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Multi-criteria analysis to rank offshore renewable technologies to support deep-water oil and gas production.

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ABSTRACT: Around 5 % of the global offshore oil and gas production is consumed as fuel to power the platforms emitting around 200 million tons of CO_2 per year. Adopting renewable energy can increase the oil and gas available for export by reducing internal consumption and opening space for the processing plant. This work presents an improvement to the classical analytical hierarchy process multi-criteria decision analysis method, where a viability check phased is introduced before the criteria weighting. The proposed methodology is then applied to a case in Brazil, where 10 MW of continuous electrical power is required by a subsea CO_2 separation and reinjection system to be installed at 2000 m water depth and 160 km from shore. The selection criteria include technical, economic, and environmental aspects weighted with the contribution of experts. The resulting ranking is offshore wind followed by wave energy, subsea small modular nuclear reactors, and ocean thermal energy conversion.

1 INTRODUCTION

Despite the greenhouse gas reduction (GHG) goals set by the Paris agreement, the global consumption of oil and gas will keep increasing at least until 2030 (DNV-GL, 2019; IEA, 2019b; Wood Mackenzie, 2019b). In this context, it is crucial to reduce GHG emissions in the oil industry. One option to be considered is the adoption of renewable energies in offshore oil and gas production systems, with the potential of liberating up to 5 % of the oil that is usually burned as fuel to be exported (Wood Mackenzie, 2019a). The advantages of adopting renewable fuels may not only be environmental but also economic, as the life cycle cost of offshore renewables is getting closer to the cost of conventional generation and can disappear if carbon taxes are applied.

New oil fields are needed to supply the consumption increase and to replace the areas with declining production during this transition period. On that context, one of the most important discoveries of the present century is the pre-salt reservoirs at Santos Basin, Brazil (Beltrão et al., 2009). The Tupi field alone has an estimated recoverable volume of 5 to 8 billion of barrels of oil equivalent. However, there are many technical challenges to be solved in order to reach a competitive development cost for this field (Chetwynd, 2016a). One example is the high CO_2 content of about 45 % in the gas, combined with the high gas-oil rate of $450\,\mathrm{m^3/m^3}$. The CO_2 separation and reinjection plant occupies 60 % of the deck space of the floating production storage and offloading unit (Chetwynd, 2016b). This plant is also responsible for a significant fraction of the total energy consumption.

One of the solutions to increase the oil processing capacity of the platforms is to allocate part of the gas separation process on the seabed as made by the so called HiSep unit developed by Petrobras (Passarelli et al., 2019). This system takes advantage of the fact that the mixture of CO_2 and gas leaves the well at supercritical condition to separate the fluid into two phases. The light phase (i.e. dense gas) will be a mixture of natural gas including 90 to 95 % of the CO_2 produced, and the second phase (i.e. liquid) will be a mixture of hydrocarbons with the rest of the CO_2. The first phase could be reinjected with pumps and the second sent to further processing at the platform.

This processing unit demands approximately 10 MW of electrical power to operate at full load, which is much less than the power required from the traditional process at the FPSO. The present project aims to evaluate the potential of both renewable and conventional energy solutions to supply the required power of a HiSep unit to be installed in the Mero oil field. This field is part of the Tupi field and is located 160km offshore from Rio de Janeiro state in Brazil within the coordinates: (24.51;24.71) S and (42.31;42.12) W, as shown in Figure 1. The gas separation and reinjection system will be positioned at a water depth of 2100 m without any electrical connection to the shore or available power supply from close platforms. Technical, economic, and environmental aspects are considered to select the power supply solution.

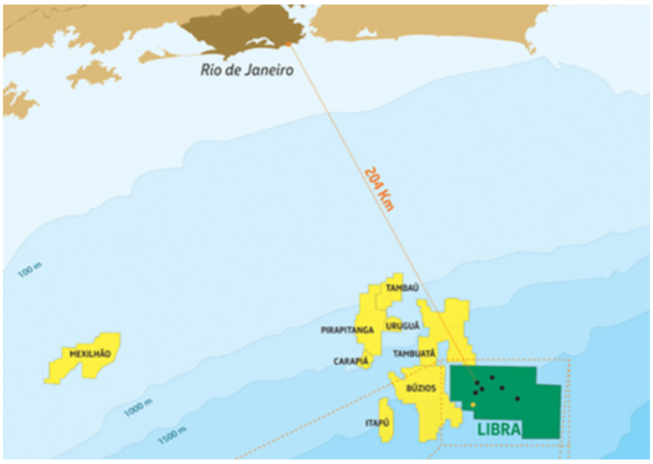

Figure 1: Bathymetry of the Santos Basin.

In this work, a multi-criteria decision analysis (MCDA) is chosen and adapted to rank the proposed technologies that can provide the required power supply. MCDA methods are very popular tools to support the decision-making process because they allow to solve complex multi-dimensional problems (Wang et al., 2009). The technological options considered at the case study are floating offshore wind turbines, ocean current energy converters, wave energy converters (WEC), ocean thermal energy conversion (OTEC), oil and gas thermal energy conversion, floating solar photo voltaic (FSPV), small modular nuclear reactors (SMR), subsea combustion systems, and subsea fuel cells (SFC). The reference year will be 2025, that is the year when the next phase of Mero field development will start to be implemented.

2 MULTI-CRITERIA DECISION ANALYSIS METHODS

The decision-making (DM) process on energy development should look at technical, social, economic, and environmental dimensions. Multi-criteria decision analysis methods could provide the tooling to reduce the complexity of addressing these multiple facets. MCDA methods have been gaining importance since the 1980s (Wang et al., 2009).

The process of decision making for energy supply, considers four stages, namely criteria selection, criteria weighting, evaluation (also named Multi-criteria decision analysis), and final aggregation (Wang et al., 2009). The typical evaluation criteria division is into technical, economic, environmental, and social aspects. They also presented some methods of criteria selection and listed five principles that should be observed:

1. Systemic. The criteria system should reflect the essential characteristic and the whole performance of the energy systems.
2. Consistency. The criteria system should be consistent with the DM objective.
3. Independence. The criteria should not have interdependence relationship.
4. Measurability. The criteria should be measurable in quantitative value as possible or qualitatively expressed.
5. Comparability. The comparability of criteria should be obvious, and the criteria should be normalized to compare or operate directly.

The work presented by T. Saaty & Ozdemir (2003) showed that the ideal number of criteria for a pairwise comparison is seven plus minus two. This assumption is based on the way that human mind works to identify the elements that generate the biggest incoherence when dealing with a high number of elements that generates small inconsistencies.

The criteria can be equal-weighted or rank-ordered. The equal-weighted are most applied due to its simplicity, but they have the disadvantage of considering that all criteria have equal importance. On the other hand, rank-ordered methods use different methodologies to rank the importance of the criteria. In this category the analytic hierarchy process (AHP) is by far the most used method in sustainable energy and the preference by similarity to ideal solution (TOPSIS) appears as the second (Ilbahar et al., 2019; Wang et al., 2009).

The evaluation methods determine the criteria weighting to rank the alternatives. There are a lot of different methodologies and the most popular are AHP, Analytic Network Process (ANP), TOPSIS, ELimination Et Choix Traduisant la Realité (ELECTRE), and Multi-criteria Optimization and Compromise Solution (VIKOR, from serbian: VIšeKriterijumska Optimizacija I Kompromisno Resenje), and their Fuzzy variations (Ilbahar et al., 2019; Mardani et al., 2017; Wang et al., 2009). Hybrid methods can use a different method at each stage or more than one MDCA method in a multi-phase process.

Some decision makers use more than one method and compare the results. If the results are different, then one aggregation method is employed. There are two types of aggregation methods, namely the voting and the mathematical aggregation (Wang et al., 2009).

The AHP method receives critics due to two main limitations: first, it does not consider the mutual dependencies among attributes while obtaining their importance degrees (Ilbahar et al., 2019). Second, it cannot reflect the human cognitive process because it does not cope with the uncertainty and ambiguity, which occurs in decision-makers (Shen et al., 2010). The ANP method was proposed by T. L. Saaty (2001) to address the first limitation. This method uses a network of criteria and alternatives (all called elements), grouped into clusters instead of a hierarchy. This approach requires that the experts know in advance the project details to evaluate the inter dependencies of the criteria (Aragonés-Beltrán et al., 2014). Fuzzy set theory can be combined with the AHP methodology to address the second limitation. These method is known as FAHP (Shen et al., 2010). In this criteria the importance scale is replaced by fuzzy numbers resulting in fuzzy weights (Kaya & Kahraman, 2010; Rosso-Cerón et al., 2019; Streimikiene et al., 2012). The disadvantages are that the experts need to understand the Fuzzy theory and the process is not as simple as the standard AHP (T. L. Saaty, 1980).

Despite these limitations, the AHP method has been selected for this work due to its simplicity to get answers from a great number of experts that do not require to know a priori the details of the fuzzy theory. As a test to the AHP methodology proposed, the experts opinion and the performance of technologies from the works of Kaya & Kahraman (2010) and Tasri & Susilawati (2014) were used as inputs and the output ranking was was validated with their results, indicating similar performance.

The AHP methodology is suitable to be used in groups that are working on complex problems, especially those with high stakes, involving human perceptions and judgments (Erol & Kilkiş, 2012). In this method, after defining the n criteria the experts made a pair-wise comparison of the relative criteria importance (w_i/w_j) in a 1 to 9 scale as shown in table 1. This importance ratio is then used as input to the matrix of pairwise comparisons A (eq. 1).

$$A = [a_{ij}] = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \quad (1)$$

For $i, j, k = 1, ..., n$, this matrix is positive ($a_{ij} > 0$) and reciprocal $\left(a_{ji} = \frac{1}{a_{ij}}\right)$ thus $a_{ii} = 1$. So if this matrix is consistent ($a_{ik} = a_{ij}a_{jk}$), it is possible to solve the eigenvector problem:

$$AW = \lambda_{\max} W \quad (2)$$

Where the eigenvalue $\lambda_{\max}$ is the scale number, and the eigenvector W is the weight vector, which shows the relative weight of each criterion. Different scales can be selected as a function of the number of criteria to better translate the perception of the experts into weights (Goepel, 2019). Consistence ratio (CR) of matrix A should be calculated, if the number is greater than 0,1 the matrix is too inconsistent to give reliable results and the expert needs to review the values (T. L. Saaty, 1980).

Table 1: AHP relative importance scale.

Scale	Importance level
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values

For each criterion a 0 to 1 rate scale should be created to put all criterion performance in the same base. Then for each option the performance values are multiplied by their weights giving a score (S). The sum of the scores give the total score (TS) of the option and a final ranking is determined. This method needs to be repeated for each hierarchy level.

3 DECISION-MAKING SUPPORT FRAMEWORK

The present work adopts a five steps MCDA listed below.

Step I - Characterization of the case study: the problem is defined.

Step II -Technology alternatives formulation and criteria selection: the list of technology options, their viability and classification criteria are defined.

Step III - Viability check: the technologies that do not match the viability criteria are discarded.

Step IV - Criteria weighting: the experts inputs are used to weight the importance of the criteria using a web interface according to the AHP methodology.

Step V -Rank of technologies: a score is defined for each technology option based on its performance and the weight of each criterion. This score is then used to create a ranking.

3.1 Characterization of the case study

In this phase, the case study presented in section 1 is further developed considering the following restrictions: (i) The subsea system does not have direct connections to receive energy or fluids from shore. (ii) The FPSOs do not have space available to accommodate any process facilities or to install new risers which could be used for fluid transport to the power plant. (iii) The sizing of the power supply system considers the average capacity, not the instant output.

3.2 Technology alternatives formulation and criteria selection

This phase consists of the creation of a comprehensive list of offshore power generation technologies in the range of 10 MW. This inventory includes both floating and seabed-mounted structures with no previous viability check. The analysis is done as part of step three according to the following viability criteria:

- Resource availability: compare the available resources with the minimum required by each of the technologies. For renewable energies, historical resource data sets are used. Fuel supply capacity is used to evaluate the non-renewable sources.
- Technology Readiness Level (TRL): express the level of readiness of each technology for application in the specific environment. This work

adopts the 9 level scale used by the European research and innovation programme Horizon 2020 (European Commssion, 2014). The threshold adopted is the same used by the oil industry at the bidding phase that is TRL 7 (Yasseri & Bahai, 2018).

A review of the criteria used to select the power generation technologies indicates that most of the authors adopt technical, economic, environmental, and social aspects (Kaya & Kahraman, 2010; Streimikiene et al., 2012; Wang et al., 2009). The social ones are more suitable for governmental policy studies and are not considered in the scope of this work. Based on the literature review, the case study characteristics and the criteria selection recommendations proposed by T. Saaty & Ozdemir (2003) and Wang et al. (2009), the adopted classification criteria (C_n) are:

- Technical;
  - C1 - TRL: the scale used at this phase is the same as the one used in the viability check.
  - C2 - capacity factor (%): expected capacity factor to be achieved by the technology at the installation location.
  - C3 - maximum installed power per unit (kW): maximum power combined with the capacity factor will determine the minimum number of units required;
  - C4 - global resource potential (thousand TW h): total energy potential in the world.
- Economic.
  - C5 - CAPEX (US$/MW installed): total investment cost for the technologies, including support structures, mooring, installation, decomissioning and auxiliary system among others.
  - C6 - OPEX (US$/year/MW installed): average annual cost of operation, maintenance, and replacement during the lifetime of the project (20 years).
- Environmental.
  - C7 - quantified externalities: they account for expected costs for the society from the supply of raw material to the discharge of the equipment. The owner of the equipment will not necessarily pay for these costs, but they are paid indirectly by the society as a whole.
  - C8 - environmental risk: this criterion considers the environmental impact in case of an accident or calamity during the operational life.

A performance scale is then defined for the criteria based on the values shown in Table 2 where a performance of 1 represents the worst possible value for the criterion, while 10 represents the best value.

3.3 Viability check

The viability check is made by direct comparison of the minimum requirements defined in Step II and the expected TRL of the technologies and energetic resources availability at the site location. The following technologies did not comply with the requirements established by the viability check.

Ocean current energy converters: the current speeds are below 1 m/s for 99.3% of the time and below 0.5 m/s for 71 % from the surface to 100 m of water depth and get lower as the depth increases (Petrobras, 2019b). Most of the technologies are developed for tidal currents that have higher velocities (Brito e Melo & Jeffry, 2014; Magagna, 2019). The systems developed for lower speeds that are in a TRL level above 6 are the current kites, like the Deep Green developed by Minesto, and GEM developed by Seapower to operate at streams flows from 1.2 to 3.0 m/s and from 1.5 to 2.5 m/s respectively (Minesto, 2019; SeaPower, 2019).

Oil and gas thermal energy conversion: this system would use the temperature difference between the seawater and the intermediate or exported current from the HiSep unit. According to the developers, the system has a small operation envelope that can be compromised if thermal energy is removed from intermediate stages. The temperature reduction at the two output current could compromise their flow, leading to problems like hydrate formation (Passarelli et al., 2019; Petrobras, 2019a).

Offshore floating solar: customized floaters, anchors, moorings, and systems components need to be designed to withstand the dynamic forces of waves and strong winds from the offshore environment. Offshore engineers have limited experience with floating solar photovoltaic(IRENA, 2019; Reindl et al., 2019), and the first developments are in near-shore applications like Oceans of Energy (2020) and Ocean Sun (2020). Currently there are no forecast in the short term for deeper-water developments, so the TRL is not expected to reach a value of 7 for that application in the context of this work.

Floating small modular nuclear reactors: there are many small modular reactors under development on the world (IAEA, 2018; World Nuclear Association, 2020). Although the first civil floating nuclear power plant entered operation in December 2019, this system needs a specially designed pier to protect it from high waves (ROSATOM, 2020). There is no perspective of development of a system for open waters in the next years. Perspectives are different for the subsea SMR, like Shelf, that are derived from submarine technology and should be licensed to production in 2020 (IAEA, 2018).

Subsea combustion systems: the gas produced at Mero field has a high content of CO_2 and other contaminants that make burning it without pre-processing challenging. Akker developed the Krypton concept

Table 2: Performance scale

	1	2	3	4	5	6	7	8	9	10
C1	7			8			9			Commercial
C2	(0;400)	[400;700)	[700; 1,100)	[1,100; 1,600)	[1,600; 2,500)	[2,500; 3,600)	[3,600; 5,500)	[5,500; 8,000)	[8,000; 12,000)	[12,000; +∞)
C3	[0;15)	[15;25)	[25;35)	[35;45)	[45;55)	[55;65)	[65;75)	[75;85)	[85;95)	[95;100]
C4	(0;8,500]	[8,500; 15,000)	[15,000; 24,000)	[24,000; 36,000)	[36,000; 54,000)	[54,000; 76000)	[76,000; 112,000)	[112,000; 185,000)	[185,000; 250,000]	[250,000; +∞)
C5	[10,600; +∞)	[9,900; 10,600)	[9,200; 9,900)	[8,500; 9,200]	[7,800; 8,500)	[7,100; 7,800)	[6,400; 7,100)	[5,700; 6,400)	[5,000; 5700)	[0; 5,000)
C6	[350;+∞)	[320;350)	[290;320)	[260;290)	[230;260)	[200;230)	[170;200)	[140;170)	[110;140)	[0;110)
C7	[0.45;+∞)	[0.40; 0.45)	[0.35; 0.40)	[0.30; 0.35)	[0.25; 0.30)	[0.20; 0.25)	[0.15; 0.20)	[0.10; 0.15)	[0.05; 0.10)	[0.00; 0.05)
C8	Irremediable large scale			Large scale			Small risk			No risk

that uses pure O_2 as a comburent to operate at Brazilian the pre-salt oil fields (Eide et al., 2019). The limitation of this system is its necessity for an offshore gas separation plant. This plant cannot be installed in an oil production facility due to safety reasons, requiring a new platform that do not comply with the conditions of this study. Other option would be the use of pre-processed fuel. For this application, ThyssenKrupp developed a concept based on submarine propulsion technology that counts with a diesel generator, a battery pack and a fuel cell (Frühling & Schiemann, 2015). This system would require a supply of diesel that is not available at the site. There are no other technologies that met the viability criteria.

Subsea fuel cells: the fuel cells and reformers are not developed to run with a high CO_2, and contaminants content fuel gas. There is no space for installation of a H_2 generation plant at the FPSO. The most advanced solution that can use pre-treated natural gas from the exportation or re-injection lines, like Protec (Prototech, 2020) are still in TRL 2 to 5 and probably will not reach 7 until 2025.

3.4 Criteria weighting

Two groups of experts were selected for the criteria weighting phase. The first is composed of researchers and professors who work with offshore energy, the second of experts in energy systems from the oil industry. They received a summary of the objectives, a description of the case study, and the methodology to be carried out. The experts had access to the AHP-OS web-based tool developed by Goepel (2018) to simplify the pairwise comparison input and the evaluation of the results.

Three experts from academy (E6 to E8) and five from industry (E1 to E5) made their pairwise comparison of the criteria importance. A weight vector for each of the experts and the group was then calculated using the generalized balanced scale. This scale has a lower uncertainty for a number of criteria between 3 and 9, and no weight dispersion (Goepel, 2019). The weight vectors are represented along the lines in Table 3.

Table 3: Group and experts weights (%)

	C1	C2	C3	C4	C5	C6	C7	C8
Group	14.2	6.8	11.0	7.8	14.4	14.1	11.6	20.2
E1	29.0	6.2	4.3	3.1	21.5	11.4	10.9	13.5
E2	5.1	3.1	20.2	3.0	30.6	22.7	2.0	13.3
E3	4.9	3.1	2.2	2.9	6.8	6.8	36.7	36.7
E4	27.2	9.4	9.1	4.5	12.3	16.6	4.1	16.9
E5	13.4	5.8	13.3	16.5	6.0	6.0	9.4	29.5
E6	34.3	7.0	22.7	4.2	7.9	14.4	3.4	6.1
E7	2.8	3.0	9.7	3.2	8.9	8.9	31.7	31.7
E8	8.0	2.9	5.1	18.4	13.4	10.8	16.0	25.4

The group input consensus is low, 56% in a scale from 0 to 100 % where 100% is total consensus. The consensus of the separate groups are also low, 57,5% for the academy and 57,2% for the industry, indicating that there is no obvious agreement between the experts. Even with this low consensus, no filters were adopted to remove values away from the average to preserve the opinions of the experts. The weights can be aggregated in 4 groups, the most important is environmental risk, followed by CAPEX, OPEX and TRL with similar importance, quantified externalities and with lowest importance are global resource and capacity factor.

3.5 Rank of technologies

The next step to rank the technologies is to determine their performance for the classification criteria. The references adopted for each of the technologies is described below and summarized in Table 4.

Floating wind turbines (FWT): the number of commercial FWT projects is increasing, like Hywind Tampen that will start up by the end of 2022 (Equinor, 2020). This expansion is motivated by the high potential of sites located in deeper waters. The scale gain in combination with the increase in turbine sizes (that will reach 12 to 15MW) will lead to a reduction in the CAPEX and OPEX expected by the mid 2020s (IEA, 2019a). The capacity factor of a 10MW academic wind turbine simulated for a site close to our case study by dos Reis et al. (2020) was adopted.

Wave energy converters (WEC): there are a significant number of demonstration units at TRL7, but they still have to achieve significant operational hours to follow to the next TRL level (Magagna, 2019). Espindola & Araújo (2017) presented an analysis of the wave power output for three WECs at different sites along Brazilian coast utilizing a 35 years reanalysis database from the ERA-Interim project (Berrisford et al., 2011). According to their study for a close site, Pelamis presented the best capacity factor and it was adopted in this work. United Nations (2011) is the reference for WEC potential. European Commission (2018) presents scenarios for marketing expansion of ocean energies in Europe, including forecasts for CAPEX and OPEX.

Ocean thermal energy conversion (OTEC): the potential and economic aspects came from the same sources of WEC. Kempener & Neumann (2014) showed the capacity factors and size of OTEC systems.

Subsea small modular nuclear reactor (SSMR): the reference for technical aspects is the Self Reactor (IAEA, 2018; World Nuclear Association, 2020). There is no data available for the costs of this reactor, so these values are assumed to be similar to other SMR of similar size with respect to the ones found in the World Nuclear Association database. The share of nuclear energy in the global power matrix is expected to have a small increase in the next years peaking on 2030 when it will start to decline (DNV-GL, 2019). SMR will represent only a small fraction of new nuclear reactors, and the submarine will only be applicable at very specific cases.

The work of Bickel & Friedrich (2005) applied by the European Union is the reference adopted for the quantified externalities. This reference takes into account health impacts from air pollution, accidents in the whole supply chain, and the assessment of other impacts like global warming, acidification, and eutrophication. This methodology was applied for renewable and conventional power plants onshore, so the following assumptions were considered for the present work: the externalities for offshore systems are similar, WEC has the same quantified externalities as FWT, OTEC does not have the impacts to air pollution of a fossil fuel power plant, but has heating effects to the surrounding seawater that needs to be taken into account.

The environmental risks for FWT and WEC are small due to the negligible amount of water pollution generated in case of an accident, mainly from the lubricant and cooling system. OTEC will have a higher content of heating exchange fluids, which can be more pollutant according to the technology chosen. Nuclear leakage is considered irremediable due to the lack of technologies to remove this contaminant once it is in the water.

Scores are attributed to the performance of each technology according to Table 2. This performance matrix is multiplied by the weight vector giving the total scores for the criteria (TS) and the final ranking as shown in Table 5.

Table 4: Performances of selected technologies

	FWT	WEC	OTEC	SSMR
C1	comercial	7	9	7
C2	15,000	750	20,000	6,600
C3	30	16.44	90	91
C4	330,000	32,000	44,000	0
C5	5,000	4,600	11,200	5,000
C5	100	180	350	150
C7	0.05	0.05	0.1	0.2
C8	small	small	Large scale	irremediable large scale

Table 5: Scores and ranking of selected technologies

	FWT	WEC	OTEC	SSMR
C1	10	1	7	1
C2	10	3	10	8
C3	3	2	9	9
C4	10	4	5	1
C5	9	10	1	9
C5	10	7	1	8
C7	9	9	5	6
C8	7	7	4	1
Total Scores	8.37	5.76	4.72	5.07
Ranking	1	2	4	3

4 CONCLUSION

This work presented the application of an improved AHP multi-criteria decision analysis method to rank offshore renewable technologies to support deep-water oil and gas production. The methodology allows to capture the perception of experts from academia and industry about the importance of eight different criteria representing the relevant technical, economic, and environmental aspects of power supply. The viability check step's adoption has proved to be efficient in filtering the non-viable options, thus making it less time consuming to gather the required information to evaluate the viable solutions.

The final ranking showed that for the case of the Mero oil field in Brazil, offshore floating wind (OFW) is the first option followed by wave energy converters (WEC), subsea small modular nuclear reactors (SSMR), and ocean thermal energy conversion (OTEC). The points of improvement to increase the competitiveness of WEC are the TRL and capacity factor, which could be improved through R&D. SSMR also needs TRL advances and has limited applicability, mainly due to its intrinsic high environmental risk. The main disadvantages of OTEC are the higher specific capital and operational costs.

A workshop could be a better way to get the experts' contributions, increasing the consensus.

Future work involves the integration and evaluation of energy storage systems to improve the availability of renewable sources studied in the present work.

More accurate methodologies for quantifying the externalities of offshore power generation systems could also improve the accuracy of the analysis.

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