Mix Sustentável

Irregular Disposal of Solid Waste in Offshore Areas: Its Problems and Perspectives

Descarte irregular de resíduos sólidos em áreas offshore: seus problemas e perspectivas

Eliminación irregular de residuos sólidos en áreas marinas: sus problemas y perspectivas

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Abstract: Offshore oil platforms operate like small cities and generate a significant amount of waste, much of which is hazardous to human health and the environment. This study analyses the environmental impacts of improper waste disposal, including the formation of plastic islands and the presence of microplastics in marine organisms, which disrupt the food chain. In response to this issue, solid waste management methods such as Reverse Logistics and the Circular Economy are discussed, as they promote material reuse and reduce environmental damage. The study highlights the importance of strategic planning, regulatory oversight, and the encouragement of sustainable corporate practices. Given the growth of offshore activities and the limited research on this topic, there is a pressing need to deepen scientific studies and improve waste management techniques in this sector.

Keywords: Solid Waste; Management; Offshore; Environmental Impacts.

Resumo: Plataformas de petróleo offshore operam como pequenas cidades e geram uma quantidade significativa de resíduos, muitos dos quais perigosos para a saúde humana e o meio ambiente. Este estudo analisa os impactos ambientais do descarte inadequado de resíduos, incluindo a formação de ilhas de plástico e a presença de microplásticos em organismos marinhos, que desorganizam a cadeia alimentar. Em resposta a essa questão, métodos de gestão de resíduos sólidos, como a Logística Reversa e a Economia Circular, são discutidos, pois promovem o reaproveitamento de materiais e reduzem os danos ambientais. O estudo destaca a importância do planejamento estratégico, da supervisão regulatória e do incentivo a práticas corporativas sustentáveis. Dado o crescimento das atividades offshore e a escassez de pesquisas sobre o tema, há uma necessidade urgente de aprofundar os estudos científicos e aprimorar as técnicas de gestão de resíduos neste setor.

Palavras-chave: Resíduos Sólidos; Gestão; Offshore; Impactos Ambientais.

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Resumen: Las plataformas petrolíferas marinas operan como pequeñas ciudades y generan una cantidad significativa de residuos, muchos de los cuales son peligrosos para la salud humana y el medio ambiente. Este estudio analiza los impactos ambientales de la eliminación inadecuada de residuos, incluyendo la formación de islas de plástico y la presencia de microplásticos en organismos marinos, que alteran la cadena alimentaria. En respuesta a esta problemática, se abordan métodos de gestión de residuos sólidos como la Logística Inversa y la Economía Circular, ya que promueven la reutilización de materiales y reducen el daño ambiental. El estudio destaca la importancia de la planificación estratégica, la supervisión regulatoria y el fomento de prácticas corporativas sostenibles. Dado el crecimiento de las actividades marinas y la escasa investigación sobre este tema, existe una necesidad apremiante de profundizar los estudios científicos y mejorar las técnicas de gestión de residuos en este sector.

Palabras clave: Residuos sólidos; Gestión; Offshore; Impactos ambientales.

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1 INTRODUCTION

Offshore oil platforms are units that house infrastructure similar to that of a small city (MAIA *et al.*, 2015). With extensive electrical networks, advanced telecommunications systems, and intense environmental exploration activities, these platforms function as living and complex ecosystems within our society, requiring special attention regarding how waste is disposed of and the environmental impacts generated.

CONAMA Resolution No. 001, dated January 23, 1986, in its Article 1, states: "Environmental impact is considered any alteration of the physical, chemical, and biological properties of the environment, caused by any form of matter or energy resulting from human activities that directly or indirectly affect: I - the health, safety, and well-being of the population; II - social and economic activities; III - the biota; IV - the aesthetic and sanitary conditions of the environment; V - the quality of environmental resources" (CONAMA, 1986).

In this regard, the implementation and maintenance of offshore platforms intersect with all areas mentioned by the resolution, highlighting their high environmental impact potential. This study specifically focuses on the impacts to biota, the aesthetic and sanitary conditions of the environment, and the quality of environmental resources affected by the improper disposal of solid waste.

Considering the physical, economic, and social magnitude of oil platforms, this research is essential due to the importance of waste management—including its proper disposal—and the difficulty, as noted by Rigas (2018) and further detailed in this work, that oil platforms face in segregating, storing, and disposing of solid waste in an ecologically responsible manner. Understanding environmental impact as a natural imbalance arising from a disrupted relationship between anthropogenic and natural forces (SANCHEZ, 2013), oil platforms must adhere to sustainable standards and practices to reduce their environmental footprint and mitigate the pollution potential inherent in their industrial and exploratory activities. To achieve this, it is crucial that academic research integrates years of theoretical knowledge with the daily operations in offshore environments.

According to data from PETROBRAS (2024), the company generated approximately 79.6 thousand tons of hazardous solid waste and 143.9 thousand tons of non-hazardous waste in 2023. For comparison, this represents only 33 times less waste than generated by the city of Rio de Janeiro (FIRJAN, 2023), which has a population of about 6,211,223 people (IBGE, 2022). This comparison underscores the magnitude of the environmental and economic impact posed by the multinational's operations, despite serving a relatively smaller population.

Recognizing the scale and importance of this industrial activity in Brazil, it is essential to delve deeper into the environmental practices adopted in offshore installations and their practical effects on improper waste disposal. In this context, offshore waste management was thoroughly analysed by Rigas (2018), who examined the daily operations of an oil platform through field visits and interviews with workers and managers. His research revealed a significant need for environmental awareness training for workers through the Workers' Environmental Education Program (Programa de Educação Ambiental aos Trabalhadores - PEAT, in Portuguese), which is mandated by the Brazilian Institute of Environment and Renewable Natural Resources (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis - IBAMA, in Portuguese), but often remains a theoretical requirement without practical implementation.

Rigas (2018) concluded his study by stating that "Strict enforcement of PEAT must be the norm so that these aspects do not compromise ongoing pollution control programs, and so that environmental awareness becomes increasingly assertive, with clearer procedures for transferring waste from origin to final destination." This highlights the urgent need for environmental education that is inclusive, comprehensive, and yields practical application rather than remaining confined to theoretical discourse.

On the other hand, the volume of waste generated often exceeds treatment and disposal capacity, leading to improper disposal and, at times, the accumulation of waste in hazardous areas (RIGAS, 2018). Therefore, environmental education programs alone are not sufficient for effective waste management, as workers must also have access to adequate infrastructure and incentives to contribute effectively to the cause (Maia *et al.*, 2015).

The lack of clear objectives, proper oversight, and a structured waste management plan becomes even more alarming when considering that approximately 54% of the waste generated by oil platforms is classified as hazardous to human health and the environment (BRASIL, 2011). Considering this, it is vital to make society and government representatives aware of the real danger posed by improper disposal of such materials to both human health and the planet, requiring serious attention from all involved sectors.

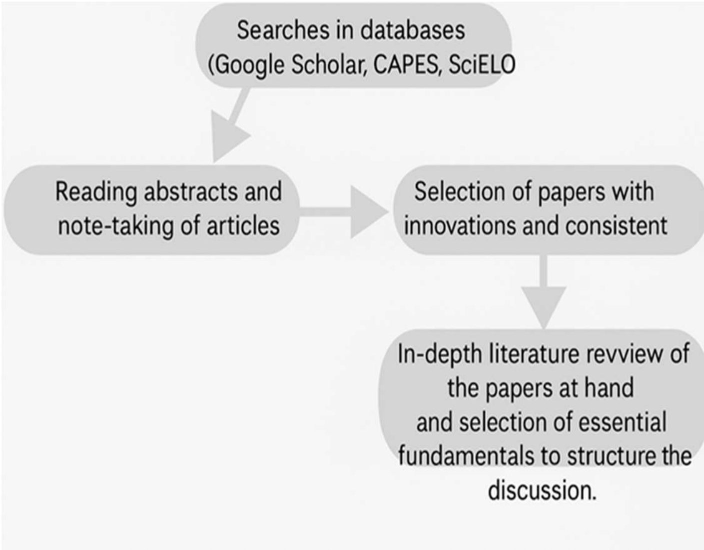
Thus, this paper aims to present multiple perspectives on the topic, intending to outline the current scenario of offshore waste management and propose avenues for its improvement. The study is structured in three parts: the first explores the issues—both for human health and the environment—related to improper solid waste disposal in offshore areas; the second presents a literature review to gather up-to-date information, modern waste management methodologies, and research perspectives for improvement; and the third discusses the current overall landscape of solid waste management in offshore areas in Brazil.

2 METHODOLOGY

The primary methodology employed for the development of this paper was a bibliographic review using search platforms such as Google Scholar, CAPES Journals, and SciELO Brazil. The objective was to identify the most current and relevant academic studies and innovations related to sustainable methods and solutions for solid waste management, in-depth research on the impacts of improper waste disposal on ecosystems, and the scale of waste generation. As illustrated in Figure 1, the methodology followed several steps: searching for academic studies, selecting and summarizing the most relevant works for the topic at hand, prioritizing papers with methodological innovations, and extracting key concepts essential for the theoretical foundation of this scientific research.

In addition, master's and doctoral dissertations were analysed, focusing on case studies that demonstrate the practical functionality and effectiveness of waste management policies on offshore platforms, as well as the broader waste disposal scenario across the country. The entire literature review aimed to capture diverse perspectives and contexts related to waste management, to construct a comprehensive overview that reveals the current landscape and its shortcomings in achieving the sustainability goals that human society aspires to reach.

Figure 1 – Search Methodology.



Source: Prepared by the authors.

3 LITERATURE REVIEW

As discussed throughout this paper, the improper disposal of solid waste in offshore areas constitutes a serious environmental and socio-economic issue for all of human society. The reason is that exploratory operations in marine environments significantly contribute to the accumulation of waste in the ocean, much of which is toxic to both humans and the environment. In order to gain a general overview of the routine solid waste management practices in offshore areas, this study draws upon the works of Maia *et al.* (2015), Nascimento *et al.* (2015), Rigas (2018), and Araruna and Burlini (2013), whose comprehensive studies on environmental education programs and techniques for the proper disposal of waste are discussed throughout this paper. Furthermore, statistical research serves as an essential complement to theoretical studies, especially when dealing with raw data such as sustainability reports from major multinational companies like PETROBRAS and accurate data from institutions such as FIRJAN (2024) and IBGE (2024).

Additionally, the need for proper solid waste disposal—especially waste that can later become hazardous to human life and the marine ecosystem—highlights the critical importance of the National Solid Waste Policy (Law 12.305/2010), which was created to establish principles, objectives, and instruments for waste management (RIGAS, 2018). However, the real-world application of public policies goes beyond the theoretical scope and depends almost entirely on the collective effort of social agents (NASCIMENTO *et al.*, 2015). Therefore, the legislation must clearly define who is responsible for waste management, what tools are required, and most importantly, which authority is tasked with oversight, ensuring an effective structure capable of meeting the high demand for enforcement.

Given these challenges, it is clear that solid waste management remains a significant hurdle for society, due to legislative ambiguity, shortcomings in environmental education, and a lack of enforcement power to ensure compliance with established rules and guidelines (Nascimento *et al.*, 2015). This situation arises because solid waste is addressed by various strands of current public policies—ranging from the Municipal Basic Sanitation Policy, which is the responsibility of local governments, to the National Solid Waste Policy (Law No. 12.305/2010), which is overseen by the federal government. This fragmentation of responsibility creates a grey area in which administrative bodies often evade their duties of intervention (Nascimento *et al.*, 2015).

Pollution resulting from waste generated on board, its onshore disposal, the dumping of residues at sea, and atmospheric emissions must be minimized as much as possible and managed in a way that safeguards both human health and the environment. This is essential for operators to maintain their legal and financial responsibilities (Araruna and Burlini *et al.*, 2013). The integration of multidisciplinary approaches in solid waste management in offshore areas is also indispensable in addressing the complexities of the issue. This includes collaboration among environmental engineers, marine biologists, legislators, and economists to develop strategies that combine technical feasibility, environmental protection, and economic sustainability.

Technologies must be developed and integrated into waste management practices, such as the use of digital monitoring systems and the development of biodegradable materials to mitigate environmental impacts. These tools can be aligned with the implementation of existing public policies, such as the National Solid Waste Policy, as well as the creation of new regulations that address specific gaps. To make this effective, continuous investment in research and innovation is required, along with partnerships among the public sector, private companies, and civil society, ensuring a collective effort capable of minimizing environmental damage and promoting sustainability in offshore operations.

Finally, the analysis of environmental impacts resulting from the improper disposal of solid waste in offshore areas (Figure 2) proves to be a matter of great relevance. This is particularly significant considering the persistent historical practice of discarding waste in prohibited locations, which has led to the accumulation of non-degradable and hazardous substances in marine and coastal ecosystems. Such waste includes plastics, toxic metals, and oil-contaminated engine parts, whose persistence and bioaccumulative potential pose serious risks to biodiversity, water quality, and human health.

In this context, Trindade & Siman (2017) and Sánchez (2013) emphasize that understanding the pathways and long-term effects of these contaminants is essential for the design of preventive and mitigating strategies. These strategies must encompass stricter regulatory enforcement, technological innovation for waste treatment, and the promotion of sustainable operational practices in maritime activities, thereby reducing the ecological footprint and safeguarding the resilience of marine environments.

Figure 2 – Oil platform.

Source: Jonathan G. Gomes, 2024.

4 DISCUSSION

The environmental emergency caused by the irregular disposal of solid waste necessitates a meticulous and in-depth analysis of potential impact scenarios and future perspectives. Within this context, there emerges an urgent need to discuss several critical aspects: the environmental impacts generated by improper waste disposal and its associated problems; current management methodologies aimed at enhancing solid waste management in marine environments, including technological innovations and sustainable approaches; the alignment between public policies and industrial practices; and the current overall panorama of solid waste management in offshore areas within Brazil.

4.1 Improper Waste Disposal and Associated Problems

According to Trindade & Siman (2017), solid waste, when improperly disposed of in the environment, can cause irreversible damage such as degradation, pollution, diseases, and even species extinction. Consequently, it is essential that this topic be debated and studied within academia through extensive research concerning the impact of such waste on ecosystems. This includes developing methodologies for classifying discarded waste according to technical standards (ABNT, 2004) to standardize appropriate responses for the irregular disposal of each material type, alongside advanced methods for environmental education aimed at civil society.

Furthermore, the recurrent improper disposal of solid waste is responsible for numerous impacts on human health and, principally, the environment. Among these are the contamination of surface and groundwater (CARIM *et al.*, 2022). The contamination of water bodies by chemical products, non-degradable refuse, and toxic metals is responsible for the significant ecological imbalance currently observed in marine ecosystems.

Coupled with rising global temperatures and the consequent warming of seawater, the formation of "Plastic Islands" (Figure 3) in the oceans represents a new form of environmental impact that has generated extreme concern within the international scientific community. The formation and buoyancy of these immense garbage patches have led to the mortality of over 1 million animals annually (IBERDROLA, 2024), contamination of fish with microplastics, and—perhaps most critically for humanity in the coming decades—a deficit in photosynthesis performed by marine algae and microalgae. This deficit occurs due to the physical blockage of sunlight in the marine environment by these vast plastic islands, preventing photosynthetic organisms from accessing sunlight and initiating their photosynthetic metabolism.

Figure 3 – Great Pacific Garbage Patch.

Source: Caroline Power Photography, 2024.

In light of this, it can be observed that a single phenomenon resulting from the irregular disposal of solid waste (i.e., Plastic Islands) is already capable of significantly altering the global marine ecosystem, impacting the demographic balance of marine species and the availability of oxygen derived from the photosynthesis of algae and microalgae.

It is important to emphasize that the majority of waste discharged into the oceans does not originate from offshore platforms. Nevertheless, their contribution constitutes an additional factor pushing humanity beyond the Earth's carrying capacity. The impact stemming from solid waste irregularly discarded in the oceans is so substantial, and still not fully understood, that recent studies already demonstrate an alarming presence of microplastics within fish organisms.

As observed in Figure 4, these microplastics, upon ingestion by aquatic organisms, can become incorporated into the musculature or stomach of various marine species consumed by humans (ROMEO *et al.*, 2015). Consequently, the impact is not confined solely to the marine ecosystem but also significantly affects human health on a large scale.

Figure 4 – Microplastics in fish organisms.

Source: Portal Ambiente Legal, 2017.

Another aspect of the environmental impact currently presented by the irregular disposal of solid waste relates to the potential reduction in fishing activity. Considered one of the most significant global economic activities, fishing is an industry responsible for generating food, employment, and income across various economic segments.

It serves as the primary economic engine for cities, states, and even island nations. This potential decline in fishing activity stems from the imbalance within the marine ecosystem and, consequently, the food chain. By causing the mortality of 1 million fish annually, the irregular disposal of waste—and the consequent accumulation of hazardous residues—alters the predation dynamics of the oceans.

This occurs because the demographic decrease in aquatic organisms reduces the food source for tertiary consumers such as sharks, dolphins, and humans. The population reduction of ichthyofauna can lead to the extinction of fish species fundamental to the human diet, such as anchovy and mullet, which once constituted a large part of the fishing market and are now endangered.

All these facts corroborate the need for an effective and comprehensive solid waste management system. However, at the critical threshold the Earth currently faces, merely mitigating future impacts is no longer sufficient. A collective effort towards the remediation of existing impacts within our ecosystems is essential.

4.2 Current Solid Waste Management Methodologies

The initial step in structuring efficient waste management is the correct classification of waste according to its potential risks. This classification defines all subsequent operational stages for handling the waste, namely: collection, storage, transport, handling, and final destination according to each waste type. For this classification, the guidelines found in the Brazilian Association of Technical Standards (Associação Brasileira de Normas Técnicas - ABNT, in Portuguese) - NBR 10.004:2004 are utilized. Waste can be categorized as Class I - Hazardous or Class II - Non-hazardous (ABNT, 2004).

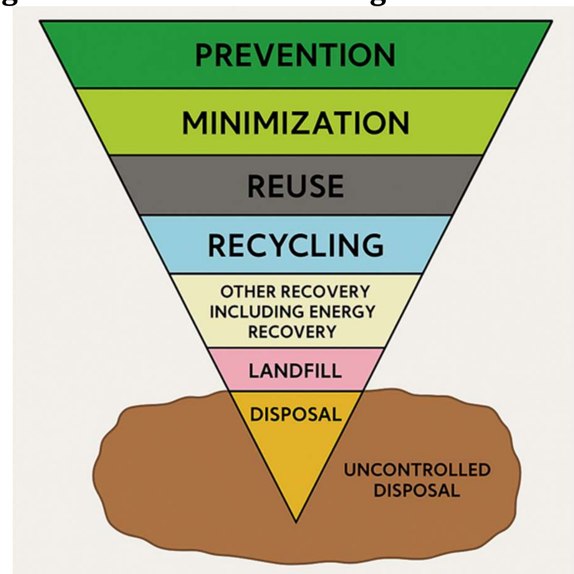
This distinction in classification is fundamental when defining the subsequent management steps, as hazardous wastes are those exhibiting dangerous properties. They may possess characteristics such as: ignitability, corrosivity, reactivity, toxicity, and pathogenicity. Consequently, they pose risks to public health, potentially causing mortality, increasing the incidence of diseases, or exacerbating existing health issues; or risks to the environment when managed improperly. Therefore, greater care is necessary in selecting methods for the collection, storage, and handling of these wastes.

In contrast, inert non-hazardous wastes are those which, when representatively sampled according to ABNT NBR 10007 (ABNT, 2004) and subjected to dynamic and static contact with distilled or deionized water at ambient temperature as per ABNT NBR 10006 (ABNT, 2004), do not have any constituents solubilized at concentrations exceeding drinking water standards, excluding aspect, color, turbidity, hardness, and taste.

Finally, non-inert non-hazardous wastes are those that do not fit the classifications of Class I - Hazardous or Class II B - Inert wastes, under the terms of this standard. Accordingly, Class II A – Non-inert wastes may possess properties such as biodegradability, combustibility, or solubility in water, resembling domestic waste. Their management is simpler as it does not need to account for activities involving hazardous or flammable materials detrimental to human health (BECHARA, 2012).

The best practice in waste management involves preventing pollution and environmental damage. A strategic tool for waste management is the waste hierarchy, as illustrated in Figure 5. This approach seeks to maximize resource use efficiency to generate the minimum amount of waste, employing modern techniques such as reverse logistics and circular economy to address economic, environmental, and social dimensions.

Figure 5 – Solid waste management hierarchy.



Source: UNEP/ISWA, 2015.

Reverse logistics involves operating and controlling the reverse flows of raw materials, such as generated products, utilized by-products, or even finished goods, as well as all materials used from the point of consumption back to the point of origin (Rogers & Tibben-Lembke, 1999).

This reverse logistics dynamic benefits both companies and the environment because it reintroduces materials—which would otherwise be destined for disposal, often improperly—back into the production chain. This material, which would otherwise accumulate as waste in nature, when reintroduced into the business chain, particularly in offshore areas, can represent an 80% reduction in the effort required to manufacture a new product (DOWLATSHAHI, 2000). A common example of reverse logistics is the collection of batteries that would typically be discarded in landfills; however, large companies and governments, under sectoral agreements, engage in a collective effort to reintroduce used batteries into the manufacturing chain for new products.

Another modern technique gaining traction in recent years is the circular economy. As described by Abdalla and Sampaio (2018), "the circular economy aims, therefore, to enable the ideal systematic utilization and reutilization of industrialized products, durable and non-durable goods, from the project design stage through to after their reuse (useful life cycle).". Thus, in conjunction with reverse logistics, the circular economy rethinks the production chain to minimize waste generation and its subsequent irregular disposal into the environment.

Furthermore, the circular economy offers significant alternatives in waste management by minimizing the substantial demand from industries for the extraction of further natural resources destined as raw materials for various manufacturing processes (ABDALLA & SAMPAIO, 2018). The circular economy emphasizes the importance of reuse, which consists of using a product again for its original purpose. A simple example is the reuse of buckets, containers (bombonas), and drums through reverse logistics, as well as oily waste and drilling cuttings. Recycling, on the other hand, is the process of utilizing the raw material from waste to generate a new product with a completely different utility than the original.

After exhausting all options for reuse, recycling, and recovery of waste, treatment is applied prior to final disposal. Various methods and methodologies for waste treatment are available in the market, including physical, biological, thermal, and chemical methods. The physical treatment method is notable for its operational simplicity and its capacity to integrate with other treatment technologies.

It can be used both as a standalone treatment technology and as a pre-treatment for subsequent stages such as recycling, reuse, or chemical and biological treatments. Common techniques within this method include filtration, sedimentation, centrifugation, and flotation, which allow for the removal of solid or liquid contaminants from complex mixtures, such as drilling fluids and oily sludges. It also enables the recovery of valuable materials, like residual oil, and reduces the volume of waste destined for disposal.

The biological treatment method employs sustainable technology utilizing living organisms—such as bacteria, fungi, and other microorganisms—to degrade or transform organic waste like oils, greases, and contaminated sediments into less environmentally harmful compounds, thereby preventing soil and water contamination by hydrocarbons originating from offshore operations. Techniques such as bioremediation, composting, and biostimulation are important for degrading waste like food scraps, sludge, and organic matter residues, which, if accumulated, can be detrimental to ecosystem balance.

The thermal treatment method utilizes a wide range of temperatures to reduce volume, eliminate toxic substances, and, in some cases, recover energy from waste. It is indicated for managing non-recyclable and hazardous waste. Among the most common techniques are incineration, or processing, and thermal desorption, which permit the destruction of hazardous compounds and the conversion of materials into less harmful by-products, such as ash, gases, and recoverable oils. The resulting material depends on the amount of heat applied; low temperatures allow for the recovery of hydrocarbons and water, whereas high temperatures destroy hydrocarbons through combustion.

The chemical treatment method is effective in managing drilling waste, such as contaminated mud fluids, and in remediating soils and sediments impacted by offshore operations. This method involves processes and technologies aimed at neutralizing, stabilizing, or transforming hazardous waste into less environmentally harmful forms. This process entails applying chemical reagents that alter the physical or chemical properties of the waste, such as neutralizing acids and bases, precipitating heavy metals, or oxidizing toxic organic compounds. Techniques may include neutralization, chemical precipitation, solidification, oxidation, and encapsulation.

4.3 Overview of Solid Waste Management in Offshore Areas in Brazil

Since the Industrial Revolution in the 19th Century, waste has represented one of the major challenges to human development. While the topic received limited discussion during the 20th century, solid waste management, particularly in offshore areas, has become a central issue in the global environmental debate in the 21st Century. This focus reflects the growing concern among developed societies to align industrial progress with sustainable practices, emphasizing the need for effective strategies to minimize environmental impacts, as highlighted by Bechara (2010).

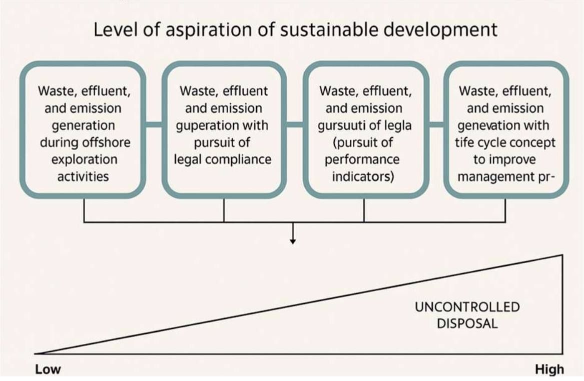
The increasing demand for energy, coupled with the likelihood that the oil industry will be responsible for meeting this substantial demand for several decades, presents offshore organizations with the challenge of balancing several priorities: discovering new abundant reserves, maintaining low production and extraction costs, and meeting societal expectations regarding socio-environmental criteria.

To measure a company's sustainable development, sustainability indicators are employed, considering economic, social, and environmental impacts. In 1999, the New York Stock Exchange established the world's first corporate sustainability index, the Dow Jones Sustainability World Index. This index serves as a global benchmark, although other internationally recognized indices exist. Offshore companies utilize international indicators for reasons including legal compliance, improved resource productivity, tax exemptions and incentives, requirements from insurers, and securing credit or loans from banks.

Within the offshore industry, the integration of solid waste, liquid effluent, and atmospheric emission management is a priority in operations and decision-making. Beyond generating legal incentives for sustainable management, this integration enhances opportunities to realize social, financial, and economic benefits. Waste management constitutes part of the metrics within corporate sustainability indicators. Figure 6 illustrates the level of ambition for sustainable development among companies, indicating that more efficient waste management correlates with a greater aspiration for companies to align with sustainable development goals.

In Brazil, solid waste management must comply with the provisions of the National Solid Waste Policy, Law No. 12.305, of August 2, 2010 (Law 12.305, 2010). This law contains fundamental instruments to enable the necessary advancements for the country in addressing the primary environmental, social, and economic problems resulting from inadequate solid waste handling.

Figure 6 – Level of corporate ambition for sustainable development.



Source: Adapted from Araruna and Burlin, 2013.

According to the environmental agency responsible for licensing maritime exploration activities (IBAMA), a waste management system should prioritize 4 fundamental aspects (Araruana e Burline, 2013):

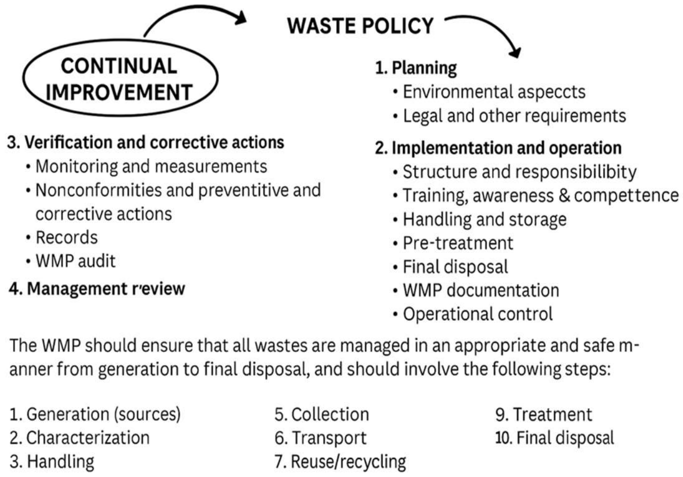
1) Generate the minimum possible amount of solid waste, liquid effluents, and atmospheric emissions;
2) Recycle the maximum possible amount of landed waste;
3) Ensure the proper final disposal, according to current normative instruments, of all landed and non-recycled waste; and
4) Seek procedures that minimize pollution generated by atmospheric emissions and by solid waste and liquid effluents eligible for sea disposal.

Consequently, it is necessary to highlight that the main wastes generated during offshore exploration activities include: atmospheric emissions, oily water, industrial effluent, drilling fluids (both water-based with sea disposal and non-aqueous based fluids), cuttings (sea disposal), metal drums, fluorescent lamps, cooking oil, plastic containers (bombonas), cement, brine, lubricating oil from engines and equipment, healthcare waste, hospitality and office waste, chemical products, and generally contaminated waste.

Among the wide variety of wastes generated during activities performed in the exploration phase of offshore blocks are healthcare waste, radioactive materials, pyrotechnics, and products controlled by the Federal Police. These are wastes that require additional certifications for transporters and receiving facilities from specific control bodies, such as the National Health Surveillance Agency (Agência Nacional de Vigilância Sanitária - ANVISA, in Portuguese), the National Nuclear Energy Commission (Comissão Nacional de Energia Nuclear - CNEN, in Portuguese), and the Federal Police's Chemical Products Control Division (Divisão de controle de produtos químicos da polícia federal - DCPQ, in Portuguese) (Araruana e Burline, 2013).

In the Offshore sector, the Waste Management Plan (Plano de Gerenciamento de Resíduos - PGR, in Portuguese) is mandated by law and is essential given the complexity of operations and the diverse composition of wastes. It aims to maximize opportunities and reduce the costs and risks associated with waste management; in other words, it seeks operational ecological balance. The PGR must cover all stages of maritime exploration, from resource extraction to final disposal. Figure 7 outlines all measures necessary to ensure safe waste management throughout all stages.

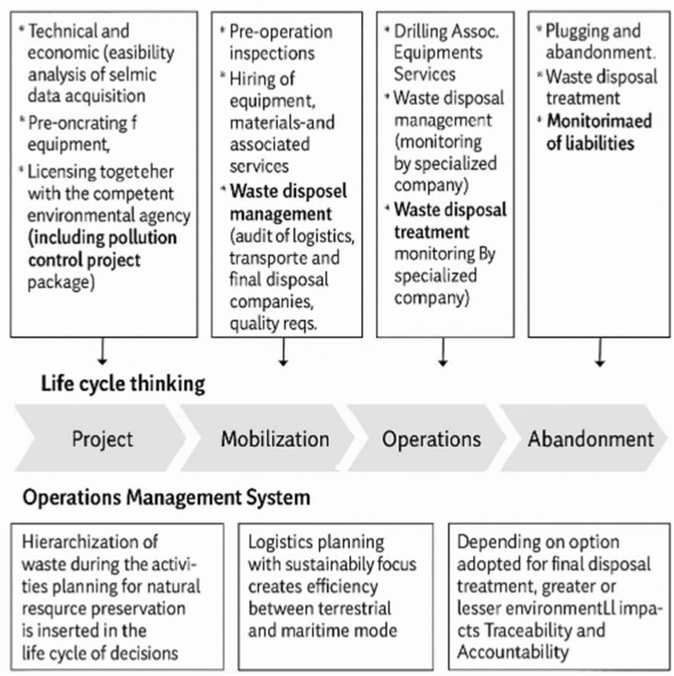
Figure 7 – Waste policy.



Source: Adapted from Araruna and Burlin, 2013.

In 1970, spurred by the oil crisis, society began questioning the limits of natural resource extraction, leading to the emergence of concepts such as "Cradle to Grave" and life cycle studies. However, it was only at the Rio 92 Earth Summit that life cycle analysis became crucial for sustainable production. Following several international conferences, the first document aimed at standardizing the Life Cycle Assessment methodology was created and disseminated: the SETAC - Guidelines for Life Cycle Assessment - A Code Of Practice. Figure 8 illustrates the complexity of the activities involved and the lack of integration among their routine operations.

Figure 8 – The four phases of the waste life cycle generated in Offshore operations.



Source: Adapted from Araruna and Burlin, 2013.

A systemic view of the life cycle provides an integrated management approach encompassing the causes and consequences of all stages in a product's physical life, thereby yielding more effective solutions focused on improving the entire product life cycle, not just a single process or stage (Calijuri *et al.*, 2013).

Currently, the Brazilian Merchant Marine has notably advanced in applying Law No. 13.019/2014, known as the Regulatory Framework for Civil Society Organizations (Marco Regulatório das Organizações da Sociedade Civil - MROSC, in Portuguese). This legislation serves as a crucial instrument for enabling partnerships between the public sector and recycling cooperatives, ensuring more efficient and sustainable solid waste management. Through such collaborations, it is possible to reduce environmental impacts, strengthen the circular economy, and promote social inclusion, making proper waste disposal an increasingly structured and responsible practice.

In practice, the Brazilian Merchant Marine has established partnerships with recycling cooperatives, adopting a sustainable approach to managing the waste generated by its maritime activities. These collaborations ensure the appropriate destination for discarded materials, contributing to environmental preservation and valuing the professionals involved in the recycling process, thereby reinforcing the circular economy and encouraging more responsible practices. The success of this initiative demonstrates how cooperation between public institutions and cooperatives can be an effective strategy for eradicating irregular disposal, serving as a model for the private sector.

Similarly, partnerships between offshore companies and waste picker cooperatives can yield both environmental and social benefits. By integrating waste pickers as key players in waste collection and recycling, these collaborations not only reduce the environmental impacts of improper disposal but also provide efficient solutions for companies.

Furthermore, they bolster social inclusion by generating employment and income, improving working conditions, and affording greater dignity to these professionals. Consequently, such partnerships become sustainable strategies that reinforce corporate commitment to socio-environmental responsibility, boost the local economy, and contribute to the well-being of the involved communities, transforming environmental challenges into social gains.

Despite the numerous benefits these partnerships can offer to both parties, significant challenges remain in making them a widespread reality. One of the main obstacles is the informality that pervades much of the waste pickers' work, hindering compliance with the legal, technical, and contractual requirements demanded for this segment. Compounding these are social stigmas and the historical devaluation of the waste pickers' labor.

5 FINAL CONSIDERATIONS

Offshore areas, and consequently oil platforms, comprise complex infrastructures and human networks akin to small cities and industrial hubs. However, linked to their intricate infrastructure, offshore areas are also responsible for intensive exploratory activities that result in severe environmental impacts, including pollution of marine ecosystems, accumulation of solid waste in natural environments, and contamination of aquatic organisms. Given this scenario, the study and theoretical deepening in the field of waste management prove fundamental to stimulating the use of innovative and efficient methodologies for solid waste management in offshore areas.

The necessity for intervention in current waste management practices is gauged by the impact generated by the improper disposal of solid waste via oil platforms. This impact affects all five areas identified by CONAMA Resolution No. 001 (CONAMA, 1986), with human health, biota, and ecosystem conditions being the most affected due to the lack of effective waste management by companies operating in the sector. Accordingly, the compilation of data and critical analysis of reports provided by multinational corporations such as PETROBRAS and Baker Hughes (USA) enable an understanding of the true scale of the disturbances these platforms generate in the environment. This impact arises both from the magnitude of the offshore platforms themselves and the enormous volume of waste generated by the oil industry.

The current scenario is alarming concerning the health of marine ecosystems and future projections. Continuous improper disposal of solid waste—whether hazardous or non-hazardous—into the aquatic environment can reach irreversible levels. This includes mass mortality of keystone species crucial for oceanic ecological balance, contamination of water bodies on continental scales, and contribution to physico-chemical alterations of water, such as temperature increases and pH decreases through intense atmospheric CO2 absorption, leading to water acidification and unimaginable future planetary impacts (OKA *et al.*, 2019).

Beyond aesthetic, demographic, and physico-chemical impacts, the irregular disposal of solid waste also permeates economic and social spheres. Developed countries with advanced exploratory activities utilize resources and labor from developing nations. Consequently, financial returns concentrate in the global north, while environmental degradation and impact are focused in poorer regions of the globe, primarily affecting societies lacking sufficient resources to mitigate and/or remediate the enormous environmental impacts generated by offshore activities. Therefore, solid waste management in offshore areas must be the responsibility of the companies benefiting from the gross profit, thereby minimizing the state responsibility of the host country, whose role should primarily be oversight. It is counterproductive to expect Brazil to be capable of fully managing the solid waste generated by corporations headquartered, and profiting, in countries on other continents.

Indisputably, solid waste management methodologies must be incorporated into industrial activities rather than being viewed as separate components of this large mechanism. The present work has compiled innovative mechanisms and techniques under constant refinement for effective waste management, indicating that theoretical study in this field is far more advanced than its practical application. This disparity is highlighted by Rigas (2018) and was analyzed throughout the article, exposing the fragility of environmental education programs, such as PEAT, implemented in offshore areas. Consequently, it is essential that technical professionals in this field be integrated into the production circuit to ensure correct management and supervision—for corrective purposes—inadequate actions by employees along the production chain, thereby scrutinizing the proper disposal of solid waste.

Prior to monitoring the production chain, it is fundamental to study the potential impacts of the activities in question even before their implementation. This ensures that appropriate professionals select the best solid waste management methodologies (physical, biological, thermal, and chemical methods) and minimize the environmental impact generated.

For the prevention of environmental impact and the accumulation of solid waste in marine ecosystems, the effective application of reverse logistics presents an extremely functional and technical solution, guaranteeing the reintroduction of waste—that would otherwise be discarded—into the production chain. Reverse logistics offers numerous positive impacts on the economy and the environment, as it significantly reduces the need for natural resource exploration and extraction while also diminishing the accumulation of toxic substances in the environment. In conjunction with reverse logistics (RL), the circular economy emerges as an important driver of social and environmental responsibility, promoting the recycling of generated waste and the reuse of discarded products.

Similar to RL, the circular economy is a social resource enabling sustainable development through changes in consumption and disposal habits that directly impact waste management (ABDALLA & SAMPAIO, 2018). The more waste is reintroduced into the production chain and/or reused in other industrial dynamics, the smaller the quantity destined for disposal. This reduction in the proportion of discarded waste alleviates the burden on treatment, collection, and sorting methodologies. Consequently, resources and energy previously allocated to waste management can be redirected towards mitigating and remediating existing environmental impacts, allowing for a significant regression of the current situation.

Finally, social and state stimulus is fundamental for civil society and large corporations to adopt ecological measures within their production chains and to heed innovative solid waste management techniques. Operating on multiple fronts—where researchers continue their studies and development of effective management methodologies—the State must act by promoting environmental awareness and intervening—whether correctively or punitively—in the negative actions of companies and social sectors. Conversely, corporations also require scientific support and tariff incentives to adopt ecological measures, alongside the use of sustainability indicators to calculate company value and achieve significant reductions in their tax burden.

The field of study concerning solid waste management in offshore areas is extremely broad and historically recent. Therefore, it is fundamental that academic works continue to be developed with the objectives of improvement, suggestion, development of new management techniques, and field research aimed at analyzing the integration of theory with practice in offshore areas. The greater the volume of academic production generated, the more theoretical robustness waste management acquires, consequently implying practical improvements for offshore activities, ensuring quality of life for platform workers and the correct disposal of waste, which positively impacts human society and the environment.

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