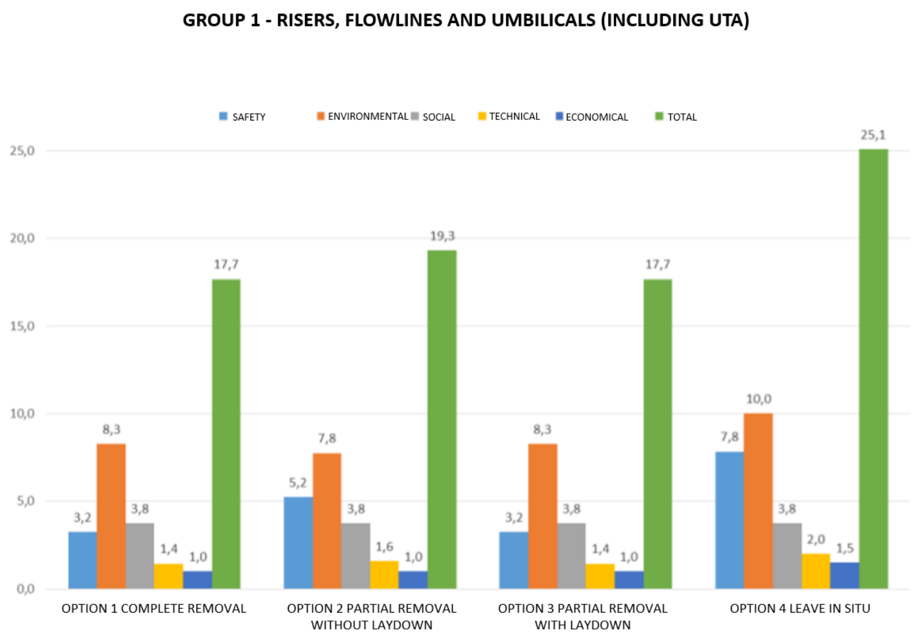
The assessment of the performances of options began by considering the performance of the option that provides the best performing 'clean seas' solution and comparing that option against the next best option (identified by having the next highest total weighted score). If the 'clean seas' option did not provide the best outcome, the comparison was made between the 'clean seas' option and the option with the highest total weighted score. Using this assessment we determined if there were any significant reasons why an option other than full removal should be proposed.

3.6 RESULTS

3.6.1 Bijupirá/Salema

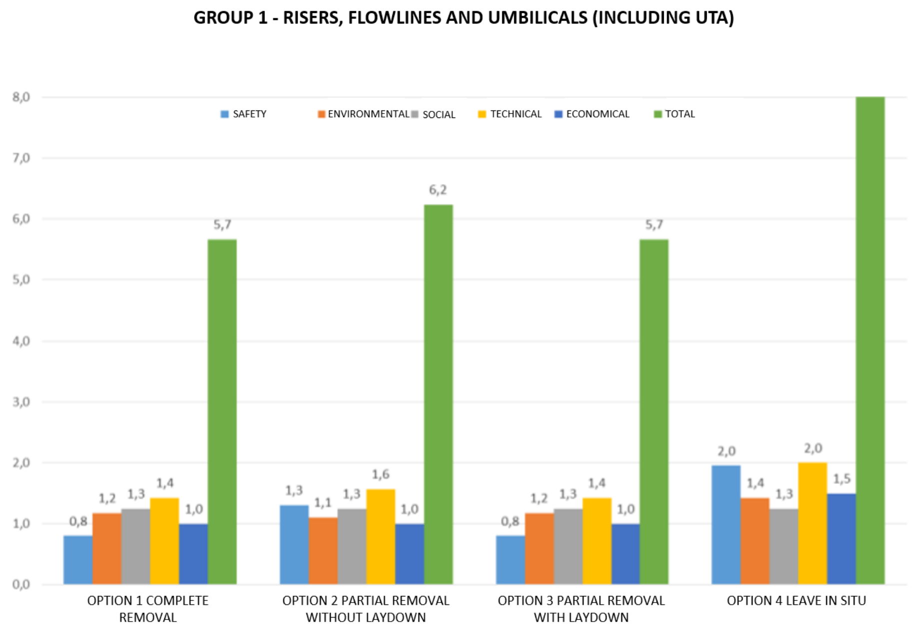
From the scores obtained for each alternative, graphs were generated to make the comparison between the alternatives more visual. For exemplification, Figure 27 and Figure 28 are presented, containing the result for Group 1 of the Bijupirá field using two weighting methods.

Figure 27 – Results of Group 1 - Bijupirá (by the sum of the sub-criteria)



Source: Adapted from Shell Brasil, 2020.

Figure 28 – Results of Group 1 – Bijupirá (by the average of sub-criteria)



Source: Adapted from Shell Brasil, 2020.

The Comparative Assessment process identified the "permanent abandonment *in situ*" option as being the optimal option for all groups in both fields, Bijupirá and Salema. The impact on deepwater corals and the effect on occupational safety played a relevant role in the outcome of the analysis.

However, despite this result of Comparative Assessment, Shell Brasil proposes an alternative decommissioning option, with the removal of risers, the dynamic part of the umbilicals, and the upper part of the mooring lines since these facilities were not positioned on the seabed throughout the life of the fields. They should be abandoned temporarily on the seabed, in areas without the presence of deepwater corals during the disconnection of the FPSO, and later removed. It should be considered that the temporary abandonment of these facilities brings several technical advantages and operational safety.

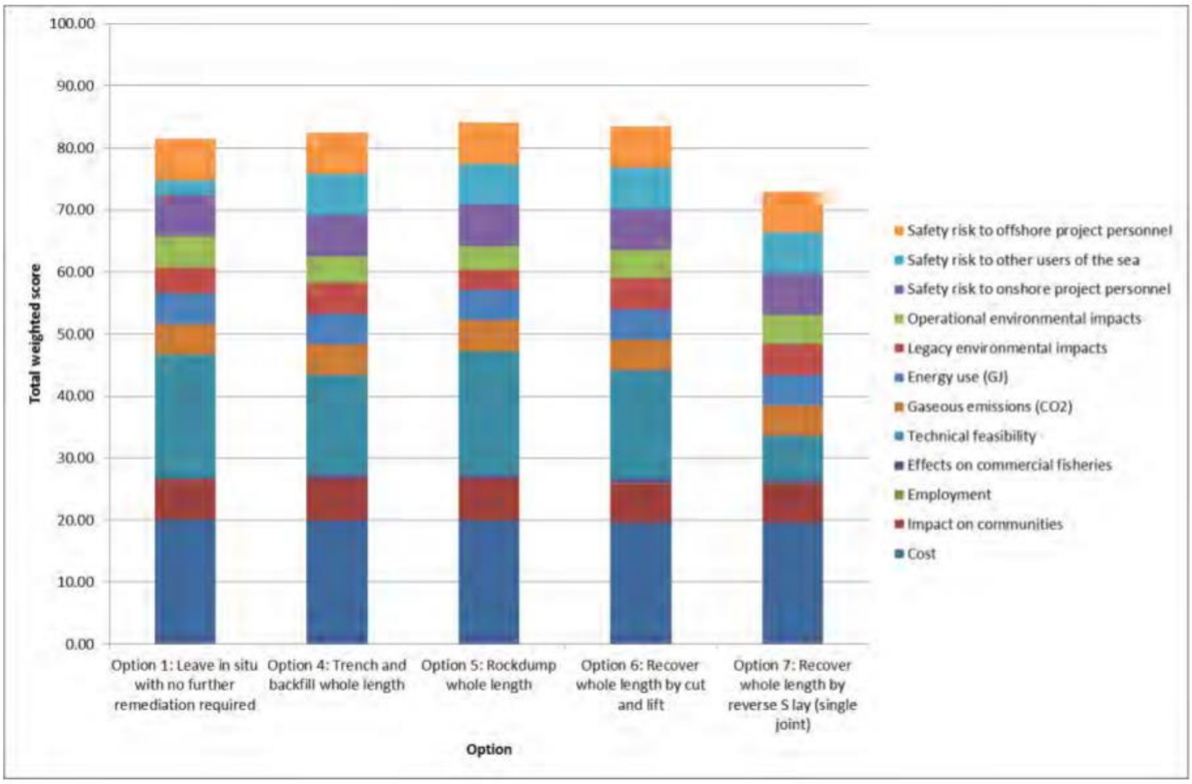
First, this reduces simultaneous operations in the field while disconnecting and preparing for FPSO tugging. Second, there are areas identified in the marine bed where deep water corals are found, in which risers, the dynamic part of the umbilicals, and the upper part of the moorings can be deposited temporarily.

Finally, the descent of these lines to the depth of the seabed will allow the elimination of copies of Sun Coral present in the above stretches of those lines, due to the water temperature in that place. This procedure for eliminating the Sun Coral is safe and mitigates the risks associated with cleaning and handling the coral on the deck of the vessels.

3.6.2 Brent

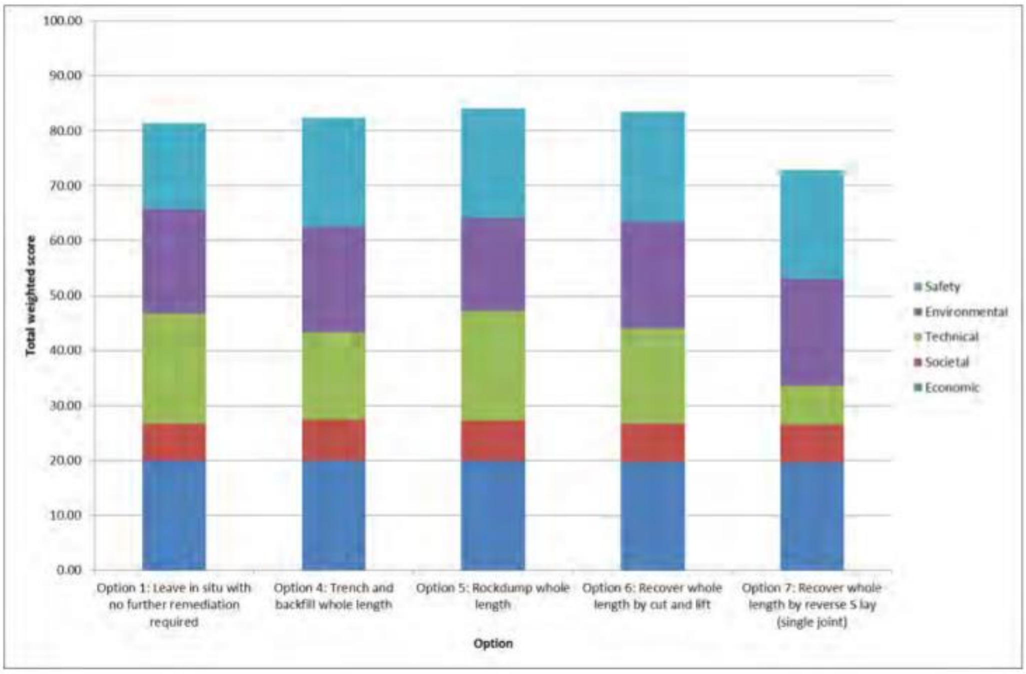
In the Comparative Assessment of Brent (SHELL U.K. LIMITED, 2AD), after obtaining the score of each alternative, bar graphs were generated, according to the examples of Figure 29 and Figure 30, being generated inclusive for sensitivity analysis scenarios. These show the relative contributions of each of the sub-criteria and each criterion to the overall performance of the option; the larger the colored segment, the greater the contribution that sub-criterion/criterion has made

Figure 29 – The Total Weighted Scores of the Options for PL046/N0304 and the Contributions.



Source: Shell UK Limited, 2017.

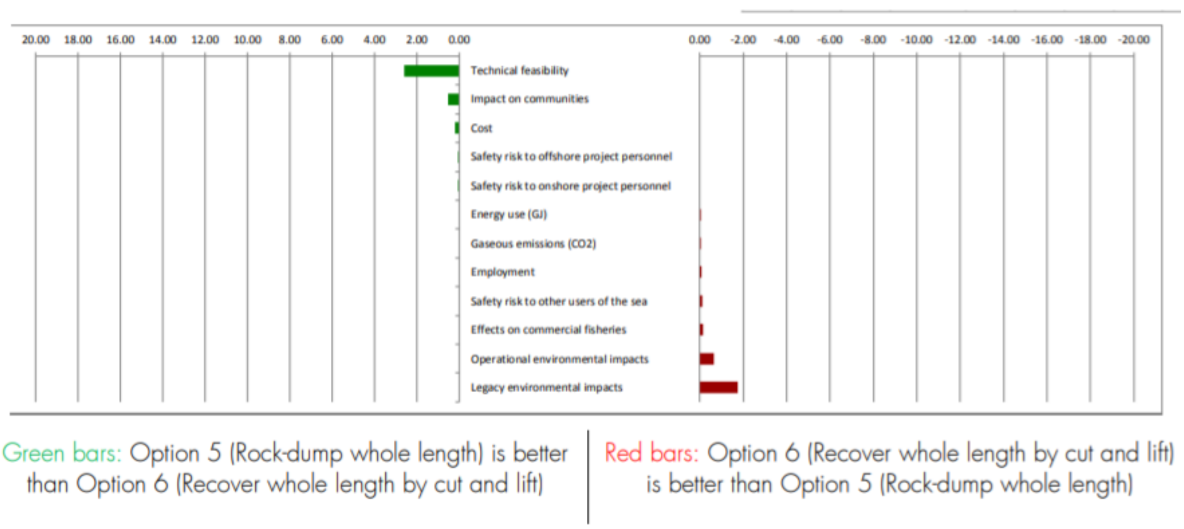
Figure 30 – The Total Weighted Scores of the Options for PL046/N0304 and the Contributions



Source: Shell UK Limited, 2017.

Secondly, to aid our examination of the important sub-criteria (the 'drivers') and enable the assessment of the trade-offs between sub-criteria, were generated 'difference charts', as shown in Figure 31. The bars show the difference in the total weighted score between the options in each of the sub-criteria, the longer the bar, the greater the difference.

Figure 31 – PL046/N0304 Difference Chart Comparing the Weighted Scores for each Sub-criterion of Option 5 (Rock-dump Whole Length) with Option 6 (Recover Whole Length by Cut and Lift), under the Standard Weighting



Source: Shell UK Limited, 2017.

For each duct, in addition to the graphics produced, the document presents a discussion about the options applicable under the light of each criterion. In this way, it is possible to understand the factors that led to the recommended option.

Figure 32, Figure 33, Figure 34, Figure 35, Figure 36, and Figure 37 summarize the result obtained for each Brent pipeline, according to the recommended options. For simplification purposes only, the recommended options fall into discrete operational categories, which are listed below:

- Recover the whole length by cut and lift;
- Recover by reverse-reeling;
- Trench and backfill whole length;
- Leave in situ with remediation of the pipeline end by rock-dump;
- Leave in situ with no further remediation; and
- Partial trench and backfill with isolation rock dump.

Figure 32 – Pipelines to be Decommissioned by Cut and Lift Recovery

BEIS pipeline number	Shell pipeline number	Type of pipeline		Diameter	Length
		Qualitative/ Quantitative	Rigid/Flexible		
PL017	N0601	Quantitative	Rigid	16 inch	0.400km
PL051	N0402a	Qualitative	Rigid	36 inch	0.147km
-	N9900	Qualitative	Flexible	4 inch	2.1km
-	N9901	Qualitative	Flexible	4 inch	2.2km
-	N9902	Qualitative	Flexible	4 inch	2.3km

Source: Shell UK Limited, 2017.

Figure 33 – Pipelines to be Decommissioned by Reverse-Reeling

BEIS Pipeline Number	Shell Pipeline Number	Type of Pipeline		Diameter	Length
		Qualitative/Quantitative	Rigid/Flexible		
PL1955	N0310	Qualitative	Flexible	12/14 inch	2.7km
PL1955	N0311	Qualitative	Flexible	12 inch	0.27km
-	N0830	Qualitative	Flexible	4 inch	0.5km
-	N1844	Qualitative	Flexible	5 inch	2.9km
-	N2801	Qualitative	Flexible	2.5 inch	0.4km

Source: Shell UK Limited, 2017.

Figure 34 – Pipelines to be Decommissioned by Trenching and Backfilling Whole Length.

BEIS Pipeline Number	Shell Pipeline Number	Type of Pipeline		Diameter	Length
		Qualitative/Quantitative	Rigid/Flexible		
PL002	N0201	Quantitative	Rigid	36 inch	1.3km
PL044	N0405	Quantitative	Rigid	24 inch	4.2km
PL045	N0303	Quantitative	Rigid	24 inch	4.6km
PL046	N0304	Quantitative	Rigid	20 inch	4.0km
PL047	N0404	Quantitative	Rigid	30 inch	4.4km
PL048	N0302	Quantitative	Rigid	16 inch	2.3km
PL049	N0301	Quantitative	Rigid	16 inch	2.8km
PL050	N0401	Quantitative	Rigid	28 inch	3.0km
PL051	N0402	Quantitative	Rigid	36 inch	2.6km
PL052	N0403	Quantitative	Rigid	36 inch	2.3km
-	N9903A	Quantitative	Rigid	24 inch	1.7km
-	N9903B	Quantitative	Rigid	24 inch	1.7km

Source: Shell UK Limited, 2017.

Figure 35 – Pipelines to be Decommissioned in situ with Remediation of Pipeline End by Rock-dump.

DECC Pipeline Number	Shell Pipeline Number	Type of Pipeline		Diameter	Length
		Qualitative/Quantitative	Rigid/Flexible		
PL987A	N0738	Qualitative	Rigid	10 inch	5km
PL987A	N0739	Qualitative	Rigid	10 inch	1.8km
PL987A.1-3	N0841	Qualitative	Flexible	5 inch	5.3km
PL988A	N0913	Qualitative	Flexible	8 inch	5km

Source: Shell UK Limited, 2017.

Figure 36 – Pipelines to be Decommissioned in situ by Partial Trench and Backfill with Isolated Rock-dump.

BEIS Pipeline Number	Shell Pipeline Number	Type of Pipeline		Diameter	Length
		Qualitative/Quantitative	Rigid/Flexible		
PL001	N0501	Quantitative	Rigid	30 inch	35.9km

Source: Shell UK Limited, 2017.

Figure 37 – Pipelines to be Decommissioned in situ with no Further Remediation.

BEIS Pipeline Number	Shell Pipeline Number	Type of Pipeline		Diameter	Length
		Qualitative/Quantitative	Rigid/Flexible		
PL050	N0952	Qualitative	Flexible	8 inch	0.03km

Source: Shell UK Limited, 2017.

3.7 CRITICAL ANALYSIS

One of the main factors to determine the applicability of each decommissioning alternative is the condition in which the pipelines are, that is, it depends on their degradation, as well as how they are inserted in the environment, considering possible entrenchments, presence of corals and free spans, for example.

While in Brent the decommissioning alternatives were thought out in a general way, considering only the application scenarios, and then had their viability evaluated for each pipeline, in BJSA these were determined specifically for each of the groups. However, the second approach, when thinking about options that meet a group of pipes, leaves aside the specifics of each pipe, such as the condition they are in, preventing the most appropriate alternative for each of them from being evaluated.

It is noteworthy that flowlines and risers, despite having the same function and similar characteristics, spend their entire productive life in different environments, subject to different efforts and, at the end of their useful lives, they are in different conditions. In this way, the most suitable decommissioning alternative for each one will often not be the same. For example, pipelines N0403 and N0601, gas import and export pipelines respectively, both rigid pipelines, had as the recommended option "Trenching and Backfilling Whole Length" for pipeline N0403 and "Decommissioned by Cut and Lift Recovery" for pipeline N0601.

Furthermore, in BJSA, the options that include permanent abandonment/leave *in-situ* are unclear as to how this will be carried out. There is no mention about the level of intervention (minimal, minor, and major) required nor about the remediation possibly necessary, using techniques such as rock dumping, trench, and/or bury, for example. Removal methods are also not specified for cases of complete and partial removal for Group 1. From this, it can be inferred that both permanent abandonment/leave *in-situ* and removal were analyzed in a general way, without considering the nuances of each type of intervention or removal method.

Regarding the sub-criteria used, BJSA has a greater number of sub-criteria, allowing some points to be evaluated more objectively as the Risk of Dissemination of Invasive Species and the Risk of spills for the marine environment, for example. Moreover, the use of Evaluation Factors makes the assessment of the sub-criteria less subjective, ensuring that all relevant aspects will be considered and evaluated by experts.

The Weighting Method 1 used in the Bijupirá/Salema Comparative Assessment, divides the weights between the sub-criteria equally, so the criteria that have the largest number of associated sub-criteria will have greater weight in the final decision. For BJSA there was no difference in the optimal option pointed out by Methods 1 and Method 2, which assigns all criteria the same weight, however, it is necessary to take care when using Method 1 so that a criterion has no greater weight without this is intentional.

Based on the information presented in both Comparative Assessment Reports, it has the perception that the Brent CA had a greater interest in understanding the contribution of each criterion/sub-criteria, as well as differences, albeit subtle, between the decommissioning options evaluated.

Both CAs have quite distinct results. In Bijupirá/Salema a single alternative of decommissioning is recommended, with a considerable margin for the others, for all groups and their respective pipelines in both fields. However, the operator itself believes that the option determined by the analysis is not the most appropriate, pointing to an alternative solution. In this way, it is understood that for some reason the methodology used does not reflect the technical positioning of the team of experts involved.

For the Brent field, a variety of optimal options are perceived, each of the operating categories of alternatives includes at least one pipeline. Moreover, only one pipeline has a recommended option to decommissioning Leave in situ with no Further Remediation (Figure 37).

4 CONCLUSION

With the advancing of the age of Brazilian production units, discussions about the decommissioning of facilities have gained more and more strength, with a view to mainly the regulatory, economic, and environmental challenges that this stage represents. Decision-making and planning of decommissioning activities require multidisciplinary knowledge and reconciliation of multi-stakeholder interests.

It is notorious that Brazil still walks its first steps in this new segment of the national oil and gas industry, however, to accelerate its development, lessons learned and good practices already consolidated in other countries, especially in the UK, has been adopted in the conception of new resolutions, standards, and guidelines. A great example is the inclusion in Resolution ANP nº 817/2020 of the obligation to present a Comparative Assessment to support the decision making.

The importance of Comparative Assessment becomes even more evident when observing the cases analyzed in this work. The diversity options, the peculiarities of each type of pipeline and the environment in which they are inserted, and the different factors evaluated, reinforce the need to assess each option in the light of well-defined criteria and sub-criteria, thought and analyzed by experts in the issues involved.

In analyzing the Comparative Assessment of Brent and Bijupirá/Salema fields, the point it deserves to be highlighted is the grouping of the pipelines and the choice of alternatives considered in the CA of BJSA. This grouping gives rise to the case-by-case analysis realized in Brent and can sometimes disregard the characteristics and individualities of each duct. This difference between the methodologies adopted can be one of the main factors for the difference between the results obtained for each of the analyzes. For BJSA, abandonment in situ is the recommended option for all ducts, while for Brent, different options are recommended.

In this sense, it is suggested for future work to carry out a macro comparison between Brazil and the United Kingdom to understand, in a systematic way, each of the aspects covered in this work (alternatives, sub-criteria, weights, results, etc.). It is also suggested to consider the elaboration of guidelines on the part of the regulatory bodies to guide operators in the construction of their methodologies and to define minimum requirements to be considered. Finally, it is recommended to investigate alternative tools to Comparative Assessment, considering including the use of artificial intelligence techniques.

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