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# CONSTRUCTION OF A SUSTAINABILITY INDICATORS SYSTEM FOR OFFSHORE OIL AND GAS PRODUCTION UNITS

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**ABSTRACT:** Production units located in the Brazilian marine environment are responsible for the production of 95.7% of oil and 78.8% of natural gas of Brazil causing economic, environmental, and social impacts motivating us to construct a system of indicators as a tool aimed to improve the sustainable management practice of these production units. To date, one of the tools most used by the oil industry is the sustainability report, oriented by guidelines from international organizations. However, these reports have a corporate character being unable to help the sustainability management of production units' activities. The indicators were selected based on a systemic approach, using current knowledge on sustainability indicators, together with the survey of aspects relevant to the operation and management of offshore oil and gas production units. This paper describes the proposed indicators and presents the hierarchical structure of the system, built on the economic, environmental, social, and operational dimensions. The application of the proposed system of indicators, based on multicriterial and multiple decision-making analyses, validates a complex decision process, providing improved sustainable management of offshore production units by identifying points for which the necessary measures and actions can be implemented.

**Keywords:** offshore oil and gas production; sustainability indicators; multicriteria and multiple decision-making analyses.

***RESUMO:*** *As unidades de produção localizadas no ambiente marinho brasileiro que são responsáveis, respectivamente, por 95,7% e 78,8% da produção total de petróleo e gás natural do Brasil, causam impactos econômicos, ambientais e sociais, sendo por isso necessário definir um sistema de indicadores como ferramenta de apoio à gestão da sustentabilidade dessas unidades de produção. Até ao momento, uma das ferramentas mais utilizadas pela indústria do petróleo é o relatório de sustentabilidade, orientado por diretrizes de organizações internacionais. No entanto, esses relatórios têm um caráter corporativo, incapaz de ajudar no gerenciamento da sustentabilidade das atividades das unidades de produção. Os indicadores do modelo construído foram selecionados com base numa abordagem sistêmica, utilizando o conhecimento atual sobre indicadores de sustentabilidade e o levantamento dos aspectos relevantes para a operação e gestão de unidades de produção de petróleo e gás offshore. Este artigo descreve a definição desse sistema de indicadores proposto, apresentando a sua estrutura hierárquica baseada nas dimensões econômica, ambiental, social e operacional. O sistema de indicadores prevê a utilização de métodos de tomada de decisão com base em análises multicritério e multidecisor, proporcionando um melhor gerenciamento da sustentabilidade das unidades de produção offshore, pela identificação de pontos para os quais as medidas e as ações necessárias podem ser implementadas.*

***Palavras-chave:*** *produção de petróleo e gás offshore; indicadores de sustentabilidade; métodos de análise multicriterial e multidecisor.*

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## 1. INTRODUCTION

The management of offshore oil and gas production units deals with conflicts of interest based on different views of decision makers, regarding technical, operational, economic, environmental, social, and political aspects. For example, the location decision for drilling wells based on technical considerations may face environmental constraints. The application of a system of sustainability indicators for these units, based on a systemic approach, can be a tool to support the management decision-making process. The management of these production units is often based on the analysis of individual criterion, intending on optimizing the operation from an economic point of view, without concern for environmental and social priorities.

Considering that the offshore oil and gas production activity covers aspects of several dimensions, it is necessary to use multicriteria analysis, based on a system that incorporates these different dimensions and considers the multiple areas of specialization disciplinary interface with the activity (Jollivet and Pavé, 2002; Weber, 2002). Criteria should guide decision-making for the sustainable management of offshore oil and gas production units that decision-makers should select, weigh and rank to identify the alternatives that best serve management. It is noticed that this is a complex process, for which the use of multicriteria methodologies seems to be adequate (Araujo and Almeida, 2009). Multicriteria methods, according to Rangel *et al*. (2009), help to manage situations that involve multiple concurrent objectives, providing a holistic view in the means that it considers all information available for decision making.

Lyra and Almeida (2018) understand that experience and knowledge of the problem situation are as essential for decision-making as the available data, a principle that is the basis of multicriteria methods. These methods incorporate multiple quantitative and qualitative criteria in the analysis and are essential considering the limitation of the human capacity to simultaneously analyze multiple possible alternatives and choose among them the best option.

Based on these premises and using the conceptual framework of sustainability indicators, presented in the Agenda 21 (UNSD, 1992), the present work presents the development of a system of indicators specifically designed to support the sustainable management of offshore oil and gas production units. The proposed system is based on multicriteria and multidecision-making methodology, contemplating indicators related to economic, environmental, social, and operational dimensions.

This work initially presents, in Section 2, the theoretical basis regarding the topics addressed and necessary to meet the primary objective of the work. Section 3 describes the offshore oil and gas production projects, highlighting technical, operational, regulatory, and environmental aspects. Section 4 describes the construction methodology and the presentation of the indicator system for oil and natural gas production units. Finally, as a conclusion, the research presents the indication of the system as a tool to be used by oil and gas companies in Brazil.

## 2. THEORETICAL FRAMEWORK

### 2.1 Sustainable development and sustainability indicators

The concept of sustainable development, initially presented by the World Conservation Strategy (IUCN *et al*., 1980) has evolved through the new concept presented by the Brundtland Report (WCED, 1987). During the Earth Summit in 1992, the Agenda 21 was launched, indicating sustainability indicators as tools for measuring the implementation of sustainable development. In 2002, the World Summit on Sustainable Development (UN, 2002) formalized the concept of sustainable development, based on the three pillars of sustainability: social, environmental, and economical with the motto “people, planet, prosperity”.

According to Dahl (2012), the measurement of sustainable development, using indicators, is a great challenge, given the size and complexity involved in the theme. The methodologies developed up to the present do not always cover all the different aspects that involve the concept of sustainable development.

Factors such as differences between regions (countries), cultural diversity and different degrees of development are relevant in the construction of indicators that sometimes cease to be part of this construction.

According to Waas *et al*. (2014), the holistic and multidimensional nature of sustainable development, with its uncertainties and risks, makes its evaluation and measurement complicated. Therefore, the principles of equity, dynamism, integration, and normativity are needed to the main changes for sustainable development implementation and should be included in the definition of sustainability indicators.

The dynamism principle is connected to the consideration that sustainable development is a process of continuous change over time. In this sense, the research must carry out accomplishments aiming at the elaboration of other indicators and goals, as well as the proposition of actions of monitoring, evaluation, and implementation.

The United Nations Sustainable Development (UNSD, 2015) indicates that the process of selecting the sustainability indicators must follow a coherent structuring model in order to avoid arbitrariness of the process. Griggs *et al*. (2014) affirm that a structure that unifies the environmental and social dimensions makes possible the compensations and emphasizes the synergies between the two dimensions. Eurostat (2014) suggests two approaches to be applied in the development of indicator structures, classified as a policy approach and conceptual approach.

Hák *et al*. (2016) report that many indicators and indices of sustainable development have already been developed, but that new metrics should still appear. Other authors criticize the use of high numbers and a great variety of indicators, while others still believe that it is necessary to develop new indicators that are better, more representative, and more decisive.

Concerning companies, competitive pressures and legal requirements have led them to discuss and assume the positive and negative social and environmental impacts of their activities in fora dealing with economic development. This position was assumed based on the understanding that corporations have social obligations and, therefore, should adopt practices aimed at improving the conditions of society and the environment (Oliveira *et al*., 2016).

Oil companies, known for their potential impacts on the environment, society, and the economy, must incorporate the concept of sustainable development into the management of their activities and, therefore, seek alternatives to support sustainability management.

Among the initiatives taken by the oil companies is the voluntary elaboration of corporate sustainability reports, based on guides for the preparation of these documents. This practice is a way for companies to communicate their sustainable actions. The institutions that authorize these initiatives also propose indicators that should be addressed in the sustainability reports and inform the presentation of the reports.

One of the tools most used by the oil industry is the sustainability report, oriented by the guidelines of the Global Reporting Initiative (GRI). GRI is an organization that counts on the participation of specialists from various business sectors, nongovernmental organizations, and government agencies, representing more than 40 countries worldwide and guides the preparation of sustainability reports for corporations of different segments (GRI, 2016).

Even though most of the oil companies worldwide adopt this practice and having GRI great credibility in the market, sustainability reports are corporate and do not allow the sustainability assessment of the various segments of an oil and gas company. However, the Sustainability Report does not function as a support tool for the sustainable management of this or any other sector within the organization. The reports are much more suited to improving the image of companies as organizations concerned with the dissemination of their sustainable actions.

Development is a coevolutionary process, involving systems in a shared environment, where each system follows its path of self-organization in response to the challenges of particular environmental circumstances (Bossel, 2003a). Interconnections between interacting systems can be decomposed into a network of individual systems, each of which has its function and can affect one or more systems. Therefore, indicators should be selected to describe the performance of the individual system and its contribution to the performance of the other systems. The search for an appropriate set of indicators must be based on the identification of the essential components of the systems and any structure relevant to their sustainability.

It is important to keep in mind that good indicators should provide essential information about the feasibility of a system and its tendency to change and still to inform about how this favor or not the sustainable development of the system as a whole (Bossel, 2003b).

Considering that, oil and gas production units are open systems, the entire environment surrounding them should be considered as a control area. In this way, the imposition of control conditions and solutions is presented as a necessary measure to preserve the limited financial and non-financial resources that affect the functioning of the system and its environment. As financial resources are usually more limited than those of a non-financial nature are, they will save preferentially concerning materials, energy, and human effort (Lieber, 2003).

Considering the system to be controlled (oil and gas production units and their environment), it is perceived that, to reduce expenditures and dedicate efforts solely to the production activity, companies end up neglecting actions aimed at reducing degradation, improvement on the conditions of the workforce and increase of the social benefits of its activities.

The choice of representative indicators is based on the identification of the states and flows that provide relevant information on the feasibility of the system. However, it is not necessary to use each system variable as an indicator; a limited set of indicators may suffice. The challenge is to choose the best set of indicators. In the context of sustainable development, those aspects that indicate imminent threats are of significant relevance (Bossel, 1999).

According to Bossel (1999), before beginning the selection of indicators to evaluate the performance of a system, it is necessary to define normative guidelines for the correct choice and that represent the most fundamental aspects of the system. The comprehensive evaluation of the performance of a system should be multicriteria, where each aspect related to the elements of the system should be considered. Attention to the basic guiding principles of all the different subsystems and the total system will guide the search for reliable indicators as well as guiding coherent decision-making concerning sustainable development.

Some advisors are familiar with any system and must be addressed to have a robust and adequate set of indicators, like existence, efficiency, freedom of action, safety, adaptability, and coexistence (Bossel, 1999).

Some steps are essential for building correctly appropriate indicators. For example, all information must be collected for the knowledge of the system to be evaluated as a whole, as well as the interrelationships between its elements and subsystems. Another critical point is the definition of scenarios of future developments arising from these interrelationships. It is also necessary to define the time horizon and the systemic horizon for the measurement of the indicators. Finally, it should be defined as the interests of the managers responsible for activities and other stakeholders in these activities.

In order to measure an indicator, it must be defined a baseline, from which the change of a given state of the system can be measured. It is essential that the baselines considered be in line with public policies or that serve as a guide for their formulators (Moldan *et al*., 2012).

### 2.2 Multicriteria and multidecision-making analyses

According to Carvalho (2013), in the decision process, there may be conflicting interests arising from different views of the same problem when aspects related to different dimensions are considered. As stated previously, sustainability is multidisciplinary and, therefore, the development of its indicators, based on the participation of specialists from the various themes involved in the indicators, can be supported by a multicriteria methodology.

Rangel *et al*. (2009) stated that multicriteria methods, help to deal with problems involving several simultaneous objectives, providing a holistic view, since they consider all the information available for decision making, which leads to the systematization and transparency of the decision-making process.

For Adissi *et al*. (2013), the multicriteria analysis has been used over the years for application in several areas of knowledge, such as economic, administrative, engineering, environmental, social and others, being possible the variations of the multicriteria method by ordering or by aggregation. Aggregation methods combine all the criteria into only one whenever one criterion of good performance can compensate for the poor performance of another. The sorting methods, on the other hand, are based on the comparison, on a par, between the opinions of the decision makers on the criteria. These can be associated with the French or American school. Among the methods of the French school is the family of methods PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations).

To choose an appropriate technique for a particular decision-making problem a detailed analysis must be carried out in different methods available, taking account of the specific advantages, disadvantages, and limitations of each of them (Gilliams *et al*., 2005). The choice of the correct method to solve one specific decision-making problem depends on the type of problem, the objectives of the decision-makers and the desired properties of the solution obtained. Sometimes 'the simpler the method, the better', but other times, complicated decision problems can also require complex methods (Gorécka, 2011).

An order is an arrangement of some elements according to defined patterns or natural relations, such as numerical order, power set order whose ordering relation is the relation between subsets. In real life, ordinal information includes ordinal attributes, preference relation and so on, especially in decision making areas. Ordering according to decision makings is to find a suitable method for evaluating ranking alternatives based on provided ordinal information and criteria (Pei *et al*., 2009).

Ordinal methods are considered very intuitive and not computationally demanding and the information required by the decision maker. The literature lists three ordinal multicriteria methods: Borda, Condorcet and Copeland, and there may be improved variations of the primary methods (Valladares *et al.*, 2008).

In this paper, we must solve the voting problem of selecting, from the preferences of several specialists' individuals, one alternative out of a set of alternatives. The voting body is a committee of specialists from the production of oil and gas offshore operational and regulatory, environmental, economic, and social areas.

For a decision making based on the ranking, the first step is to find some suitable structures to represent the ordinal information involved, known as information representations. Next, it is necessary to choose the appropriate aggregation algorithm or inference mechanism to aggregate or classify the alternatives according to the ordinal information provided. The final step is to choose the "best" alternative, which usually consists of two phases: (a) the aggregation of order relations to obtain a collective performance value in the alternatives; and (b) the exploration of the collective performance value in order to establish a classification among the alternatives for choosing the best (Öztürk and Tsoukiàs, 2008).

The Copeland method orders the alternatives by the number of wins, minus the number of losses, in paired comparisons. In this method, each pair of alternatives is compared, using all preferences to determine which one is most preferred. The preferred alternative receives 1 point. If there is a tie, each alternative will receive a half point. After all comparisons between pairs, the alternative with more points and, therefore, the one with the highest number of paired wins, is declared the winner (Gomes Júnior and Soares de Mello, 2010).

## 3. KNOWING THE STUDY SYSTEM - OFFSHORE OIL AND GAS PRODUCTION UNITS

### 3.1 Structure and operation

Most of the energy demand in the world is served by the production of oil and natural gas in the offshore environment. According to Maribus (2014), since 2000 offshore oil and gas fields have produced around 30% of world oil production and 27% of the world's natural gas production. In Brazil, according to the Monthly Production Bulletin, of National Agency for Petroleum, Natural Gas and Biofuels (ANP), referring to June 2018, offshore oil production was 95.7%, and offshore natural gas production accounted for 78.8% of all production (ANP, 2018).

Offshore oil and gas projects have many subsystems and components, Figure 1.

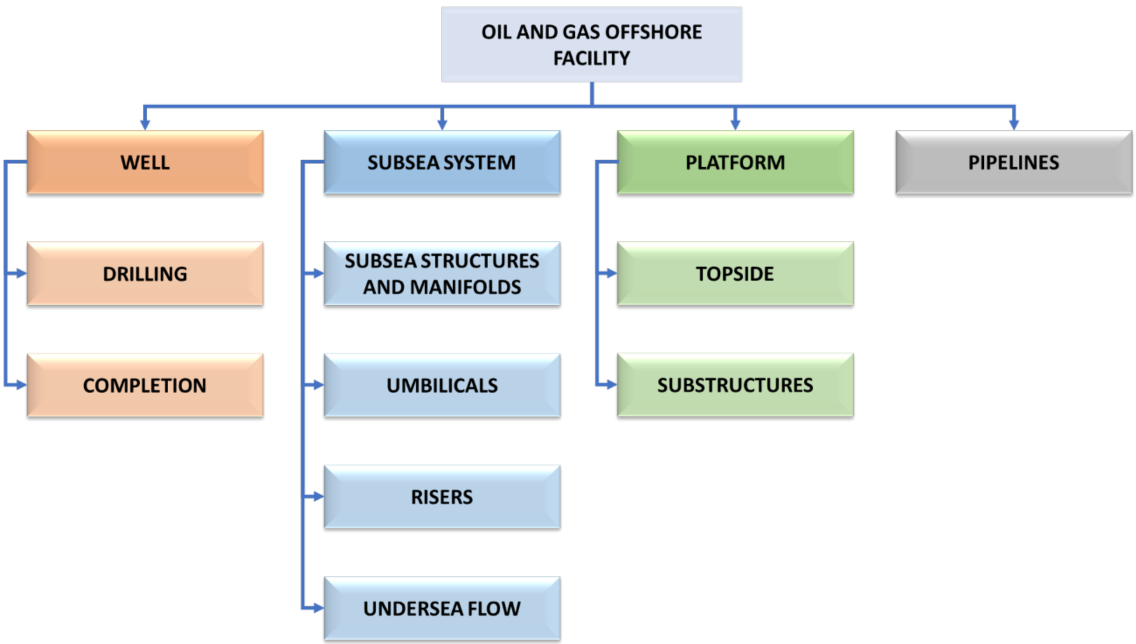


Figure 1. Typical structure of an offshore oil and gas facility (Rui *et al.*, 2017).

A typical offshore oil and gas production project includes the well, the submarine system, composed of the entire underwater structure of pipelines, risers, and manifolds; the platform (fixed or floating), to where the fluids produced are directed and where they should receive the preliminary treatment; and the pipelines, in charge of the production flow. Each of these components is composed of several elements, which vary depending on parameters such as location, distance from shore and depth and which will also guide the choice of the type of platform to be used.

For the development of suitable indicators for different types of offshore projects, Rui *et al*. (2017) employed a hierarchical structure that ensures the correct benchmarking of the projects currently operated.

Oil and gas production at sea requires a set of structures, known as offshore production system. This system is composed of three main components: the production unit or platform (UP), the submarine equipment, among which risers, manifolds, and fixed lines and the anchorage system, Figure 2.

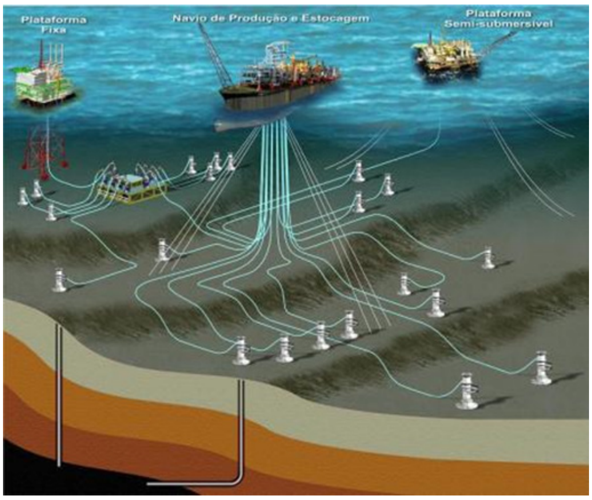


Figure 2. Offshore oil and gas production system (Petrobras, 2018).

The submarine equipment comprises the flexible lines, which have the purpose of transporting the fluids withdrawn from the reservoir in the subsoil at various pressures and temperatures. These lines can transport fluids between the well or manifold to the production unit, as well as carry out the transfer of oil and gas between interconnected units (Amorim, 2010).

There are also rigid lines, which are steel pipes arranged on the seabed with the function of transferring treated oil and gas to other units or to land, where production will be directed to the appropriate destination.

As far as the system carries out the extraction of the oil and natural gas from the subsoil to the surface, it routes the fluids produced to their proper destination (refinery, natural gas processing unit, terminal, and port of export).

The choice of UP typology varies, among other parameters, with the location (water depth) where it will operate, with the environmental conditions of waves, winds and currents, type of marine soil and time and with the operating conditions. The UP can contain its storage tank, when the unit itself also functions as an ocean terminal or, if storage is not available, the transfer of the fluids produced must be carried out by a relief vessel or by a duct (Morais, 2013).

There are several types of platforms that can be classified by fixed platforms, self-elevating platforms; semisubmersible platforms, and Floating, Production, and Storage (FPSO) (Corrêa, 2003; Morais, 2013).

Another relevant element of the production system is the platform's anchoring system, which consists of structures that connect floating units to the seabed and has as main function to keep them as close as possible to their original positions. According to Albrecht (2005), the more rigid the anchorage system of a platform, the smaller is its displacement from its initial position. There are also dynamic positioning systems, where the vessel has automatic control of its position and direction, exclusively employing propellers or thrusters.

According to Corrêa (2003), companies use natural and artificial methods for the extraction of oil and natural gas. When fluids are trapped in underground reservoirs with sufficient pressure to reach the surface, and there is no need to use any external energy, the wells are characterized as naturally occurring. Already when there is the need for external energy application for fluids to reach the surface, it is called an artificial lift. There are 4 main methods developed with the purpose of promoting the artificial elevation of fluids to the surface, Leonez (2011): continuous gas lift (GLC) and intermittent (GLI); submerged centrifugal pump (BCS), mechanical pump by rod (BMH) and progressive cavity pump (BCP).

For recovery of hydrocarbons remaining in the underground reservoir, after the use of natural and artificial upwelling processes primary, secondary and advanced recovery processes of oil in place can be used. Among the conventional techniques used, the injection of water and of gas employing injector wells made to boost the rise of the oil to the surface (Corrêa, 2003). Also, there are advanced methods that make use of more sophisticated technologies such as electromagnetic waves and can increase the recovery factor by up to 45% (Bressan, 2008).

Once the hydrocarbons are on the platform, the production water, and other impurities must be removed so that the oil and gas produced can finally be directed to their destination (refining and processing). Therefore, the platform should be equipped with production facilities for the primary processing of fluids. The processing structures imply the complexity of components of the production unit that will depend on the fluids produced (Moraes, 2013). If the water produced is reinjected, it must be treated in order to eliminate waste gases and oil. If the destination of the water produced is discharging, its treatment must be sufficient to meet the standards established by CONAMA Resolution Nº 393, of 2007.

The work in offshore oil and gas production units is very demanding and requires continuous qualification and training, as well as a differentiated work regime, with a different routine, away from daily living with the family and with the presence of constant risks.

In order to compensate for the difficulties of onboard work, oil companies offer well-being environments during their stay on the platform, such as a variety of leisure time entertainment, meeting space, of good food and means of communication with land.

Commonly, companies offer compensatory financial bonuses in addition to days off calculated in proportion to one day's leave for each workday, in addition to legal holidays provided by legislation (Pinheiro Neto Advogados, 2018).

The Ministry of Labor (MT) is the body responsible for overseeing compliance with the rights and obligations of workers on offshore platforms and carries out inspection actions to monitor the application of the labor law.

Another highlight in this approach is the evolution of female participation in this segment, previously exclusively male. The participation of women in various activities developed within the platforms has provided the expansion of this participation allowing those workers who have the vocation for the work embarked, without preventing the occupation of essential functions and even positions of leadership or command.

Martins (2006) claims that the remuneration and social prestige of embedded workers are not commensurate with the high efforts required by the activities and, in his view, labor laws do not favor them, causing class frustration. The author also presents the "precariousness of labor relationships regarding to wages, medical assistance, training and development and rest regime", in addition to highlighting the high turnover and lack of adequate qualification of outsourced workers, which, according to the author, constitute risk factors for the safety and health of all those on board.

Therefore, it is clear the need for demanding and adequate management of Safety, Environment and Health (SMS) to the offshore production unit labor force.

### 3.2 Impacts of offshore production activity

The offshore oil and gas production activity has impacts on the physical, biotic and socioeconomic resources of the entire area of influence of the facility. These impacts are identified in the environmental study, prepared for licensing, which should also present the mitigating measures, *i.e.*, actions to avoid or reduce the adverse effects of impacts (CONAMA, 1986); and the control and monitoring measures, aimed at monitoring the effects of environmental impacts.

In the offshore oil and gas production and outflow of production, the identified impacts are classified as operational (effective or real), related to the normal operation of the activity, and the potential impacts, those of uncertain nature, related to the occurrence of accidents. The impacts related to offshore oil and gas production may occur during the installation, operation or unit deactivation stages and vary, among other factors, with the location and type of platform.

In general, at the installation stage, effective impacts on the physical and biotic environments, such as interference in the marine communities (benthic, mammals, fishing resources and birds) and changes in water and air quality, can be identified. This stage also causes impacts in the socioeconomic mean, such as interference in fishing, variation in employment and income, increase in the cost of living, interference in the local economy, pressure on marine traffic and pressure on the infrastructure of final waste disposal.

In the phase of operation of the production units, are identified impacts in the physical and biotic media similar to the installation phase, plus the impacts of altered water quality and interference with plankton, resulting from the disposal of produced water. In the socioeconomic environment, although there is a valid positive impact by the generation of royalties, there are also negative impacts resulting from the establishment of 500 m fishing restriction zones around the platform.

Regarding the potential impacts of the activity, gravity and magnitude can be considered variable according to the type of occurrence, the most relevant being those related to accidental chemical and oil leaks at sea. These impacts may vary depending on the type and volume of leaked product, on the time of the year in which the leak occurred, on physical factors such as distance from the coast and water depth, on local meta-oceanographic conditions and the presence of natural resources in the area. It should be considered that, in cases of oil spill accidents, in addition to the marine environment, the coastal environments and all the natural resources and socioeconomic activities of the area of influence of the enterprise may also be affected (Petrobras, 2011).

## 4. METHODOLOGICAL ASPECTS FOR STRUCTURING OF THE SUSTAINABILITY INDICATORS SYSTEM

The construction of the sustainability indicators system for offshore oil and gas production units presented in this paper is based on a systemic approach, where the production units are considered complex systems, composed by several elements that interact, causing multiple effects between them and responsible for causing effects on other elements and on the environment.

The selection of appropriate sustainability indicators for offshore oil and gas operating units depends on the essential aspects as the detailed knowledge of the activity and its interaction with the external environment and the type of information available for assessing the sustainability performance of the activity (Labuschagne *et al*., 2005). Other points of emphasis are the use of an adequate scientific methodology to translate the information, in order to allow the interpretation of the phenomenon associated with it, and the identification of the evaluators and decision makers who will use the indicators system to support the management of the activity.

### 4.1 Structuring the problem

The construction of the sustainability indicators system was preceded by a survey of the elements that make up an offshore oil and gas production system and by the analysis of how each component interacts with the others and the external environment, as well as by the relationships between them within the system as a whole (Step 1). This stage involved a bibliographical and documentary survey and the contact with professionals in the technical area of production and regulation of oil and gas production activities, environmental and social analysts, as well as representatives from various interface academic areas. The contact with these professionals aimed at the knowledge about the structure and operation of the units studied, as well as on the regulatory requirements to which they are submitted, and the social and environmental impacts associated with them. This step was necessary for the certification that the scope of the selected indicators is realistic and applicable and meets the scope defined in this work.

With the survey of the knowledge about the system under study, we went to the brainstorming stage (Step 2), with the participation of a group of supporters in discussions about the aspects of the studied activity, for the selection of the appropriate indicators and the respective dimensions, which should be covered by the indicator system. The group of supporters made up of professionals from various backgrounds (chemical, environmental and civil engineers, sociologists, economists, and law graduates) played a relevant role in this stage. From the opinions released and the discussions made, based on the bibliography analysed, the system indicators were pre-defined.

Indicators used in previous works by Viana (2012), GRI (2016) and IPIECA (2016), served as a basis for the definition of those of the model developed. A customized analysis of each selected indicator was carried out in order to recognize its specific conditions and restrictions concerning the system to be proposed. National and international sensitivities were identified and recognized for the topics addressed, considered of importance for the oil and gas sector, to avoid either under or supervaluation analyses.

The participation of the multidisciplinary supporter's group ensured that a variety of sustainable themes were contemplated, seeking to ensure that no relevant topics were overlooked and thus ensuring the maximization of the use of the participatory approach in the evaluation of the proposed indicators. After consensus on the pre-selected indicators, they were submitted to an analysis (Step 3), which followed the scheme presented in Figure 3.

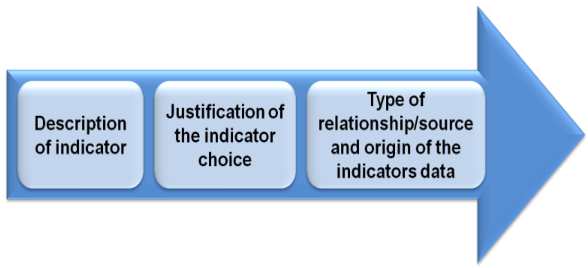


Figure 3. Scheme for selecting the indicators (Adapted from Carvalho, 2013).

For each pre-selected indicator, its meaning was described, and what should be measured through it. Next, it was indicated the justification for the selection of the indicator and the type of its relationship (positive or negative), *i.e.*, if the aspect to which the indicator refers, is favorable, the relationship should be positive, or otherwise the indicator has a negative relation, and its quantification must be minimized. The sources of data origin were also identified in this phase. It is worth noting that this was a criterion for cutting some indicators selected previously for their relevance but discarded by the absence or inaccessibility of the data needed for their measurement.

### 4.2 Hierarchical structure of the sustainability indicators system

After the selection of all the indicators of the model, the hierarchical structuring stage of the indicator system (Step 4) was defined, where the sub-dimensions that make up the indicator system were also defined, according to their thematic. It is essential to use the hierarchical analysis that makes it possible to approach complex problems, considering multiple simultaneous criteria.

From the top of the hierarchical structure of the indicator system economic, environmental, social, and operational dimensions are derived (Figure 4). For each dimension were defined sub-dimensions grouping indicators according to related themes. Thus, hierarchical structuring allows the same indicator to be analyzed from the perspective of different dimensions and subdimensions, and a complex decision problem can be analyzed separately for later analyzes to be aggregated and, finally, the problem is solved.

The final model is composed of 54 indicators, grouped into the dimensions: economic (10 indicators), environmental (14 indicators), social (11 indicators), and operational (19 indicators), also presenting three sub-dimensions of economic dimension; five of environmental, four of social dimension and three of operational dimension. Figures 5, 6, 7 and 8 show the structures of the indicator system for the selected dimensions.

Measurement is based on individual metrics, which consider the characteristics of the indicator and the guiding references by regulations, public policies or good practices of the oil and gas industry.

To define the degree of sustainability of offshore oil and gas production units, the indicators were submitted to the appreciation of specialists from various professional backgrounds. These experts expressed their opinions on the indicators, according to their perception, assigning weights, related to the classification of very high, high, medium, low or none. These weights and the indicators' values, calculated from real data, fed software that processed input data.

The application of the multicriteria associated with the multidecision-making analysis provided the presentation of the sustainability ranking among the analyzed production units.

Table 1. Dimensions and indicators of the system.

| Dimension | Indicators |
|---|---|
| Economic | Interference in the region's economy; duration of the development; environmental sensitivity of the influence area; contribution of the activity to the oil sector; field profitability; produced fluid(s); environmental compensation fee; environmental fines; labor fines and investment in research, development, and innovation. |
| Environmenntal | Electric power generation system; atmospheric emissions; extraordinary gas burnings; environmental sensitivity of the influence area; chemical injection; water production; field area; degree of effective impacts of the activity; impacted land area; extent of influence area; pollution control project; oil spill warning system; individual emergency plan and production outflow. |
| Social | Public hearings; interference with fishing; extent of influence area; individual emergency plan; platform crew; Health, Environment and Security (HES) of the development; labor fines; interference in the region's economy; influence of activity on poverty reduction in the region; influence on human development and duration of the enterprise. |
| Operational | Water demand; extraordinary gas burn; operating license; conditions of the operating license; labor fines; environmental finess; accidents in the management; production estimate; environmental audits; development plan; produced fluid(s); anchorage system; incidents with risks to health and the environment; platform crew; fire detection and fire fighting system; plant production processing; on-board communication system; preliminary hazard analysis and number of interconnected wells. |

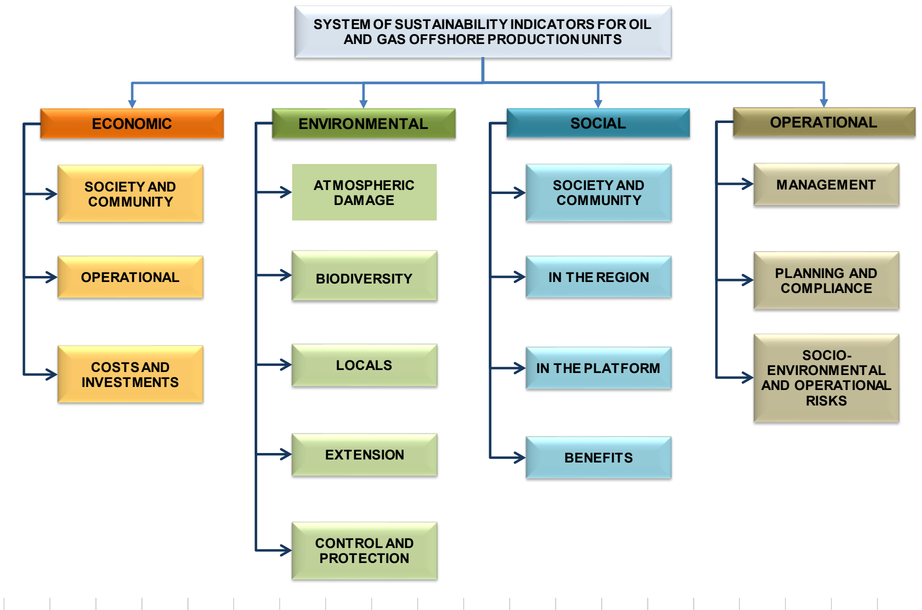


Figure 4. Hierarchical structure of the indicator system for offshore oil and gas production units.

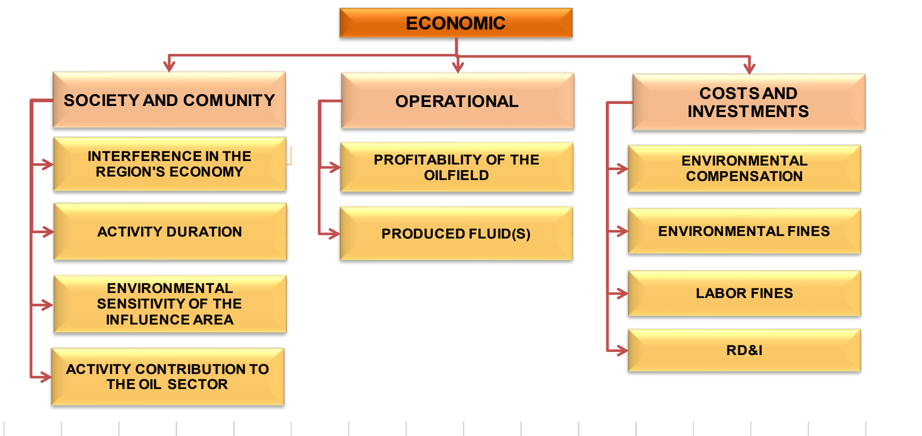


Figure 5. Flow chart of the sustainability indicators system for offshore oil and gas production units (Economic dimension).

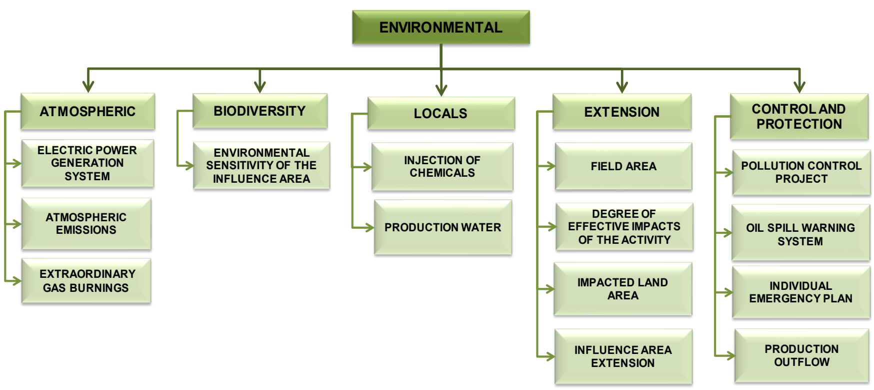


Figure 6. Flow chart of the sustainability indicators system for offshore oil and gas production units (Environmental dimension).

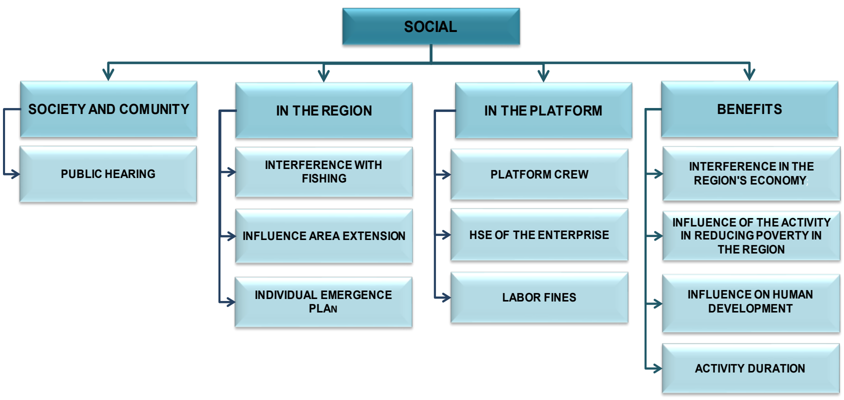


Figure 7. Flow chart of the sustainability indicator system for offshore oil and gas production units (Social dimension).

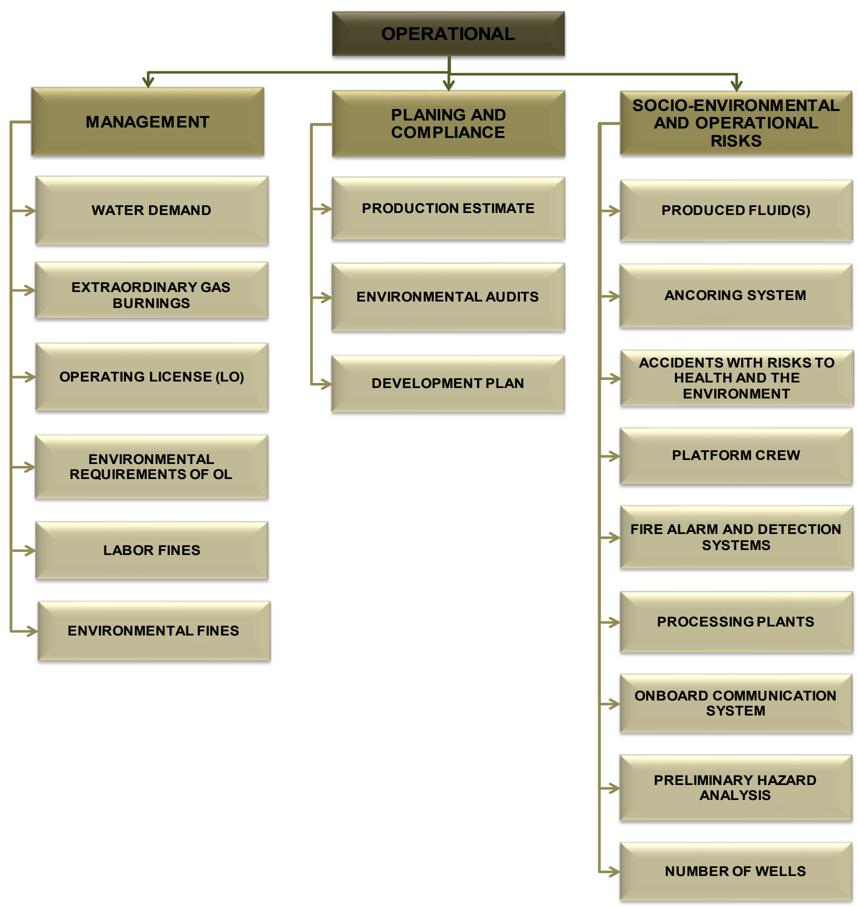


Figure 8. Flow chart of the sustainability indicator system for offshore oil and gas production units (Operational dimension).

## 5. APPLICATION OF THE SUSTAINABILITY INDICATORS SYSTEM TO OIL AND GAS PRODUCTION UNITS IN ACTIVITY IN OFFSHORE SEDIMENTARY BRAZILIAN BASINS

To validate the sustainability indicators system, the research presents the results of its application, using the River Basin Information and Operation Support System (RIOSS) platform. RIOSS is a decision support software developed by the researchers of the Total Water Optimization Group (GOTA), Federal University of Campina Grande. One of the objectives of RIOSS is the comparison of scenarios through indicators, multicriteria analysis, and multidecision-making analysis or using combinations between them.

The multiple decision-maker analysis associated with the multicriteria counted on the participation of a multidisciplinary group of decision-makers, who gave their opinion on the importance of each indicator, through the attribution of weights, defined in the questionnaires submitted to each decision-maker. The responses reflected the perception of each one and it was observed that no indicator received equal weight by all decision-makers simultaneously. On the contrary, there was a variation in the perception of decision-makers regarding the influence of the indicator on sustainability. It was also observed that for the evaluation of the indicators related to the sub-dimension "socio-environmental and operational risks" there was more agreement between the opinion of the decision-makers.

These data were inserted in the RIOSS computational platform, after the previous registration of all indicators, with the definition of their positive or negative influence on sustainability. The metrics for the measurement of each indicator were also previously defined, obtaining their respective values, which were also registered in RIOSS.

The next step was the registration of decision-makers in RIOSS, with the attribution of weights equal to 1 for all of them, being established that all decision-makers have equal decision power. After this stage, the weights of all indicators, assigned by each decision-maker, were registered, and based on these values the software calculated the relative weights for all indicators, to promote data standardization. To meet yet another requirement of the PROMETHEE II multicriteria method, the preference functions of each indicator were defined, observing the behavior of each one individually and the existence of legal, normative, or empirical parameters.

With all the data necessary for the multicriteria and multiple decision-makers' analyzes properly inserted in the RIOSS platform, the result of the sustainability performance ranking was obtained.

In the particular case of this research, the comparison among three scenarios was made (oil and gas production units in activity in Brazilian sedimentary basins), by meeting the sustainability indicators of the proposed system. Also, the weights attributed to them by 34 decision-makers (specialists) were considered, the application of hierarchical multicriteria analysis (PROMETHEE II), which selects the best alternative for decision-making and multi-decision analysis (Copeland), for the combination of individual rankings defined by each decision-maker in a global ranking.

The scheme presented in Figure 9 represents the sequence of activities performed in RIOSS to obtain the sustainability performance result of the analyzed oil and gas production units.

After carrying out the entire sequence of activities, the results of the ranking of the sustainability performance of the three oil and gas production units in activity in Brazilian sedimentary basins (Figure 10) were obtained. The three units were selected considering different characteristics regarding the platform typology, location in different water depths and distance from the coast, productivity, profitability, crew capacity, generation of royalties and other aspects contemplated by the indicators of the proposed system.

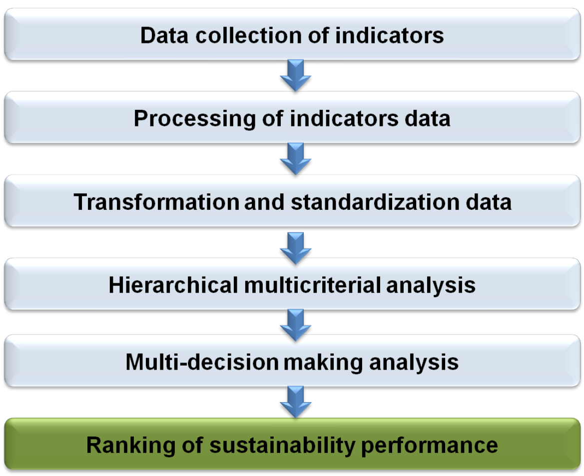


Figure 9. Activities carried out to obtain the sustainability performance ranking of the oil and gas production units.

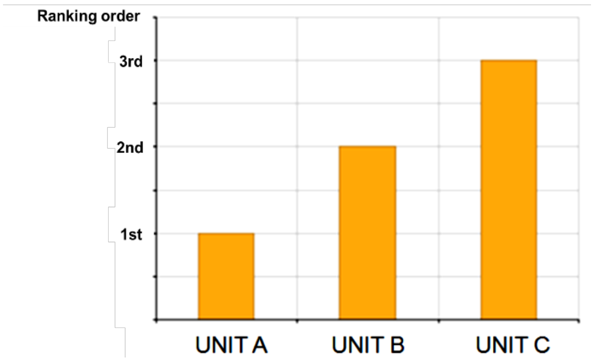


Figure 10. Ranking of sustainability performance of the analyzed production units (RIOSS, 2018).

The result shows that, among the three (3) production units analyzed, Unit A is the one that presents the best sustainability performance, calculated from the calibration of the 54 indicators of the proposed system, considered in a weighted way, from weights attributed by multiple decision-makers, the economic, environmental, social, and operational dimensions. In second place in sustainability performance is Unit B, and, finally, Unit C. The result, unpredictable by partial or sectoral considerations, is coherent when considering aspects related to the multiple dimensions that involve such a complex system. For example, if an analysis is made considering only aspects of the economic dimension, Unit B would probably be in the first place because it is a highly profitable unit about the others. However, the result changes when aspects of the other dimensions are considered together, to define the best performance in sustainability.

## 6. CONCLUSIONS

The adoption of processes of environmental management and social responsibility is no longer an option and has become a competitive differential between companies operating in the globalized market, such as oil companies. The pressures of the market and of the society itself impose dynamism on the insertion of the environmental variable and social responsibility in the management of the companies, being considered sources of essential transformations.

The growing degradation of the environment, coupled with the change of consciousness and the behavioral pattern around the world, made it possible for organizations to understand the importance of generating social benefits and environmental preservation in the development of their activities. Even the agencies that certify economic performance changed the strictly financial indexes for the adoption of financial sustainability indexes, such as the BOVESPA Sustainability Index and the Dow Jones Sustainability Index, among others.

The present paper presents a system of sustainability indicators, built appropriately for the application on offshore oil and gas production units, as a tool for sustainability management, and intend to induce their adoption by oil companies.

The use of this tool will not only provide greater competitiveness to companies in the Brazilian and world markets but will also offer to stakeholders, society as whole, public policies makers on the sustainability performance of production units.

The use of the sustainability indicators system, presented in this paper, can improve the sustainable management of the operators of offshore oil and gas production units, guiding the search for productive and profitable results. The adoption of this tool can lead to the creation of processes and products less aggressive to the environment and more socially responsible, promoting profit, and generating a more sustainable market.

The article presents a proposal for a multicriteria approach, based on the prioritization of strategic alternatives to sustainability, to be adopted by operators of the oil and gas production units.

The proposed method accomplishes its purpose, since it performs a complex process of decision, based on the opinion of several decision makers of multidisciplinary formations, avoiding that a unit that performs better in one criterion and inferior in the others is privileged. That is, the best performance in sustainability will be considered the one of the production unit for which the calculation of all the criteria, calculated with the consideration of the weights attributed to them by the decision makers, represents the best alternative.

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