






# Challenges and Opportunities in VLFS Project Decommissioning

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## Abstract

This article addresses the challenges and opportunities related to the decommissioning of offshore structures, focusing on Very Large Floating Structures (VLFS), considering technical, regulatory, environmental, and economic aspects, and evaluating the potential for sustainable reuse of these structures in the context of the energy transition and circular economy. A multidisciplinary review was conducted involving national and international regulations, offshore industry case studies, technological innovations applied to decommissioning, and environmental and socioeconomic analyses. The research included a survey of key removal technologies, an evaluation of decommissioning methods (total removal, partial removal, toppling, repurposing), and a study of environmental-governance practices, sustainability, and local social impacts. Decommissioning is a complex process structured around early planning, deactivation and removal of structures, material recycling, and environmental monitoring. Total-removal methods eliminate future environmental risks but entail high costs and operational impacts. Partial-removal and toppling methods are cost-effective alternatives but leave submerged debris whose environmental impact must be monitored. Repurposing VLFS emerges as a promising option, allowing structures to be converted into platforms for renewable energy, research, and logistics use, thereby promoting a circular economy and cutting emissions tied to material manufacturing and transport. Advanced technologies such as abrasive water-jets, underwater drones, and digital modelling enhance safety and reduce environmental impacts. Socio-environmental governance and public policy are essential to integrating sustainability, social responsibility, and industrial competitiveness. Sustainable decommissioning of VLFS should be treated as a strategic opportunity for the energy transition and for the sustainable development of the maritime industry. Sustainable decommissioning

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sioning of VLFS should be viewed as a strategic opportunity for the energy transition and the sustainable development of the maritime industry. The incorporation of innovative and sustainable practices, coupled with effective governance and cooperation between public and private stakeholders, is crucial to maximizing environmental, social, and economic benefits, transforming VLFS into valuable assets beyond their productive lifespan, in alignment with global decarbonization and circular economy goals.

## Keywords

Offshore Decommissioning, Sustainability, VLFS, Energy Transition, Platform Reuse

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## 1. Conceptual Foundations

### 1.1. Concepts and Phases of Decommissioning

According to Resolution No. 817/2020 by Brazil's National Agency of Petroleum, Natural Gas and Biofuels (ANP), decommissioning refers to the permanent cessation of oil and natural gas exploration and production activities. This includes well abandonment, facility removal, proper waste disposal, and environmental restoration of affected areas. The process requires a minimum five-year advance planning for offshore facilities and two years for onshore operations, supported by technical, environmental, social, and economic studies to ensure operational safety, regulatory compliance, and mitigation of negative impacts.

Per ANP Resolution No. 817/2020, deactivation refers to the temporary or permanent shutdown of equipment, systems, or facilities; decommissioning encompasses all activities related to the permanent operational cessation, removal, and proper disposal of facilities and waste; while divestment involves asset sales with contract transfers (ANP, 2020).

Decommissioning is structured in five main stages. The first consists of a careful analysis for evaluating, selecting, and designing the decommissioning process, with a focus on spatial engineering. The second stage involves the cessation of production and the plugging of wells. The third covers the partial or total removal of the installed structure. The fourth stage concerns the disposal or recycling of equipment and materials. Finally, the fifth stage corresponds to environmental monitoring of the previously occupied area, ensuring follow-up of post-decommissioning effects (Teixeira, 2013a).

Conventional offshore platforms and Very Large Floating Structures (VLFS) share naval engineering principles and maritime operations, but differ in purpose and structural design. While traditional platforms—such as jackets, semi-submersibles, and FPSOs—are designed for oil and gas exploration and production in fixed locations, VLFS are distinguished by their large surface area and shallow draft, acting as modular and multifunctional platforms. This allows them to serve multiple applications—renewable energy, logistics, housing, or storage—and to

be moved or reconfigured with relative ease. Thus, VLFS represent an evolution of the offshore concept, expanding the use of ocean space beyond hydrocarbon exploration toward a sustainable and adaptable infrastructure for the energy transition.

## 1.2. Principles of the Socio-Environmental Rule of Law

The modern Rule of Law has evolved to incorporate a socio-environmental dimension, reflecting growing needs to reconcile fundamental rights, social justice, and environmental protection. This context gives rise to the Socio-Environmental Rule of Law concept, where sustainability becomes a structuring principle for legal and political relations.

Among the pillars of this model, the principle of solidarity stands out as a constitutional-legal benchmark that guides cooperation among citizens, businesses, and the State to ensure an ecologically balanced environment. This principle not only underpins the formulation of public policies but also legitimizes sustainable management tools such as environmentally responsible logistics plans in the public sector.

Another core principle is the prohibition of socio-environmental regression, which seeks to prevent the elimination or weakening of environmental norms and guarantees already achieved. The effectiveness of this principle ensures that advances in environmental protection are not reversed, consolidating a minimum core of non-derogable rights for society.

In the field of environmental civil liability, the principles of full compensation and polluter-pays stand out, guiding jurisprudence to ensure environmental damages are fully remedied and that degradation costs do not fall on society. These principles directly align with the axiology of the Socio-Environmental Rule of Law, reinforcing the preventive and reparatory nature of environmental legal systems.

## 1.3. Governance and Sustainability in Industrial Environments

Incorporating sustainability into industrial management requires aligning business practices, public policies, and environmental governance tools. Environmental governance emerges as a mechanism to integrate diverse social and economic actors around green economy strategies, steering production toward more responsible standards. This aspect is reinforced—globalization and technological advancement as factors that intensify the need for multi-level governance, in which coordination between the public and private sectors becomes essential for addressing socio-environmental challenges.

The context of public policy highlights initiatives such as the Green Municipality Seal Program (PSMV) in Ceará, which demonstrates the importance of decentralized environmental governance as a tool for encouraging sustainable practices. Similarly, it observes that in urban electoral arenas, environmental governance is used as a political agenda, reflecting not only power struggles but also the growing

importance of sustainability as a development guideline.

For the industrial sector, challenges are even more evident. It analyzed how Industry 4.0 technologies, when applied to environmental management, represent an innovation opportunity for sustainability, improving resource efficiency and impact reduction. The export furniture sector is a link between sustainability practices, performance, and competitiveness—demonstrating that environmental strategies can be not just a cost but a competitive advantage.

Moreover, sustainability indicators serve as key monitoring and evaluation tools. Their use strengthens governance by providing measurable decision-making parameters, enabling companies to align production goals with broader environmental targets.

On the international stage, the global governance must coordinate multilateral sustainability commitments to reduce asymmetries between countries and productive sectors. Meanwhile, governance and transparency are essential principles for protecting an ecologically balanced environment, particularly in high-impact industrial sectors where social legitimacy depends on clear, accountable business practices.

#### **1.4. Very Large Floating Structures (VLFS): Definitions, Applications, and Future Prospects**

Very Large Floating Structures (VLFS) represent an innovative solution for utilizing oceanic and coastal areas, particularly in contexts where land space is limited or where environmental challenges exist for traditional land reclamation and construction. The VLFS can be defined as floating systems spanning hundreds of meters, designed to support complex human activities such as transportation, energy generation, housing, and storage. Their key characteristic is the hydroelastic interaction between waves and the structure, which requires advanced modeling methodologies and mitigation of dynamic responses.

The applications of VLFS have diversified significantly in recent decades. Classic and recent studies demonstrate their use in floating airports, ports, logistics platforms, and as foundations for offshore wind farms. Another promising field is the integration of floating structures for renewable energy, such as hybrid wave energy converter systems as well as large-scale floating photovoltaic panel installations. These applications reveal the potential of VLFS to meet the growing demand for sustainable infrastructure in densely populated coastal regions.

Regarding future prospects, VLFS are viewed as having strategic potential to address global challenges such as rising sea levels, urban space scarcity in coastal regions, and the energy transition. Research is expected to advance toward integrating VLFS with renewable energy systems, enhancing their economic and environmental viability.

Thus, VLFS emerges as a promising technological advancement for ocean engineering and global sustainability, combining innovative structural solutions with growing demands for maritime space utilization and clean energy production.

## 2. Offshore Decommissioning

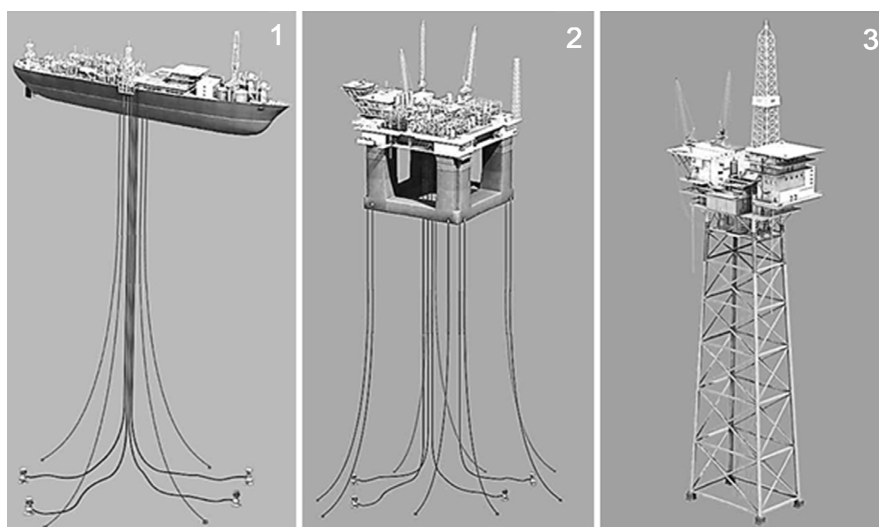
### 2.1. Types of Offshore Structures

Floating Production Storage and Offloading (FPSO) units consist of tanker ships anchored to the seabed, designed to process and store oil from underwater wells. Production is offloaded via shuttle tankers (Petrobras, 2015; Martins, 2015).

Semi-submersible (SS) platforms, on the other hand, feature support columns that provide stability and can operate either anchored or with dynamic positioning—an automated system that maintains the vessel in the desired position. Production can be offloaded via pipelines or stored on ships (Petrobras, 2015).

Both types—FPSO and SS—are floating platforms capable of operating in water depths exceeding 2000 meters, thanks to advancements in anchoring systems and subsea well control (Petrobras, 2015).

Fixed platforms, in contrast, are rigid structures supported on the seabed by driven piles. Their substructures can be made of steel (jackets or compliant towers) or concrete (gravity platforms). The upper part (topside) houses the drilling, production, and accommodation modules. These units typically operate in water depths of up to 300 meters, with well control managed at the surface—via the so-called dry Christmas tree—and oil transported through pipelines (Amorim, 2010; Petrobras, 2015). A representation of these platforms can be seen in Figure 1.



Source: Martins, 2015.

**Figure 1.** Representation of the main types of offshore platforms in Brazil: on the left (1), FPSO type; in the center (2), SS type; and on the right (3), Fixed type—steel substructure.

### 2.2. Technologies Applied in Offshore Decommissioning

Offshore decommissioning requires a combination of physical, digital, and operational technologies to ensure safe, efficient operations with minimized environmental impact. Some of the most significant advancements occur in automation, monitoring, simulation, cutting/submersion, and digital modeling.

An important source is the report *Offshore Oil and Gas Decommissioning Technologies* by the Australian Academy of Technological Sciences & Engineering (ATSE), which analyzes emerging and already applied technologies in the decommissioning chain. This document highlights the growing interest in automation for removing submerged infrastructure, as well as the use of remote monitoring systems and advanced sensors to assess marine ecosystems and environmental quality (ATSE, 2024).

Among the applied physical technologies, the following stand out:

ROVs (Remotely Operated Vehicles) and AUVs (Autonomous Underwater Vehicles) are remotely operated or autonomous vehicles for underwater inspection, detailed corrosion mapping, damage identification, structural verification, and removal planning (NST Authority, 2024).

Hydraulic cutting, abrasive water jets, diamond wire saws, and hydraulic grabs for sectioning submerged structures have a lower environmental impact than explosives; these methods enable precise cuts in metal and concrete while minimizing seabed disturbance (NST Authority, 2024). **Table 1** summarizes the main cutting technologies used worldwide.

Non-explosive and cold-cutting methods (AWJC, DWC, and mechanical) are now the international standard for offshore operations, particularly in the Campos and Santos basins, due to environmental requirements set by ANP (Resolution No. 817/2020) and IBAMA (2022). AWJC is Petrobras' most widely used method, as it is remote-operated and adaptable to ROVs, ensuring operational safety and reduced thermal or chemical waste emissions. The use of explosives is virtually banned in Brazil, permitted only in emergency situations and subject to EIA/RIMA and military authorization. Meanwhile, mechanical and diamond wire methods stand out for material recyclability and the reuse of structural modules in green decommissioning projects.

On the digital front, innovations are optimizing planning, safety, and risk control:

- 1) Digital twins and 3D modeling: virtual replicas that simulate different removal scenarios, predict structural stresses, optimize operation sequences, and plan logistics for transporting removed components (Offshore Network, 2025; ATSE, 2024).

- 2) Predictive analytics and artificial intelligence (AI): algorithms that forecast failures, detect structural weaknesses, prioritize interventions, and make data-driven decisions using historical and real-time data (NST Authority, 2024).

In addition, environmental well-being and impact-mitigation technologies:

- 1) Sensors for monitoring environmental parameters such as turbidity, underwater noise, marine life, water quality, and detecting leaks or contamination before, during, and after decommissioning activities (ATSE, 2024; Offshore Network, 2025).

- 2) Less invasive well abandonment methods (plug and abandonment or P&A), using alternative barriers like resin plugs or metal alloys, and more effective iso-

lation techniques with reduced reliance on conventional cement—or even “rig-less” P&A (eliminating the need for drilling platforms)—lower risks and costs (Offshore Network, 2025; ATSE).

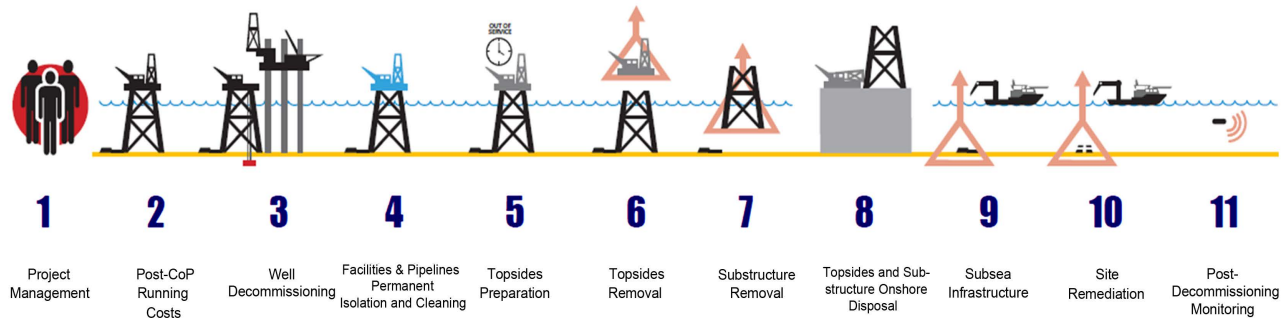
There is also growing emphasis on topside-removal technologies (the upper section of the platform) using single-lift operations (raising the entire structure in one piece), which reduces support-vessel time on site, crew risk, and maritime environmental impact (NST Authority, 2024).

**Table 1.** Main cutting technologies used worldwide.

Cutting Method	Working Principle	Key Advantages	Limitations and Disadvantages	Safety	Relative Cost	Offshore Applicability (Brazil)	Reference
Abrasive Waterjet	It uses a very high-pressure water jet (up to 4000 bar) mixed with mineral abrasive (garnet/silica) to cut steel, concrete, and composites.	Cold cuts, no risk of ignition; high precision; reduced structural damage.	High water consumption and abrasiveness; fine waste needs environmental management.	High	High	Preferred in FPSO series flexible; used by Petrobras in projects in Campos and Búzios.	BOEM (2004); Oceaneering (2024); Petrobras (2023a).
Internal Waterjet Cutting	A tool is inserted inside the conductor or pile, performing complete circular cutting via an abrasive water jet.	It allows you to cut conductors below the seabed; it avoids digging.	Expensive equipment; complex remote operation (ROV).	High	High	Used in the abandonment of wells and multiple conductors in the pre-salt.	Oceaneering (2024); Petrobras (2023a).
Diamond Wire	Synthetic diamond coated metal wire is tensioned and moved by pulleys, cutting by continuous abrasion.	High efficiency in large thicknesses and complex structures; clean cuts.	Time-consuming installation and the need for access to the structure's surroundings.	High	Medium-High	Used in jacket bases and concrete structures; Marlim and Albacora.	Petrobras (2023b); CIRP Encyclopedia (2019).
Mechanical Cutting (Guillotine/Hydraulic Saw)	A mechanically or hydraulically driven blade or saw that cuts metal pipes and supports.	Safe, low cost, no heat; ideal for confined areas.	Slow on thick materials; requires frequent maintenance.	High	Medium	Applied to smaller structures or in hard-to-reach places.	BOEM (2004); Oceaneering (2024).
Hot Cutting (Oxyfuel/Blowtorch)	Combustion of oxygen gas with acetylene/propane melts the metal.	Fast, portable, and widely known.	Risk of explosion; prohibited in areas with hydrocarbons.	Low	Low	Restricted to disassembly in dry docks; not used in the field.	BOEM (2004); Petrobras (2023b).
Chemical Cutting	Controlled chemical reactions with reagents that corrode the metallic material.	Cold method, without heat or noise.	Little environmental control; risk of toxic leakage.	Low	High	Experimental; rarely used in Brazil.	IBAMA (2022); UK Government (2023).
Explosives (Underwater Cutting)	Shaped charges break through structures by shock waves.	Extremely fast; it allows simultaneous cutting.	High environmental impact and risks to marine fauna; licensing required.	Low	Medium	Restricted use by the Navy and IBAMA; common in the Gulf of Mexico, rare in Brazil.	National Academies (1996); IBAMA (2022).

According to Oil and Gas UK (OGUK) (2014), this necessitates an integrated

vision for decommissioning projects, as illustrated in **Figure 2**.



**Figure 2.** Integrated vision for decommissioning projects 2014.

To achieve this, the following steps should be taken:

- 1) Operator project-management team covers overhead items such as project insurance, tendering, paid studies, and assurance activities.
  - 2) Operational costs of assets after production ceases.
  - 3) All activities are related to the permanent isolation of any rock formations with flow potential.
  - 4) Isolate assets from pressure sources and ensure, as far as possible, that they are free from hydrocarbons and contaminants.
  - 5) Interventions to surface facilities are required for decommissioning and preparing them for abandonment, if necessary.
  - 6) Offshore removal of topsides from substructures, along with transportation and load-in at the disposal site.
  - 7) All activities associated with substructure removal, including transportation and load-in at the disposal site, are included.
  - 8) Reuse, recycling, or disposal of topsides and substructures, including dismantling and waste management.
  - 9) Removal or remediation of all subsea structures, including transportation, loading, and disposal of removed materials.
  - 10) Removal of oilfield scrap as required, along with transportation and disposal of all removed materials.
  - 11) Post-decommissioning infrastructure inspections and monitoring programs.
- Finally, the ATSE report highlights gaps in the development of certain technologies, particularly for aging infrastructure or regional tropical/marine equivalents, where conditions like temperature, salinity, and biodiversity require specific adaptations (ATSE, 2024).

### 2.3. Methods: Total Removal, Partial Removal, Toppling, Repurposing

In offshore decommissioning, different methods are applicable depending on factors such as regulations, depth, environmental impact, cost, and technical feasibility. The primary methods include total removal, partial removal, controlled

toppling or abandonment (leave-in-place), and repurposing of existing structures.

#### Total Removal

Total removal involves extracting all parts of the structure (topside, substructure, foundations, connected pipelines, etc.) for onshore dismantling, recycling, or disposal. This method is often mandated by international or national regulations, particularly when there is a risk of navigation interference or ongoing environmental impact (Colaleo et al., 2022).

In the case study of the “Viviana 1” platform in the Adriatic Sea, Colaleo et al. (2022) applied the total removal method in a life cycle analysis, considering all phases: pre-removal, cutting and transportation of the structure, decontamination, material recycling (especially steel), and final waste disposal. They concluded that while the environmental cost of removal (energy, transportation) is high, the benefits of steel recycling avoid impacts associated with primary steel production, significantly reducing carbon emissions.

In the total removal modality, the Brent Delta project (North Sea) stands out, in which Shell carried out the complete dismantling of the topside and substructure using the crane vessel *Pioneering Spirit*, removing more than 24,000 tons for recycling in Teesside, United Kingdom (Shell, 2017).

#### Partial Removal

Partial removal involves removing the topside of the platform and some sections of the substructure, but leaves parts of the main structure fixed to the seabed or below a certain depth. This may include cutting jacket legs below the seabed, leaving the bases or support structures submerged.

This method can be advantageous by reducing costs, energy consumption, and environmental disturbance, while also simplifying logistics. However, it may leave submerged debris, create corrosion points, or affect ecosystems that have formed on the remaining parts (UD-TP dissertation, cited in the study “Decommissioning Options Assessment on Environmental Impact”) (Scheelhaase, 1998, as cited in UTPEDIA, 2024).

In partial removal, the Frigg field (Norway-France) exemplifies the strategy of keeping part of the foundations submerged after topside removal, aiming to reduce environmental risks and operating costs (TOTAL, 2010).

#### Toppling/In-Situ Abandonment (Leave-in-Place)/Artificial Reef

The toppling, abandonment, or leave-in-place method involves leaving parts of the structure on-site—typically the foundations or submerged portion—converting them into artificial reefs or lowering them to minimize visual or navigational impact. This approach leverages ecosystems already established on the structure, reducing removal costs and the potential impacts of cutting and transportation (Syriac & Prashak, 2022) (e.g., fixed platforms turned into artificial reefs).

#### Examples:

Syriac & Prakash (2022) review options for repurposing fixed platforms to support marine renewable-energy projects, including using the submerged structure as a foundation for new wind turbines.

Conservation Evidence reports that obsolete offshore structures can function as

artificial reefs, benefiting biodiversity, although their long-term impacts remain uncertain (Repurpose obsolete offshore structures to act as artificial reefs).

Controlled toppling has been applied to platforms in the Gulf of Mexico, such as in the Rigs-to-Reefs program, where structures were intentionally toppled to create artificial reefs, providing ecological benefits (BOEM, 2018).

#### Repurposing

Repurposing means converting a structure—or parts of it—to new uses while retaining some of the original framework. Applications can include renewable-energy infrastructure, scientific research, logistics hubs, industrial bases, or power generation.

Academic examples:

Quissanga, Nascimento, and Galgoul (2020) assessed the feasibility of reusing fixed platforms as substructures for wind turbines, evaluating structural integrity, additional loading, and retrofit costs. Such repurposing can add economic value to decommissioning by reusing existing assets (Quissanga, Nascimento, & Galgoul, 2020).

Finally, the reuse of platforms has gained momentum—in Brazil, studies by CENPES/Petrobras and universities indicate the potential to convert decommissioned jackets and FPSOs into substructures for offshore wind turbines or floating hydrogen and ammonia units (Quissanga, Nascimento, & Galgoul, 2020; Petrobras, 2023a).

At an ASME conference, the repurposing of jacket platforms for wind-turbine installation was examined, accounting for accumulated fatigue damage and proposing an optimization strategy that weighs retrofit costs, remaining life, and energy yield.

Table 2 provides a summary including the advantages and disadvantages of each method.

**Table 2.** Summary of key removal methods, including advantages and disadvantages.

Method	Description	Advantages	Disadvantages	References
Removal Total	Complete removal of all parts of the structure (topside, substructure, and foundations) for disassembly, recycling, or disposal on land.	Eliminates potential sources of pollution; completely restores the seabed; reduces future risks of structural failure.	High operating costs; risk of accidents; emissions associated with transportation and cutting.	Colaleo et al. (2022); Pinheiro & Monteiro (2023)
Removal Partial	Removal of the upper parts and sections of the substructure, leaving part of the submerged structure below a certain depth.	Reduces costs and logistical impacts; less environmental disturbance during the removal process.	It can leave residues submerged; there is a risk of corrosion; and there is a possible impact on local ecosystems.	UTPEDIA (2024); Pinheiro & Monteiro (2023)

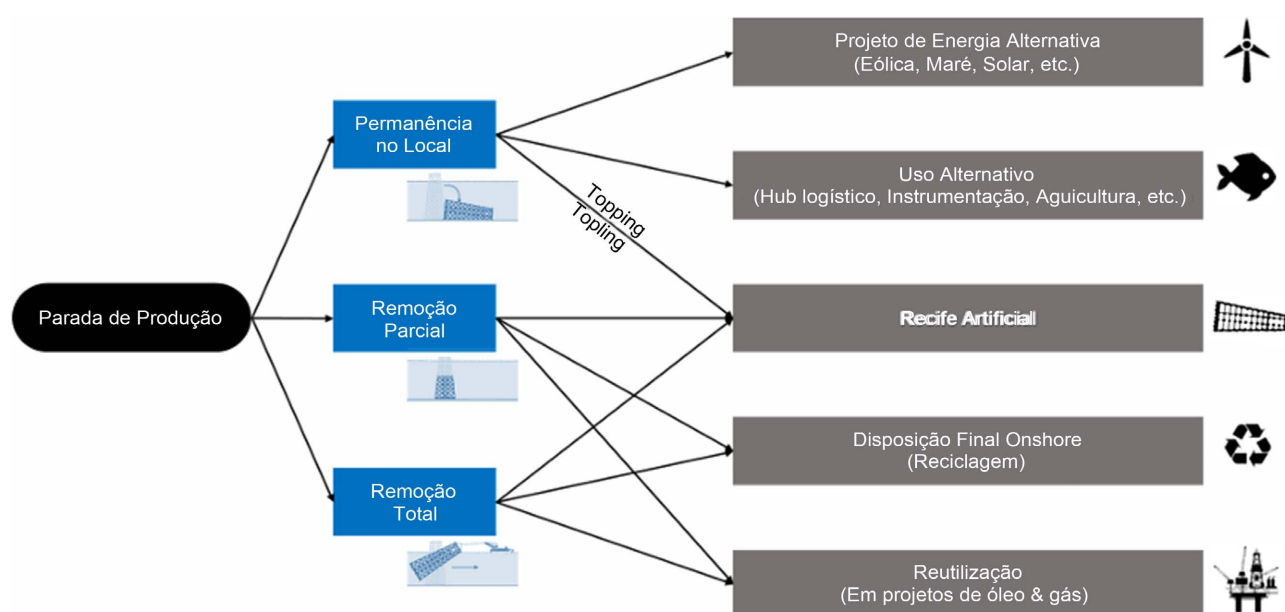
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Tipping In-Situ Abandonment	Leaving parts of the structure in place, usually foundations, can turn them into artificial reefs or leave them inactive.	Preserves established ecosystems; reduces costs; it can generate ecological benefits (artificial reefs).	May contain toxic materials; requires continuous monitoring; depends on regulatory approval.	Syriac & Prashak (2022)
Reuse	Conversion of the structure or parts of it for new uses, such as bases for wind energy, scientific research, or logistical support.	Reduces waste of materials; generates additional economic value; promotes sustainability and a circular economy.	High cost of modification; structural and geographical limitations; requires detailed technical evaluation.	Quissanga et al. (2020); Syriac & Prashak (2022)

### Comparative conclusion

The choice between total removal, partial removal, toppling, or repurposing depends on multiple factors: local/international regulations, operational costs, structural integrity, environmental impact, presence of established ecosystems, and repurposing opportunities.

Recent studies suggest that repurposing or controlled abandonment with maintenance of submerged sections may be environmentally and economically advantageous, particularly in contexts where ecosystems already benefit from existing structures or where there is potential for renewable energy generation (Syriac & Prashak, 2022; Quissanga et al., 2020). Conversely, in cases where there is a risk of contamination or interference with navigation, total removal remains the preferred method (Colaleo et al., 2022). **Figure 3** presents a summary of the main destinations that could be applied to VLFS:



Source: Prepared by the authors.

**Figure 3.** Main potential destinations for VLFS.

## 2.4. Green Decommissioning and Sustainable Practices

Discussions about environmental decommissioning and the impacts of abandoning oil platforms gained international prominence following the emblematic Brent Spar case, which occurred in 1995 in the North Sea under UK jurisdiction (Teixeira, 2013b). Strong public pressure led to a change in the initially proposed strategy—sinking the structure (dumping)—with the option instead being the complete removal and repurposing of the platform for dock extension works on the Norwegian coast. Though more costly and risky, this alternative gained greater social acceptance, particularly among European consumers, marking a milestone in the debate about environmental responsibility in the offshore industry (Ruivo, Morooka, & Guerra, 2001; Martins, 2015).

In the context of offshore production structure decommissioning, two critical moments stand out regarding environmental impacts: the first, during production abandonment, through well cementing or capping; and the second, related to the disposal of the platform structure—whether through controlled sinking, removal, or recycling of its metal and concrete components (Luczynski, 2002, cited in Machado, Teixeira, & Vilani, 2013).

During partial or complete removal of fixed platforms, explosives are commonly used to cut sections of substructures, generating shockwaves and releasing underwater sound energy. These impacts can harm marine species such as fish, turtles, and mammals, requiring rigorous environmental monitoring and the adoption of mitigation techniques (Teixeira, 2013b).

According to the Climate and Pollution Agency (CPA, 2011), an agency under Norway's Ministry of the Environment, decommissioning processes frequently identify various waste materials, including hazardous substances—such as heavy metals, toxic materials, radioactive substances, and asbestos—particularly in older facilities, which may contain components whose use was later banned.

Oil and gas extraction and production activities can also lead to the accumulation of Naturally Occurring Radioactive Material (NORM), which contains radionuclides such as radium-226, radium-228, polonium-210, and lead-210 (Schenato et al., 2013). In many cases, these materials remain temporarily stored at production facilities, requiring proper disposal during decommissioning in accordance with National Nuclear Energy Commission (CNEN) regulations, including transfer to licensed landfills.

The removal of platform substructures can also significantly impact aquatic fauna due to seabed disturbance and the loss of artificial substrate that has become habitat for various species. Sammarco, Atchison, and Boland (2004) emphasize that the degree of coral colonization on structures should be assessed prior to decommissioning, as these artificial ecosystems in the Gulf of Mexico have demonstrated positive environmental value.

Moreover, decommissioning operations can directly impact fishing activities due to temporary restrictions on access to fishing grounds and the inability to anchor in areas with remaining pipelines. The magnitude of these impacts varies

depending on location (shallow or deep waters) and interaction with local fishing fleets (IBAMA, 2015).

According to Luczynski (2002, cited in Machado, Teixeira, & Vilani, 2013), the main environmental issues observed during decommissioning include:

- 1) Oil leaks and surface slicks, along with sediment contamination;
- 2) Inadequate treatment or disposal of drilling cuttings containing lubricants, polymers, and natural radionuclides;
- 3) Bioaccumulation of toxic substances in aquatic organisms affects the entire food chain;
- 4) Improper disposal of large sections of platform structures;
- 5) Presence of residual chemical compounds and drilling waste.

The best way to mitigate such impacts is through strict environmental controls and compliance with international legislation and conventions throughout the project's lifecycle. In this regard, recent studies and strategic plans by companies like Petrobras reinforce their commitment to sustainable decommissioning and material reuse, aligning with ESG (Environmental, Social, and Governance) practices (FGV Energia, 2024; Petrobras, 2023b).

In Brazil, for instance, Petrobras will invest \$11 billion in decommissioning between 2024 and 2028, removing 23 platforms and approximately 1900 km of flexible lines, while closing over 550 wells—with a strong focus on ESG practices and sustainability. The company plans to allocate 70% of the budget to well abandonment and 30% to subsea equipment removal, aiming for material recycling and reuse. Petrobras views decommissioning not just as a legal requirement but as a business opportunity, boosting local supply chains and pursuing technological solutions to make the process more efficient and sustainable (Sinaval, 2024; Petrobras, 2023b).

## 2.5. Integration with VLFS: Reuse of Floating Platforms and Conversion for Logistical, Scientific, or Energy Purposes

Very Large Floating Structures (VLFS) consist of large floating constructions that can take various forms (pontoons, semi-submersibles, stabilized platforms, etc.), with broad potential applications—from maritime infrastructure and renewable energy to scientific research, logistics, and residential use (Lamas Pardo, Iglesias, & Carral, 2015).

### 2.5.1. Reusing Fixed Platforms as Substructures for Wind Energy

One of the most promising avenues for VLFS integration is repurposing existing fixed platforms, such as jackets, to serve as foundations for offshore wind turbines. Quissanga, Nascimento, and Galgoul (2020) conducted a feasibility study in Brazil, evaluating decommissioned fixed platforms by subjecting them to new loads from 10 MW turbines. They analyzed the remaining structural integrity, retrofit requirements, adaptation costs, and expected energy returns, concluding that in many cases, reusing these structures is more economical than building new foundations.

Another key initiative is the DeP2WIND project (2024) (European Commis-

sion), which proposes an interdisciplinary, data-driven framework to assess the structural health of decommissioned platforms, determine which components should be retained or replaced, optimize maintenance, and adapt the structures to safely and efficiently support wind turbines. The goal is to reduce costs and the carbon footprint associated with new construction.

### 2.5.2. Conversion for Logistical, Scientific, or Energy Applications

Beyond wind energy, floating platforms can be adapted for other functionalities:

**Logistical uses:** Platforms can serve as floating supply terminals, maritime operation bases, or support hubs for exploration. A conceptual example is the “Floating Logistics Terminal” (FLT) proposed by Yamamoto et al. (2017) for Brazil’s equatorial margin, featuring floating structures to support exploration and production (E&P), transport, and maritime logistics in remote regions.

**Scientific research and environmental monitoring:** Stabilized floating platforms can serve as ocean laboratories, meteorological observatories, or biodiversity monitoring stations, especially useful in deep or hard-to-access ocean areas. Although documented cases are fewer, the VLFS concept supports multiple uses—including military facilities, research installations, storage, etc.

**Floating solar energy, combined generation, microgrids, or renewable integration:** Repurposing decommissioned platforms or fixed-platform foundations as bases for floating photovoltaic modules (FPVs) or integrated wind turbines is a growing area of interest. The paper *Towards the Sustainable Decommissioning of Fixed Platforms by Aligning Ecosystem Services and Wind Generation: A Brazilian Case* (Barboza, Meiriño, Barros, & Bella, 2023) proposes maintaining ecosystem services formed on substructures while leveraging the structures for wind generation, highlighting environmental and economic benefits.

### 2.5.3. Challenges for Conversion and Reuse

While the potential is great, there are significant challenges:

**Structural integrity and fatigue:** Platforms exposed to marine environments for years may suffer from corrosion, fatigue damage, deformations, or vulnerabilities that complicate safe structural adaptation for new loads or uses (e.g., wind turbines). Retrofitting may require reinforcements and detailed inspections—not just visual, but involving non-destructive testing and modeling.

**Adaptation and maintenance costs:** Modifying an aging structure can involve high expenses for transportation, structural reinforcement, safety system installation, support foundations for new loads, and ongoing maintenance. These costs must be weighed against the expected return (energy generated, logistical uses, or services) and the remaining lifespan.

**Regulation, environmental licensing, and legal liability:** Reusing platforms involves regulatory, environmental, and maritime safety considerations. It is essential to ensure hazardous waste (heavy metals, toxic materials, NORMs) is properly handled, contamination risks are mitigated, and adaptations do not interfere with navigation or marine ecosystems. In many countries, including Brazil, legislation re-

quires environmental impact assessments, monitoring plans, and specific permits.

**Meteorological and hydrodynamic suitability:** Older platforms may not have been designed for the loads and environmental conditions expected in new uses, such as tall turbines, strong winds, or currents. Wave interactions and hydrodynamic behavior could cause instabilities or necessitate additional anchoring or damping systems. Studies such as those on VLFS show that for pontoon structures, elastic deformations, hydrodynamic response, and the effects of fluid dynamics on the floater must be considered.

## 2.6. Technical, Operational, and Environmental Risks

Decommissioning offshore oil facilities involves a range of risks that must be rigorously assessed to ensure safety, regulatory compliance, and minimal environmental impact. These risks fall into three broad categories: technical, operational, and environmental.

The risks associated with offshore decommissioning encompass technical, operational, and environmental aspects related to structural integrity, operational safety, and ecological impacts. However, when considering the reuse of these platforms and their conversion into Very Large Floating Structures (VLFS), additional and specific risks arise, such as structural adaptation—requiring reassessment of buoyancy and material fatigue—integration of energy systems (wind, solar, or hydrogen), and regulatory uncertainties, since these structures occupy a hybrid space between offshore units and new multifunctional platforms. Furthermore, there are emerging environmental risks resulting from changes in use and interaction with marine ecosystems. Thus, risk assessment in VLFS conversion must go beyond the perspective of safe removal, incorporating a life cycle and sustainability perspective, aligned with the principles of the circular economy and energy transition.

### 2.6.1. Technical Risks

**Deteriorated structural integrity:** Aging or corroded structures may experience unexpected failures during cutting, lifting, or relocation. Deterioration can compromise anchor points or equipment support, leading to serious accidents or structural collapses.

**Failures in well abandonment procedures (P&A—Plug and Abandonment):** If the well is not properly sealed, residual fluids or hydrocarbons may leak. This includes failures in cementing or plugging conductors, resulting from technical errors, inadequate materials, or poor controls (A&O Shearman, 2023).

**Risks associated with pipeline and flexible line removal:** Handling, cutting, and transporting subsea pipelines require specialized equipment, vessel stability, and control of weight and stresses. Failure to monitor the condition of these pipelines or using inadequate technology for cutting them may cause ruptures or structural failures that compromise the operation (BOEM, 2004; Ekins et al., 2006).

**Design errors and load miscalculations:** When planning lifts or movements of topsides, prisms, or heavy modules, crane members or anchor connections may have been overlooked or underestimated. In offshore operations, wind, rough

seas, or currents can introduce unexpected dynamic loads that, if not accounted for, may lead to mechanical failures.

### **2.6.2. Operational Risks**

**Workforce safety:** Includes falls from height, falling objects, lifting equipment failures, hazardous movements, or lack of proper safety procedures. Special attention must be given to training and the use of Personal Protective Equipment (PPE), as well as the inspection of critical equipment.

**Complex logistics and adverse conditions:** Offshore operations require specialized vessels, logistical support, and preparation for severe weather, rough seas, and extreme depths. The complexity of mobilizing marine cranes, transporting heavy modules, and coordinating multiple vessels increases the risk of delays, additional costs, and accidents.

**Planning failures and regulatory oversight:** Absence or inadequacy of prior environmental impact and risk studies, flaws in permits or public consultations, weak enforcement, or non-compliance with applicable regulations—all of which can lead to litigation, fines, and activity shutdowns (A&O Shearman, 2023).

### **2.6.3. Environmental Risks**

**Marine and sediment contamination:** Abandoned or removed materials containing contaminants such as heavy metals, NORMs (naturally occurring radioactive materials), hydrocarbons, or chemical waste may contaminate sediments, waters, and bioaccumulate in the food chain (Albeldawi, 2023).

**Habitat and biodiversity disturbance:** The removal or abandonment of structures alters established ecosystems, potentially destroying artificial reefs or habitats colonized by benthic organisms. Cutting or demolition causes turbidity, sediment suspension, and underwater noise pollution—all of which affect marine fauna such as fish, corals, and marine mammals (Ben-Hamadou et al., 2022; Decommissioning offshore structures environmental management, UK shelf, etc.) (Simpson, 1998) [Springer].

**Risk of leaks and spills:** Aging equipment or poorly sealed wells may release residual oil or gas. Damaged flexible lines or pipelines, accumulation of residual fluids, fuels, lubricants, or even NORMs can cause continuous leaks if not properly isolated or removed (Ekins et al., 2006).

**Acoustic and thermal impacts:** Explosions, hot cutting, or the use of explosives generate extremely high underwater noise levels, which can cause mortality, displacement, or stress in marine organisms. The disturbance of sediments may also release trapped nutrients or toxic metals, altering local water temperature or oxygenation (Albeldawi, 2023).

## **3. Onshore Decommissioning**

### **3.1. Typical Infrastructure: Refineries, Onshore Wells, Pipelines, and Vessels**

Onshore energy infrastructure constitutes the material foundation for land-based

exploration, production, transportation, and processing. These structures encompass a diverse array of equipment and facilities whose function is to enable the production cycle of these operations from extraction to distribution. However, the development of this energy infrastructure, whether in the traditional oil and natural gas (O&G) sector or in renewable sources such as wind, implies a life cycle that ends in the decommissioning phase. Therefore, there are certain infrastructures that have different impacts and particularities from one another.

The inclusion of onshore decommissioning in this article aims to broaden the comparative understanding of the challenges faced in the decommissioning of energy assets, highlighting both the differences and the lessons transferable to the offshore context. While the onshore environment offers greater logistical predictability, environmental control, and lower operational complexity, it also provides relevant lessons on waste management, material reuse, and the application of circular economy practices, which can be adapted to the maritime reality. Thus, the integrated analysis of onshore and offshore decommissioning contributes to identifying technological and regulatory synergies, as well as reinforcing the importance of sustainable and standardized strategies that can support the transition from conventional platforms to Very Large Floating Structures (VLFS).

The refinery, in the context of the oil and gas (O&G) industry, is recognized as a fundamental component of the downstream phase of the production chain. This phase, in turn, encompasses the stages that follow hydrocarbon extraction, including the storage and transportation of the extracted oil until its distribution to the consumer. In addition to its operational role in transforming crude oil, the refinery is identified in technical analysis as an existing and measurable industrial unit. Environmental efficiency studies, for example, use attributes such as 'Refinery Age' as a variable in the evaluation of decision-making units (DMUs). In the Brazilian corporate landscape, the corporate purpose of major companies in the sector, such as Petrobras, expressly includes refining, processing, trading, and transporting oil from various sources (wells, shale, or other rocks), its derivatives, natural gas, and other fluid hydrocarbons, as well as related activities.

In the oil and gas (O&G) industry, onshore wells are critical components of exploration and production infrastructure. Decommissioning these facilities focuses on reversing the installation process, beginning with well closure (abandonment). Permanent well abandonment is one of the most costly activities in facility decommissioning, requiring significant investment. The abandonment phase occurs when a well reaches the end of its operational life or becomes economically unviable (Costa et al., 2021).

Pipelines, or piping systems, are essential components of the production system, referring to flow lines and service lines. Onshore pipelines are fundamental for integrating isolated production areas with refineries and consumer centers, although they are associated with risks of leaks and environmental impacts. Pipelines and facilities of flow lines and production pipelines that are not reused or transferred must be removed, recycled, or disposed of in appropriate locations,

unless removal is not recommended for technical, economic, or environmental protection reasons.

The term “vessel” encompasses a wide range of floating structures, whose end-of-life management poses significant environmental, technical, and legal challenges. In energy infrastructure, vessels serve as Stationary Production Units (SPUs), essential for offshore oil and gas (O&G) exploration. Meanwhile, in coastal and riverine areas, the issue manifests in the deliberate abandonment of common vessels, resulting in socio-environmental liabilities. In the O&G sector, the most common vessels end up being FPSOs (Floating Production, Storage and Offloading units) and semi-submersible platforms, which are assets designed to operate for long periods, typically 20 to 30 years as pointed out by Madi in 2018. However, their decommissioning process faces numerous challenges, the main one being that decommissioning should be seen not as a last resort event, but as an integral phase of the project life cycle, planned and attentive to the particularities of the space and environment into which they were inserted. The regulation of decommissioning and recycling requires the consolidation of a legal framework that promotes safe dismantling, and is therefore a fundamental step to honor the fundamental right to an ecologically balanced environment for present and future generations.

### 3.2. Decommissioning Logistics and Final Disposal

Decommissioning logistics is a complex, multidisciplinary activity requiring meticulous planning. The definition of logistical strategies and final disposal methods for each structure is largely achieved through Multi-Criteria Decision Analysis (MCDA). This tool ensures scientifically grounded choices that account for diverse dimensions, including socio-environmental, financial, health, safety, and other parameters (Wei & Zhou, 2024).

Resolution No. 817/2020 stipulates that all facilities must be removed from the concession area. However, in exceptional cases, partial removal or even in situ retention may be authorized, provided technical and environmental requirements are met and properly justified. In this process, waste management plays a central role in reducing environmental impacts. Waste is classified as hazardous (Class I) or non-hazardous (Class II) under NBR 10.004:2004, with the former requiring disposal at properly licensed landfills.

Cleaning and decontamination procedures are equally critical. Equipment and pipelines impregnated with hydrocarbons require strict safety protocols, involving techniques such as pigging and flushing. Meanwhile, managing naturally occurring radioactive materials (NORM) presents high complexity and follows specific CNEN regulations in Brazil. In these cases, generators must conduct radiological characterization and segregation of materials. NORM must be temporarily stored in appropriate locations and transported in accordance with CNEN-NN-5.01 guidelines.

In this context, the circular economy emerges as an innovative alternative, prioritizing the reuse and recycling of materials to improve resource efficiency and

recover high-value inputs. For vessels, Bill No. 1584/2021 proposes mandating that end-of-life ships be sent to specialized recycling shipyards in Brazil—a measure that, beyond mitigating environmental impacts, could help revitalize the national shipbuilding industry.

### 3.3. Local Social and Environmental Challenges

The development of public policies for decommissioning is framed as an essential pillar for ensuring socio-environmental protection and consolidating a sustainable development model. In this context, such policies aim not only to improve the existing legal framework but also to mitigate the socio-spatial vulnerabilities that emerge in territories and communities affected by the shutdown of energy production systems. Thus, decommissioning requires participatory regulation and planning processes grounded in socio-environmental responsibility to reduce risks, prevent environmental liabilities, and foster economic alternatives that ensure social justice and the continuity of sustainable land use.

In strategic sectors like oil and gas (O&G), public policy is shaped by the actions of regulatory agencies and federal environmental bodies. The National Petroleum Agency (ANP), the Brazilian Institute of Environment (IBAMA), and the Brazilian Navy (MB) simultaneously exercise regulatory and policing authority over the industry. For offshore decommissioning—a complex and environmentally high-risk segment—coordination between federal entities and agencies is crucial. ANP Resolution No. 817/2020 was jointly developed by ANP, IBAMA, and the Brazilian Navy to standardize procedures and harmonize the review of Facility Decommissioning Plans (PDI), ensuring greater legal certainty and speeding up the process (Meireles, 2022).

However, in the Socio-Environmental Rule of Law, responsibility for environmental preservation is assigned not only to the State but also to the society in which we are embedded. This shared responsibility creates the need for public participation in decision-making and oversight of government actions. Yet it is undeniable that market and development interests are prioritized over society's core interests, making it necessary to adjust regulations so they contain no loopholes that could penalize the areas where these operations are installed and later dismantled (Teixeira, 2013a).

The key finding is that Brazil's legal framework for decommissioning is inconsistent with environmental law standards and the sustainable development model established by the 1988 Federal Constitution. The end of operations is a period of significant environmental vulnerability, requiring strict state oversight, as the operator no longer has financial incentives, leaving the site prone to severe environmental damage (Meireles, 2022).

Therefore, public involvement in environmental decision-making is essential, particularly through instruments available in Brazil, such as access to Public Hearings during environmental licensing (EIA/RIMA), as well as other forms of Popular Action that ensure the exercise of environmental citizenship. Equally urgent

is strengthening institutional cooperation among federal entities to align sectoral and environmental regulations and prevent overburdening specific agencies.

### 3.4. Public Policy and the Participation of Federal Entities

The decommissioning of facilities presents a range of social and environmental challenges requiring multi-criteria assessment and tailored solutions. These challenges manifest in various dimensions, such as protecting human health and ecosystems, as well as the socioeconomic impacts on adjacent communities. In many cases, the process can lead to soil and water contamination, with risks of pollutant mobilization during dismantling activities, which generate large volumes of waste. Notable examples include metals, plastics, hazardous waste (Class I, such as flammable, toxic, reactive, and corrosive materials), hydrocarbons, and Naturally Occurring Radioactive Materials (NORM).

Socially, the impacts are just as far-reaching. Specialist literature shows that consequences vary with local context, often outpacing the forecasts made in initial studies. Research carried out by the Wind-Energy Observatory at the Federal University of Ceará offers an illustration. The study by [Bastos and Moura \(2023\)](#) on the Quilombo do Cumbe in Aracati shows that one of the most striking social effects of wind-farm construction was the abandonment of children born from relationships between local young women and temporary workers brought in from other regions. This example prompts the question: would simply removing the structures and ceasing operations during decommissioning be enough?

Another recurring social impact is unemployment. Social evaluation parameters must consider the relationship between the project and the local community, whether it will interfere with existing activities, and most importantly, how residents will sustain themselves after operations cease. [Martins \(2018\)](#), in analyzing the decommissioning of the Jorge Lacerda Thermoelectric Complex, highlighted that the facility directly and indirectly employed approximately 28,000 workers, representing a dependent population of around 110,000 people. This case demonstrates how the closure of a production cycle can trigger mass unemployment and income loss in regions where job opportunities are scarce ([MARTINS, 2018](#)).

Therefore, decommissioning should not be treated merely as a technical process of shutting down and removing structures, but as a strategic phase of territorial and environmental planning. Adopting proactive, participatory early planning that directly involves impacted communities, coupled with ongoing investment in detailed socio-environmental studies, is essential to balance technical and economic efficiency with long-term social and environmental viability. This approach ensures decommissioning projects can operate effectively and equitably.

## 4. Regulation

### 4.1. National Regulation

There is significant uncertainty regarding decommissioning regulations in Bra-

zil—specifically, whether clear rules exist for this phase of the petroleum sector’s production chain. This stems from the fact that existing legislation lacks specificity for the processes involved in decommissioning projects. This section aims to clarify, within Brazil’s legislative framework, which norms govern this economic activity.

The regulatory framework that decisively influences decommissioning projects in Brazil consists of two specific international treaties on dismantling processes, broader federal legislation on waste concepts, and finally, resolutions from the sector’s regulatory agency.

Given the importance of the protected legal asset, the principles applicable to International Environmental Law are not embodied in a single instrument or a few normative documents. It is also crucial to highlight the guiding principles of International Environmental Law—essential to this topic—as outlined in the 1972 Stockholm Declaration and later reaffirmed in the ECO92 Rio Declaration and the Conference on Sustainable Development (Rio+20). These demonstrate the evolution of International Environmental Law concerning environmental damage (Rosado, 2015).

The development process for an international regulatory regime also led to the signing of the United Nations Convention on the Law of the Sea (UNCLOS) in Montego Bay, Jamaica, on December 10, 1982. The treaty entered into force only on November 16, 1994. The Montego Bay Convention established detailed regulations on maritime space and its resources, including, among others: provisions regarding territorial seas, contiguous zones, continental shelves, exclusive economic zones, and the high seas; protection and preservation of the marine environment; and scientific research, development, and transfer of marine technology (UNCLOS, 1996).

A key highlight of the Convention is its concern with the exploitation of ocean resources and their subsoil, the delimitation of national jurisdiction limits for each matter, and the consolidation of customary principles that states must observe in the joint use of the ocean, such as: freedom of the seas, the exercise of states’ internal jurisdiction within the limits of the sea adjacent to the state, and the characterization of the continental shelf (UNCLOS, 1996).

The Convention stipulates that disused or abandoned structures must be removed to ensure the maintenance of fishing activities and vessel traffic in the area, as well as to safeguard the rights and obligations of other states and ensure proper protection of the marine environment (UNCLOS, 1996).

Consistent with UNCLOS’s position are the IMO (International Maritime Organization) resolutions, applicable to Brazil as a member of that organization, which incorporated the Convention on the International Maritime Consultative Organization, signed in Geneva on 6 March 1948, by means of Decree No. 52,493 of 23 September 1963 (Rosado, 2015).

The IMO is a specialized United Nations agency responsible for regulating maritime transport and preventing sea pollution caused by ships, issuing specific res-

olutions for activities involving sea use (Menezes, 2015).

Among these resolutions, IMO A.672 stands out, establishing standards and guidelines for the removal of offshore installations and structures on the continental shelf and in the exclusive economic zone. Complementing the Montego Bay Convention, the IMO recognizes exceptions to the removal rule and provides detailed regulations on partial removals and abandonment (Menezes, 2015).

Brazil also acceded to the Basel Convention through Decree No. 875/1993, which incorporated it domestically, and through CONAMA Resolution No. 452 of July 2, 2012, addressing waste import procedures. This resolution outlines processes and specifies licenses required by importers of hazardous substances (Meireles, 2022).

Should Brazil become an attractive hub for vessel decommissioning, dismantling, and recycling, and begin receiving international ships for this purpose, this Resolution will be one of the standards operators must follow (Meireles, 2022).

In contrast to the international regulations applicable to Brazil, Federal Law No. 12,305/2010, known as the Solid Waste Law, is broadly framed to ensure applicability across sectors without major distinctions. The law, which establishes the National Solid Waste Policy, provides several definitions in its second chapter, including Article 3 (XVI), which states that solid waste comprises ‘materials, substances, objects or goods discarded as a result of human activities in society,’ with classifications that contribute to a better understanding of solid waste according to origin and hazard (BIM, 2017).

The next regulation analyzed comes from the sector’s regulatory body, ANP (National Petroleum Agency) Resolution No. 27/2006, governing facility decommissioning and area restoration during production and exploration phases. Here, the ANP aligns with international regulations and recognizes the possibility of partial removal and abandonment (BIM, 2017).

The Agency’s criteria require the concessionaire to ensure that facilities remain in safe condition and pose minimal risk to the environment and human health. The ANP recognizes that non-removal—or partial removal—of installations must be technically justified and authorized by the competent authorities, and also provides that any production facility whose removal is inadvisable must be buried below 55 meters (BIM, 2017).

Under this legislation, the ANP also recognizes the potential use of structures for artificial reef creation, subject to approval by competent authorities. In such cases, the concessionaire remains responsible for maintenance and monitoring (BIM, 2017).

The ANP resolution on decommissioning provides a pathway for developing projects to convert decommissioned structures into artificial reefs. However, environmental issues still have to be regulated by IBAMA (Brazilian Institute of Environment and Renewable Natural Resources), since ANP Resolution No. 817 does not address this matter (Cruz & Santos, 2019).

To achieve this objective, IBAMA issued Normative Instruction No. 28, which

outlines the environmental licensing process for installing artificial reefs within federal jurisdiction. Additionally, IBAMA imposes further conditions for approving artificial reef projects, specifying in Article 10 of Normative Instruction No. 28 that if a project includes excessive amounts of hazardous materials, potential pollutants, heavy metals, or substances that could cause injuries or accidents, it will be deemed unfeasible (Milaré, 2015).

It is understood that regulatory approval for the installation and use of decommissioned structures for artificial reef construction—within the bounds of situation-specific technical recommendations—would align with SDG 14, as it would promote ocean conservation and sustainable use. Managing the converted reef structure post-decommissioning is a critical project phase, as it may require new institutional regulatory frameworks (Milaré, 2015).

#### **4.2. International Standards: IMO, Basel Convention, Hong Kong SAR Convention**

This section covers the main international standards on decommissioning: the IMO, the Basel Convention, and the Hong Kong SAR Convention. These were created to ensure that decommissioning is carried out in compliance with environmental and safety legislation.

Decommissioning is the final disposal/deactivation of complex facilities in the oil & gas industry, of naval warships, or the dismantling of abandoned vessels and their proper disposal.

The first international standard discussed here is the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, adopted by the UN on March 22, 1989. It was created to establish international control mechanisms for hazardous substances crossing borders. Countries adhering to this convention must uphold the principle of prior and explicit consent for the transit and import of hazardous waste (Basel Convention, 1989 as cited in Meireles, 2022).

On July 19, 1993, through Decree No. 875, Brazil joined the Basel Convention and committed to achieving its proposed goals, namely:

a) Reduce transboundary waste movements to the minimum consistent with environmentally sound management; b) Minimize the quantity and toxicity of generated hazardous waste and ensure its environmentally sound disposal as close as possible to the production site; c) Assist developing countries in the environmentally sound management of hazardous waste they produce.

Among the key requirements imposed on signatory countries are: prohibiting the export of hazardous waste to nations that ban its import or have not given formal written consent; ensuring the availability of appropriate disposal facilities to promote environmentally sound management of hazardous and other wastes; and requiring that those involved in managing hazardous and other wastes within their territory take essential measures to prevent contamination—and, should pollution occur, to mitigate its effects on human health and the environment (Ba-

sel Convention, 1989 as cited in [Meireles, 2022](#)). Those involved in managing hazardous and other wastes within their territory must take essential measures to prevent contamination by such wastes and, should pollution occur, to reduce its effects on human health and the environment (Basel Convention, 1989 as cited in [Meireles, 2022](#)).

By ratifying the Basel Convention, Brazil committed to adhering to its stipulated rules and ensuring the existence of facilities for the proper decommissioning and recycling of vessels within its territory. This aims to prevent the export of such hazardous substances to other countries, thereby safeguarding a healthy environment for all ([Meireles, 2022](#)).

The second international standard addressing decommissioning in this context is the Hong Kong SAR Convention (HKC), which outlines measures for the proper recycling of vessels. It provides guidelines for preparing ships for recycling and for the operation of shipyards.

To mitigate unnecessary risks to human health and the environment, the Hong Kong SAR International Convention establishes guidelines for the safe recycling of end-of-life ships, ensuring that waste from shipbreaking is handled in an environmentally sound manner (Hong Kong SAR International Convention, 2009, as cited in [Meireles, 2022](#)).

[Meireles, Pereira, and Rodrigues \(2022\)](#) highlight that the HKC's key provisions include: mandatory preparation of an inventory of potentially hazardous materials in ship structures (to control these substances); a recycling plan requirement for each vessel; and the implementation of certification and authorization systems to regulate ship recycling facilities (Hong Kong SAR International Convention, 2009, as cited in [Meireles, 2022](#)).

Furthermore, the HKC also seeks to compel shipowners to responsibly dispose of their vessels at the end of their operational lives, rather than selling them to third parties who may dismantle them irresponsibly and hazardously—a practice notably observed in parts of Asia and globally criticized for its harmful effects ([Meireles, 2022](#)).

Despite its significant provisions on decommissioning, the aforementioned convention has yet to enter into force, as its validity hinges on meeting concurrent criteria that remain unfulfilled ([Meireles, 2022](#)).

Following its future enactment, it is crucial to emphasize the importance of Brazil eventually joining the HKC, as it establishes standards guiding best practices in ship recycling processes. These include procedures for recycling facilities and monitoring hazardous materials aboard vessels through the implementation of a hazardous materials inventory ([Meireles, 2022](#)).

Lastly, the final international regulation to be addressed pertains to the resolutions of the IMO (International Maritime Organization), which apply to Brazil as a member state. This stems from Brazil's internalization of the Convention on the International Maritime Consultative Organization, signed in Geneva on March 6, 1948, through Decree No. 52,493 of September 23, 1963 ([Rosado, 2015](#)).

The IMO is a specialized United Nations agency responsible for regulating maritime transport and preventing marine pollution caused by ships, issuing specific resolutions for activities involving sea use. Among these, IMO Resolution A-672 stands out, establishing standards and guidelines for the removal of offshore installations and structures on the continental shelf and in the exclusive economic zone. Complementing the Montego Bay Convention, the IMO acknowledges exceptions to the removal rule, providing detailed regulations on partial removals and abandonment (BIM, 2017).

IMO Resolution A.672 stipulates that removal decisions must be assessed case by case, considering a multicriteria analysis involving: potential impacts on navigational safety and other maritime uses; the material's deterioration rate and its present and future effects on the marine environment; potential harm to marine resources; risks of future material displacement; costs, technical feasibility, structural damage risks, and hazards to removal operators; and justification for leaving installations or structures on the seabed (Rosado, 2015).

The resolution also specifies cases in which complete removal is mandatory regardless of other criteria. These are: disused or abandoned structures in water depths of less than 75 m and weighing under 4000 t (excluding decks and facilities); or disused or abandoned structures in water depths of less than 100 m and weighing under 4000 t (excluding decks and facilities) that were installed before 1998 (Antunes, 2009).

### 4.3. Bill No. 1584/2021: Vessels and Recycling

Bill No. 1584/2021 seeks to tackle this issue by closing the legislative gap, linking vessel disposal to recycling. It should be noted that Brazil currently has no regulations on ship recycling, which prevents Brazilian shipyards from operating in this sector. Against this backdrop, we propose an analysis of Bill No. 1584/2021 (Brasil, 2021a as cited in Meireles, 2022).

The sole paragraph of Article 2 of the regulation stipulates that its provisions apply to all ship recycling yards and all vessels in AJB, regardless of their flag, with two exceptions: Navy vessels and vessels under eight meters in length without fixed mechanical propulsion (Brasil, 2021a as cited in Meireles, 2022).

On the other hand, Article 4 of the regulation in question provides definitions for the terms used therein, enabling a more precise delineation of its scope (Meireles, 2022). In this context, item XVII of Article 4 establishes that ship recycling is 'the activity of total or partial dismantling of a vessel in a ship recycling yard, with the purpose of recovering components and materials for reprocessing,' also encompassing the management and handling of hazardous substances (Brasil, 2021a as cited in Meireles, 2022).

Article 4 further clarifies that the term 'vessel' also covers offshore oil- and gas-exploration facilities that must be decommissioned in the near future (addressed in ANP Resolution No. 817/2020), in addition to boats, barges, and ships that transport people or cargo and are already commonly understood as vessels (Meireles, 2022),

as follows:

Any structure, including floating platforms and, when towed, fixed ones, that is subject to registration with the maritime authority and is capable of moving on water, whether self-propelled or not, for the transport of persons or cargo (BRASIL, 2021a)

With regard to recycling, the bill is highly relevant for directing vessels to recycling, and it sets out the steps and guidelines that the owner must follow to prepare the vessel for recycling, namely (Brasil, 2021a as cited in [Meireles, 2022](#)): “Maintain an inventory of hazardous materials (in the form proposed by the IHM in the HKC) to be compiled before the vessel enters the yard, so as to minimize the amount of waste remaining on board after the operation, and to hold a certificate of readiness for recycling issued by the competent authority.”

By requiring the owner of a vessel to decommission it properly and send it for recycling, the proposed regulation will close a regulatory gap and help tackle the problem of improper disposal and the emergence of ship graveyards, a situation the country currently faces ([Meireles, 2022](#)).

## 5. Very Large Floating Structures (VLFS) as a Sustainable Solution

### 5.1. Benefits of Reusing VLFS Post-Decommissioning

Driven by growing interest in deep-water natural-resource exploration, the environmental impact of the offshore production chain has moved to the forefront of debate. Concern for sustainability is now unmistakable, especially in oil- and gas-related activities—sectors viewed as controversial amid climate change and the energy transition. Consequently, every stage of offshore operations must minimize impacts, decommissioning included.

In the early days of the oil-and-gas industry, many structures were installed with no clear plan for the end of production; they were simply abandoned or sunk once their useful life was over, sidestepping the high cost of proper planning and disposal. As the offshore sector matured, however, decommissioning—the phase in which facilities are taken out of service—gained prominence and is now deemed essential to the life cycle of deep-water projects, above all because of safety and environmental concerns. According to [FGV Energia \(2024\)](#), decommissioning comprises: process planning, integrity assessment, depressurization, removal of residual contaminants, isolation, disconnection, cutting and lifting the platform in manageable sections, removal or abandonment of production-infrastructure lines, dismantling, and final disposal. The early steps are tightly regulated to ensure legal compliance and mitigate environmental harm, whereas the later steps can be tailored to the chosen post-decommissioning solution, allowing cost savings and logistical optimization—so long as the solution remains within regulatory bounds.

Today, the main options for decommissioned platforms are: leave-in-place for reuse, complete removal, partial removal, or toppling—each carrying distinct eco-

conomic, environmental, and logistical trade-offs. Complete removal entails full disassembly of the platform, transport to shore or, in some cases, controlled sinking in authorized areas. Although it incurs high costs and significant environmental impacts during decommissioning, it eliminates permanent interference with the marine environment and shipping lanes once the platform is gone. Partial removal consists of taking off only the topsides or high-risk sections, leaving part of the structure submerged. It carries intermediate cost, causes less environmental disturbance during decommissioning, yet creates greater long-term occupation of marine space. Toppling—depositing the structure on the seabed close to its original position—proves the least viable option because of safety and environmental risks. Finally, reuse through preservation and adaptation of the platform for new functions offers low cost, minimal environmental interference, and lower safety risks during decommissioning, even though it entails maintenance challenges, stricter legal hurdles, and continued occupation of marine space (Santos et al., 2024).

Among the post-decommissioning solutions, the most promising approach is repurposing the structure, thereby transforming a liability into a socioeconomic asset. Rather than scrapping these platforms, they can be adapted for new functions, extending their lifespan and reducing waste generation. Maintenance for reuse offers not only environmental benefits but also economic and logistical advantages, which may incentivize public agencies and corporations to adopt this practice. Adapting platforms for new purposes leads to significant cost reductions and optimizes the logistical and strategic aspects of dismantling and disposal—particularly in cutting, transportation, and material management. Additionally, environmental impacts and safety risks during decommissioning are minimized, primarily through reduced waste handling and fewer hazardous operations, resulting in less disruption to marine ecosystems. Finally, these platforms can host new business opportunities, accelerated by leveraging existing infrastructure, generating profit from post-decommissioning economic activities (Santos et al., 2024).

## 5.2. Technical, Regulatory, and Environmental Challenges

Despite being the most advantageous alternative in economic, environmental, and safety terms compared to other decommissioning solutions, platform repurposing still faces implementation barriers. The first challenges are regulatory: under ANP Resolution No. 817/2020, all installations must be removed from the contracted area, so alternatives such as partial removal or permanent in-situ retention may only be admitted as exceptions, provided applicable regulatory requirements are met and properly justified. Therefore, it is clear that maintaining platforms for reuse is still restricted by legislation and lacks clear regulatory frameworks for oversight and compliance, creating barriers to fully realizing its benefits (Santos et al., 2024).

Regarding environmental issues, even though platform reuse is regarded as the alternative with the lowest environmental impact, it still demands careful atten-

tion to be considered a sustainable solution. The advantages relate to less interference with the marine ecosystem, since complete dismantling or sinking of the structure is avoided—along with the use of explosives, marine-life mortality, and displacement of native species to the coast caused by full platform removal—and to oil spills and release of toxic substances into the sea from platform toppling. Additionally, the effects on local ecosystems—such as the transport of fouling organisms to new ecosystems and alterations to marine habitats, currents, and food chains due to platform relocation or modification—must be monitored long-term to assess the biodiversity and water quality impacts of repurposed structures (Santos et al., 2024). Moreover, the impact on local ecosystems—such as the transport of fouling organisms to new habitats and the alteration of marine environments, currents, and food webs caused by relocating or modifying the platforms—must be monitored over the long term to assess the effects of the repurposed structure on biodiversity and water quality (Santos et al., 2024).

Finally, the technical challenges are related to maintaining the structure after its service life and adapting it to a new function. First, once its original purpose has ended, it is necessary to ensure thorough cleaning and decontamination—including the complete removal of hydrocarbon residues, heavy metals, and biological fouling—to avoid environmental and health risks, as well as to verify structural integrity, since many aging platforms suffer from corrosion, fatigue, and material wear, requiring costly inspections and reinforcement. Next, one must plan the adaptation to new uses—such as layout changes, hull reinforcement, and installation of new systems—as well as relocation, since moving large structures to another region involves stability risks, seabed impacts, and high costs (FGV Energia, 2024).

### 5.3. Innovative Applications

#### 5.3.1. Floating Power Platforms

Driven by the growing share of renewables in the energy mix, one of the most promising reuse strategies is to convert fixed or semi-submersible platforms into offshore power-generation facilities. These structures are retrofitted to produce renewable energy in deep water, taking advantage of favorable wind, solar, and wave conditions to turn former oil and gas platforms into sustainable generation units. However, beyond the usual barriers to platform reuse—high upfront adaptation and maintenance costs, regulatory issues including specific environmental licensing, safety, and logistics—there are still challenges unique to each type of offshore generation.

The reuse of post-decommissioned offshore platforms for wind-power generation has been studied as a sustainable alternative that cuts high dismantling costs and taps Brazil's coastal wind resource. The northeast coast offers exceptional wind conditions, making it feasible to install offshore wind turbines on the jackets of decommissioned fixed platforms. The main benefits of this practice include the reduction of environmental impacts through the reuse of existing structures,

waste reduction, and contribution to the energy transition. However, significant barriers remain: many Brazilian jackets, originally designed for oil exploration, do not meet the structural criteria required by modern large-scale turbines (10 MW or more), and there are also regulatory and financial uncertainties that hinder large-scale implementation. Thus, reuse presents great potential but depends on technical solutions for structural reinforcement and advances in the national regulatory framework to establish itself as a viable alternative (Quissanga, Nascimento, & Galgoul, 2020).

The reuse of post-decommissioning offshore platforms for solar power generation emerges as an innovative alternative to the challenge of sustainable energy transition. These structures, already installed in maritime areas, could be adapted to receive photovoltaic panels, taking advantage of the ample available space and the favorable natural cooling conditions provided by water, which increases efficiency by up to 15% compared to terrestrial plants. Among the benefits are the use of existing infrastructure, reduced pressure for large areas on land, and contribution to the diversification of the Brazilian energy matrix. However, significant barriers persist, such as the high costs of adaptation and maintenance, specific design requirements to withstand wave motion, and risks of environmental impacts on marine biodiversity, including reduced water oxygenation due to limited sunlight penetration (Fontes, 2022).

Reusing offshore platforms after decommissioning for wave-energy production represents a strategic opportunity within the sustainable energy transition. Originally built for oil and gas extraction, these structures can be retrofitted to convert the energy of wave- and wind-induced rocking motion into electricity, taking advantage of their existing robust foundations. Key benefits include lower infrastructure costs, extended service life of ocean assets, and the creation of a clean, predictable renewable source that can complement other intermittent sources such as solar and wind. Yet significant barriers remain: the technical complexity of adapting conversion systems to harsh marine conditions, high operation and maintenance costs, and the need for geometric and structural optimization to maximize energy absorption. Thus, the proposal combines technological innovation and sustainability, but it hinges on advances in modeling, prototyping, and regulation to become viable at scale (Braga, 2016).

Floating Power Platforms, which integrate offshore wind, solar, and hydrogen generation, are at TRL 6 - 8, with prototypes and pilot projects in operation in South Korea, Japan, and Norway, demonstrating technical feasibility, but still facing economic challenges associated with the cost of installation and maintenance in the open sea.

### 5.3.2. Maritime Cities and Industrial Hubs

Maritime cities are urban centers strongly connected to the sea—through port, fishing, tourism, or energy activities—and play a strategic role in coastal and global economies. In the context of reusing post-decommissioning offshore platforms, these cities can become innovation hubs by adapting such structures for

renewable-energy generation, marine research, or sustainable tourism. Benefits include stronger local energy security, the creation of skilled jobs, and the stimulation of technological development that reinforces the city's position in the international blue-economy arena. Moreover, by concentrating activities offshore, pressures on already saturated urban and coastal spaces are reduced. The main barriers, however, are the high costs of adaptation and maintenance, the logistical infrastructure required to connect to the onshore power grid, and complex environmental regulations that must ensure the protection of marine biodiversity.

Industrial hubs are logistic and production centers that cluster interconnected economic activities, serving as integration points for value chains and technological innovation. Converting post-decommissioning offshore platforms into industrial hubs allows these structures to be used as bases for energy production and storage, support for floating wind and solar farms, or even centers for ocean monitoring and research. The benefits of this approach include leveraging existing infrastructure, diversifying the energy mix, and creating integrated industrial ecosystems that enhance economic competitiveness. However, the barriers are substantial: they involve high technological and financial investment, the need to ensure operational safety in severe offshore environments, and dependence on regulatory frameworks and government incentives that enable large-scale deployment.

Maritime Cities and Industrial Hubs are at TRL 4 - 6, still in the prototyping and simulation phase, with conceptual examples in Japan (Ocean Spiral) and the United Arab Emirates (Sustainable Floating City), focusing on resilient urbanism and green infrastructure, but far from large-scale commercial application.

### **5.3.3. Aquaculture, Research, or Defence Bases**

Reusing offshore platforms after decommissioning for marine aquaculture represents an innovative strategy for productive ocean integration. In the face of declining fish stocks and growing global demand for seafood, offshore aquaculture emerges as a sustainable alternative to ensure food security and reduce dependence on imports. Utilising existing platforms would cut infrastructure costs, expand open-sea farming areas, and exploit synergies with other activities such as renewable-energy generation. Benefits include large-scale supplies of fish, shellfish, and algae, economic diversification of coastal regions, and the creation of direct and indirect jobs. Nevertheless, significant barriers remain: high maintenance costs in high-energy marine environments, technological requirements to withstand currents and waves, consumer prejudice against farmed fish, and the need for strict environmental controls to avoid impacts on marine ecosystems. Thus, integrating decommissioning and aquaculture can be a viable path, provided it is accompanied by technological innovation, appropriate public policies, and public awareness of the quality of farmed products (Freitas, 2013).

Reusing offshore platforms post-decommissioning for defence purposes fits within the context of protecting the so-called Blue Amazon, a maritime area strategic to Brazil that holds high-value energy, mineral and biological resources.

These structures, originally intended for oil and gas exploitation, could be repurposed as forward surveillance, monitoring and logistics-support points for the Armed Forces, strengthening national sovereignty in areas far from the coast. Benefits include lower costs compared with building new bases, a stronger military presence in sensitive regions and integration of the platforms into strategic systems such as SisGAAz (Blue Amazon Management System), designed for maritime monitoring and defence. However, major barriers persist, such as the high cost of adapting the structures for military use, vulnerability to attack and sabotage, complex open-sea maintenance requirements and the need to comply with international treaties and environmental legislation. Therefore, although they represent a strategic defence resource, their implementation demands strong coordination between security policy, technological development and diplomacy (Sande, 2015).

Floating bases for aquaculture, research, and defense are becoming more established, reaching TRL 8 - 9, with several systems in operation in Norway, China, and Singapore. These applications are considered technically mature and economically viable, benefiting from standardized modules and operation in coastal waters.

#### **5.4. Circular Economy and the SDGs in the Context of Decommissioning**

In the context of offshore platform decommissioning, the circular economy emerges as a strategic alternative for reducing environmental impacts and optimizing resources. Rather than following a linear logic of disposal after the end of service life, the aim is to reuse materials, equipment, and structures, extending their life cycle and reducing the need for new raw materials. This approach favors practices such as steel recycling, recovery of technological components, and adaptation of platforms for new purposes such as renewable energy generation, scientific research, or aquaculture. In addition to mitigating waste and emissions, the circular model strengthens sustainability in the oil and gas sector, aligning with global decarbonization and energy transition commitments (Calderon, 2021).

In post-decommissioning, the circular economy expands its role by encouraging the creation of productive chains focused on reintegrating materials and structures into the economic system. Platforms repurposed as industrial hubs, defense bases, offshore energy parks, or aquaculture centers exemplify the application of this concept, transforming environmental liabilities into economic and social assets. The benefits include reducing costs associated with disposal, generating new business models and jobs, and promoting the so-called blue economy. However, challenges persist, such as the need for technological advances to enable adaptations, clear regulations that encourage circularity, and financing mechanisms that make such projects economically competitive (Calderon, 2021).

In the context of offshore platform decommissioning, the Sustainable Development Goals (SDGs) offer an important framework for guiding decisions that rec-

oncile economic growth, environmental preservation, and social well-being. The activity, which involves the removal, recycling, or reuse of complex structures, connects directly to goals such as SDG 12 (responsible consumption and production) and SDG 14 (life below water), by seeking to minimize impacts on marine ecosystems and ensure proper disposal of materials. Furthermore, the application of sustainable practices during decommissioning can strengthen technological innovation and the circular economy, aligning the oil and gas sector with global energy transition demands and the climate agenda (SDG 13) (FGV Energia, 2024).

In post-decommissioning, the incorporation of the SDGs expands opportunities to transform former liabilities into socioeconomic and environmental assets. Decommissioned structures can be adapted for renewable energy generation, sustainable aquaculture, scientific research, or industrial hubs, contributing to goals such as SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth) and SDG 9 (industry, innovation and infrastructure). In this way, the process is not limited to the closure of operations, but becomes part of an integrated sustainable development strategy that generates value for coastal communities, promotes social inclusion, and strengthens the so-called blue economy. However, achieving this potential depends on clear regulatory frameworks, financial incentives, and mechanisms of governance that ensure compatibility between investments and the commitments undertaken by Brazil in the 2030 Agenda (FGV Energia, 2024).

Finally, the integration of the Circular Economy and the SDGs in Decommissioning is situated in TRL 3 - 5, representing an emerging approach focused on material reuse, recycling, and conversion of platforms for new uses (such as energy or logistics VLFs). This aspect still requires regulatory advancements, economic incentives, and standardized methodologies for measuring environmental impacts and benefits.

## 6. Final Consideration

Offshore decommissioning represents one of the greatest contemporary challenges for the oil and gas industry, requiring integrated solutions that balance operational efficiency, safety, and sustainability. A comparison between onshore and offshore projects shows that while the marine environment imposes higher costs and greater technical risks, it also offers unique opportunities for innovation, especially in the reuse of floating structures and integration with new energy sources.

VLFS (Very Large Floating Structures) stand out in this context as a strategic driver of the energy transition, allowing the repurposing of decommissioned platforms for logistical, scientific, and renewable generation functions (offshore wind and solar). This approach not only reduces environmental liabilities but also contributes to creating a circular economy in the maritime-energy sector.

From a regulatory perspective, it is essential that Brazil improve its regulatory framework—such as ANP Resolution No. 817/2020—by integrating more robust environmental guidelines and incentives for technological innovation, similar to

what occurs in the United Kingdom and Norway.

Very Large Floating Structures (VLFS) are emerging as strategic solutions for the offshore energy transition, offering a promising path for the sustainable reuse of decommissioned assets, renewable energy generation, and the integration of industrial processes in the marine environment. This study demonstrates that Brazil-South Korea cooperation can catalyze significant advances in ocean engineering, combining Korean technological maturity with Brazilian expertise in offshore exploration, opening space for innovation, technology transfer, and strengthening the blue economy.

However, research gaps remain that need to be addressed to consolidate the large-scale adoption of VLFS. First, there is a need for long-term studies on the ecological and oceanographic impacts resulting from the conversion and continued operation of repurposed structures, especially regarding the alteration of benthic ecosystems and local biogeochemical cycles. Second, research into new structural materials—such as hybrid composites, lightweight alloys, and intelligent anti-corrosion coatings—is essential to enable the retrofitting of existing platforms and increase their durability under harsh conditions. Finally, there is a lack of integrated economic and regulatory models capable of quantifying positive environmental externalities, structuring financial incentives, and aligning VLFS projects with global carbon neutrality targets and maritime SDGs.

Therefore, future research should prioritize multidisciplinary approaches, combining engineering, economics, law, and environmental sciences, to consolidate the technical, ecological, and institutional viability of floating light rail systems (FLRS). Only with this integration will it be possible to transform floating structures into pillars of a just, resilient, and globally sustainable energy transition.

Finally, sustainable decommissioning in the country must be guided by regulatory transparency and predictability for investors, integrated planning between ANP, IBAMA, and the Navy, incentives for research in cutting, removal, and reuse technologies, and recognition of VLFS as a solution for a just and efficient energy transition.

Thus, decommissioning ceases to be merely a legal obligation to become an opportunity for innovation and industrial reconversion, contributing to a new sustainable cycle of the Brazilian blue economy.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

- A&O Shearman (2023). *Q&A: What Disputes Risks Will Flow from the Decommissioning of High-Carbon Infrastructure*.  
<https://www.aoshearman.com/en/insights/decarbonization-disputes/>
- Albeldawi, M. (2023). Chapter 10—Environmental Impacts and Mitigation Measures of Offshore Oil and Gas Activities. *Developments in Petroleum Science*, 78, 313-352.
- Amorim, C. A. (2010). *Comparative Analysis of Different Types of Offshore Platforms*.

UFRJ.

Antunes, P. de B. (2009). *Environmental Law*. Atlas.

ATSE—Australian Academy of Technological Sciences & Engineering (2024). *Offshore Oil and Gas Decommissioning—Technologies*. Report.

<https://www.atse.org.au/what-we-do/strategic-advice/offshore-oil-and-gas-decommissioning-technologies>

Bastos, E. E. G., & Moura, A. R. B. (2023). *Children of the Wind: Wind Energy and Socio-environmental Impacts in the Cumbe Quilombo, in Aracati*. Undergraduate Thesis, Federal University of Ceará.

Ben-Hamadou, R., Mohamed, A. M. D., Dimassi, S. N., Razavi, M. M., Alshuiael, S. M., & Sulaiman, M. O. (2022). Assessing and Reporting Potential Environmental Risks Associated with Reefing Oil Platform during Decommissioning in Qatar. In L. Cochrane, & R. Al-Hababi (Eds.), *Sustainable Qatar* (pp. 167-191). Springer.

[https://doi.org/10.1007/978-981-19-7398-7\\_10](https://doi.org/10.1007/978-981-19-7398-7_10)

Bim, E. F. (2017). Decommissioning Offshore Oil and Gas Installations. *Revista do Advogado*, 37, 60-66.

BOEM—Bureau of Ocean Energy Management (2004). *An Assessment of Techniques for Removing Offshore Structures*. U.S. Department of the Interior.

<https://www.boem.gov/sites/default/files/boem-newsroom/Library/Publications/2004/2004-074.pdf>

BOEM—Bureau of Ocean Energy Management (2018). *Rigs-to-Reefs Program in the Gulf of Mexico*.

BRAGA, Gonçalo Mesquita Guimarães Oliveira (2016). *Desenvolvimento de tecnologia para produção de energia a partir do movimento de plataformas flutuantes offshore multi-funcionais*. Dissertação (Mestrado em Engenharia Civil), Universidade do Porto.

Calderon, H. L. (2021). *Economia circular e o descomissionamento offshore: Desafios e oportunidades*.

CIRP Encyclopedia of Production Engineering (2019). *Water-Jet Cutting*. Springer.

Climate and Pollution Agency (CPA) (2011). *Guidelines for Decommissioning Activities*. Ministry of Environment Norway.

Colaleo, G., Nardo, F., Azzellino, A., & Vicinanza, D. (2022). Decommissioning of Offshore Platforms in Adriatic Sea: The Total Removal Option from a Life Cycle Assessment Perspective. *Energies*, 15, Article No. 9325. <https://doi.org/10.3390/en15249325>

Cruz, D. S., & Santos, J. V. M. (2019). *Tendência do Descomissionamento de Plataformas Marítimas no Brasil*. TCC-Universidade Federal Fluminense.

Da Costa, L. F., Losekann, D. V., Oliveira, D. R. d., Dos Santos, E. M., Costa, H. K. M., & Brito, T. L. F. (2021). Decommissioning of Petroleum Production: Decommissioning Methods and CO<sub>2</sub> Capture. *Brazilian Journal of Development*, 7, 88186-88200.

<https://doi.org/10.34117/bjdv7n9-128>

DEP2WIND (2024). *A Data-Driven Framework towards Sustainable Reuse of Decommissioned Petroleum Platforms as Support Structures for Wind Energy Production*. European Commission/CORDIS.

Ekins, P., Vanner, R., & Firebrace, J. (2006). Decommissioning of Offshore Oil and Gas Facilities: A Comparative Assessment of Different Scenarios. *Journal of Environmental Management*, 79, 420-438. <https://pubmed.ncbi.nlm.nih.gov/16373078/>

FGV ENERGIA (2024). *Cadernos FGV Energia: Descomissionamento Offshore no Brasil—Perspectivas e Alternativas para um Futuro Sustentável*.

Fontes, Y. M. (2022). Energia em alto mar: Considerações sobre a implantação de usinas

- solares offshore e seus Efeitos. *Pensar Acadêmico*, 20, 716-723.  
<https://doi.org/10.21576/pa.2022v20i3.3503>
- Freitas, A. J. C. de (2013). *A aquicultura marinha offshore: Desafios e oportu-nidades para a inovação e sustentabilidade do negócio*. Dissertação (Mestrado em Gestão), ISCTE.
- IBAMA (2015). *Diretrizes ambientais para descomissionamento de instalações de produção de petróleo e gás offshore*. IBAMA.
- IBAMA—Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (2022). *Diretrizes para Avaliação Ambiental de Projetos de Descomissionamento Offshore*. IBAMA.
- Lamas-Pardo, M., Iglesias, G., & Carral, L. (2015). A Review of Very Large Floating Structures (VLFS) for Coastal and Offshore Uses. *Ocean Engineering*, 109, 677-690.  
<https://doi.org/10.1016/j.oceaneng.2015.09.012>
- Machado, C. A. M.; Teixeira, C. A., & Vilani, C. M. (2013). Descomissionamento de Instalações Offshore no Brasil: Aspectos regulatórios e ambientais. *Revista Brasileira de Energia*, 19, 73-91.
- Martins, C. F. (2015). *O descomissionamento de estruturas de produção offshore no Brasil*. Monografia—UFES.  
<https://engenhariaambiental.ufes.br/sites/ambiental.ufes.br/files/field/ano-o-descomissionamento-de-estruturas-de-producao-offshore-no-brasil-cecilia-freitas-martins.pdf>
- Martins, C. P. (2018). *A transição energética e os impactos socioambientais do descomissionamento de sistemas de geração de energia elétrica*. UFSC.
- Meireles, T. P. B., Pereira, N. N., & Rodrigues, L. M. (2022). *Aspectos jurídicos e constitucionais do descomissionamento e reciclagem de embarcações abandonadas na Baía de Guanabara dentro do limite territorial do município de Niterói/RJ entre 2021 e 2022*. Dissertação (Mestrado em Direito Constitucional), Faculdade de Direito, Universidade Federal Fluminense.
- Menezes, W. (2015). *Direito do Mar: Desafios e perspectivas*. Arraes Editores.
- Milaré, E. (2015). *Direito do Ambiente*. Revista dos Tribunais.
- National Academies of Sciences (1996). *An Assessment of Techniques for Removing Offshore Structures*. The National Academies Press.
- National Petroleum, Natural Gas and Biofuels Agency (ANP) (2020). *ANP Resolution No. 817, of April 24, 2020. Provides for the Decommissioning of Oil and Natural Gas Exploration and Production Facilities and Other Measures*. Official Gazette of the Union: Section 1.  
<https://www.gov.br/anp/pt-br/assuntos/exploracao-e-producao-de-oleo-e-gas/se-guranca-operacional/descomissionamento-de-instalacoes>
- NST Authority (2024). *Technology Insights-Facilities Decommissioning 2024*. United Kingdom.
- Oceaneering International (2024). *Cutting Solutions for Offshore Decommissioning*. Oceaneering. <https://www.oceaneering.com/decommissioning/cutting-solutions/>
- Offshore Network (2025). *Enhancing Decommissioning with Advanced Technologies*. <https://offsnet.com/content/north-america/enhancing-decommissioning-with-advanced-technologies>
- Oil and Gas UK (OGUK) (2014). *Decommissioning Work Breakdown Structure Guidelines*.  
<https://oeuk.org.uk/wp-content/uploads/2022/09/OGUK-Decommissioning-Work-Breakdown-Structure-Guidelines.pdf>
- Petrobras (2015). *Descomissionamento Offshore*. Petrobras.

- <https://Petrobras.com.br/sustentabilidade/descomissionamento-offshore>
- Petrobras (2023a). *Descomissionamento Offshore—Diretrizes Técnicas e Ambientais*. Petrobras.
- Petrobras (2023b). *Plano Estratégico 2024-2028*. Petrobras.  
<https://static.poder360.com.br/2023/12/Plano-Estrategico-Petrobras-2024-2028.pdf>
- Pinheiro, M.S., & Monteiro, P. R. D. (2023). Decommissioning Strategies for Fixed Offshore Platforms in Brazil. In *Uniting Knowledge Integrated Scientific Research for Global Development*. Seven Editora. <https://doi.org/10.56238/uniknowindevolp-012>
- Quissanga, V. M., Nascimento, E. A. d., & Galgoul, N. S. (2020). Feasibility Study for the Reuse of a Fixed Offshore Platform as a Substructure for Wind Towers. *Research, Society and Development*, 9, e8618. <https://doi.org/10.33448/rsd-v9i10.8618>
- Rosado, M. (2015). Temas de Direito do Mar e a Atividade Petrolífera. In W. Menezes (Ed.), *Direito do Mar: Desafios e perspectivas* (p. 27). Arraes Editores.
- Ruivo, C., Morooka, C., & Guerra, J. (2001). *Descomissionamento de Instalações Offshore: Desafios técnicos e ambientais*. Interciência.
- Sammarco, P., Atchison, A., & Boland, G. (2004). Expansion of Coral Communities within the Northern Gulf of Mexico via Offshore Oil and Gas Platforms. *Marine Ecology Progress Series*, 280, 129-143. <https://doi.org/10.3354/meps280129>
- Sande, E. A. (2015). *A ANP e o Poder Militar—A Segurança e a Defesa das Plata-formas Offshore*. Monografia—Escola Superior de Guerra.
- Santos, F. O. dos et al. (2024). Abordagem multicritério para descomissionamento de instalações petrolíferas offshore na Bacia de Campos. In *ENMC/ECTM 2024* (p. 12). IFF.
- Schenato, F. et al. (2013). *NORM seresíduos radioativos na indústria do petróleo e gás*. CNEN.
- Shell (2017). *Brent Decommissioning Project—Brent Delta Topside Removal*. Shell U.K. Limited.
- Simpson, G. (1998). The Environmental Management Aspects of Decommissioning Offshore Structures. In D. G. Gorman, & J. Neilson (Eds.), *Decommissioning Offshore Structures* (pp. 1-21). Springer. [https://doi.org/10.1007/978-1-4471-1552-6\\_1](https://doi.org/10.1007/978-1-4471-1552-6_1)
- Sinaval (2024). *Brasil avança no descomissionamento com foco em sustentabilidade, apontam agentes*.  
<https://sinaval.org.br/2024/10/brasil-avanca-no-descomissionamento-com-foco-em-sustentabilidade-apontam-agentes/>
- Syriac, R., & Prakash, M. N. S. (2022). A Review on the Reuse Possibilities of Decommissioned Offshore Fixed Platforms for Marine Renewable Energy Applications. *Journal of Naval Architecture and Marine Engineering*, 19, 71-82.  
<https://doi.org/10.3329/jname.v19i2.50359>
- Teixeira, B. M. (2013a). *Aprimoramento da política pública ambiental da cadeia produtiva de óleo e gás offshore no Brasil: O descomissionamento das tecnologias de exploração*. Tese (Doutorado), UERJ.
- Teixeira, C. A. (2013b). *Descomissionamento de plataformas marítimas e sustentabilidade ambiental*. IBP.
- TOTAL (2010). *Frigg Decommissioning Project—Environmental Statement*. Total E&P.
- UNCLOS (1996). *United Nations Convention on the Law of the Sea Act*.
- United Kingdom Government (UK Government) (2023). *The Use and Environmental Impact of Explosives in the Decommissioning of Offshore Wells and Facilities*. UK Department for Energy Security and Net Zero.

- UTPEDIA (2024). *Decommissioning Options Assessment on Environmental Impact*. UTP.
- Vieira Barboza, D., Jasmim Meiriño, M., Da Silveira Barros, S. R., & Fernandes Bella, R. L. (2023). Towards the Sustainable Decommissioning of Fixed Platforms by Aligning Ecosystem Services and Wind Generation: A Brazilian Case. *International Journal of Energy Economics and Policy*, 13, 235-242. <https://doi.org/10.32479/ijeep.14114>
- Wei, X., & Zhou, J. (2024). Multi-Criteria Decision Analysis for Sustainable Oil and Gas Infrastructure Decommissioning: A Systematic Review of Criteria Involved in the Process. *Sustainability*, 16, Article No. 7205. <https://doi.org/10.3390/su16167205>
- Yamamoto, M., Wada, R., Kamizawa, K., & Takagi, K. (2017). The Concept of Flt. *Marine Systems & Ocean Technology*, 12, 104-116. <https://doi.org/10.1007/s40868-017-0027-1>