Planning for a safe and sustainable decommissioning of offshore hydrocarbon platforms: complexity and decision support systems. Preliminary considerations

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A national decommissioning programme of offshore hydrocarbon platforms, regardless of the total or partial removal hypothesis for further alternative uses, should be based on sustainability and safety principles. In order to carry out this sensitive and complex activity, it is necessary that the competent authorities and operators have, in addition to a relevant regulatory framework, criteria and methodologies that make the assessment of technological options from a safety, social, economic and environmental viewpoints possible. This paper presents a first overview of the study performed on decision support system methodologies with focus on Multi-Criteria Analysis (MCA), carried out within the framework of the "Safe and Sustainable Decommissioning (SSD)" project whose goal is to develop a decommissioning program based on the definition of indicators and of objective criteria for removing or converting offshore hydrocarbon platforms.
Keywords: *offshore platforms, Oil&Gas, Multi-Criteria Analysis, Decommissioning, Adriatic Sea.*

Pianificare in modo sostenibile e in sicurezza la dismissione delle piattaforme di idrocarburi offshore: complessità e sistemi di supporto di alle decisioni. Considerazioni preliminari. *I programmi a scala nazionale per la dismissione delle piattaforme di idrocarburi offshore, indipendentemente dall'ipotesi di rimozione totale o parziale o per ulteriori usi alternativi, devono essere basati sui principi di sostenibilità e sicurezza degli impianti e dei lavoratori. Per poter svolgere questa delicata e complessa attività, è necessario che le autorità competenti e gli operatori dispongano, oltre che di un quadro normativo di riferimento, anche di criteri e metodologie sostenibili e sicure che consentano la valutazione delle possibili opzioni tecnologiche. Questo lavoro presenta una prima panoramica dello studio condotto sulle metodologie di supporto decisionale con particolare riferimento all'Analisi Multi-Criteri (AMC). Lo studio si svolge nell'ambito del progetto "Safe and Sustainable Decommissioning (SSD)", il cui obiettivo è quello di sviluppare un programma di dismissione degli impianti offshore basato sulla definizione di indicatori e criteri oggettivi per la rimozione o la conversione ad altro utilizzo delle piattaforme offshore.*
Parole chiave: *piattaforme offshore, Oil&Gas, analisi multi-criteri, dismissione mineraria, Mar Adriatico.*

1. Introduction

The perception of decommissioning of offshore facilities in the Oil&Gas industry and public opinion has changed over the years. Indeed growing attention in projecting, environmental impact assessment and in public awareness has been observed in the past decades. In the 1990s, the main trends were: advanced planning (planning ahead at least 2 years before production ended), engineered solutions, research and development, reuse and the discussion on sustainable disposal (Twachtman, 1997). Decommissioning is an important phase of the life-cycle of offshore Oil&Gas platforms and should be based on principles of: safety, economic efficiency, preserving ecological integrity as well as social inter- and intra-generational equity, in one word it has to be "sustainable".

In Italy, as well as in other parts of the world (such as the USA, the North Sea, etc.), the vast majority of the offshore Oil&Gas installations (mainly jacket steel platforms) were developed during the 1960s and 1980s. In particular, 49 platforms, positioned in very shallow waters, have already reached the end of their economic life and decommissioned (Assomineraria, 2016) (see Table 1) whilst about 145 offshore Oil&Gas platforms are still in operation offshore in the Italian coast within and outside the 12-mile zone.

It has to be noted that in the former decommissioning campaigns all the topsides, treatment facilities, deck infrastructures were dismantled and conveyed in dedicated onshore areas for the final recovery and disposal whilst 23 jacket steel infrastructures were used as an artificial reef in a pre-selected dedicated area in the Adriatic Sea, approximately 12 nautical miles offshore the coastline, named «Pa-

Tab. 1. List of decommissioned offshore platforms in Italy (years 1966-2016) (source: Assomineraria, 2016).
Lista delle piattaforme già dismesse minerariamente in Italia (anni 1966-2016) (fonte: Assomineraria, 2016).

Platform	Installation (year)	Sea depth (m)	Well (n.)	Decommission (year)	Destination
Porto Corsini 6	1965	24	1	1966	T
Porto Corsini 9	1965	24	1	1967	T
Porto Corsini 1	1966	23	1	1968	T
Cervia mare 3	1966	22	1	1985	T
Porto Corsini b alloggi	1968	25		1986	T
Porto Corsini 3	1963	21	1	1989	T
Nilde (FPSO)	1982	100	2	1989	T
Porto Corsini 4	1964	22	1	1990	P
Porto Corsini 7b	1965	25	1	1990	P
Porto Corsini 10	1966	25	1	1990	P
Porto Corsini 11	1966	25	1	1990	P
Porto Corsini 12	1966	25	1	1990	P
Porto Corsini 7	1966	25	1	1990	P
Porto Corsini 8	1966	24	1	1990	P
Cesenatico mare 1	1961	9	1	1991	P
Ravenna mare 5	1962	10	1	1991	P
Ravenna mare 6bis	1961	10	1	1991	P
Cesenatico mare 3	1965	10	1	1991	P
Cesenatico mare 4	1965	3	1	1991	P
Punta Marina 3	1966	9	1	1991	P
Porto Garibaldi mare 1	1968	25	1	1991	P
Punta Marina 2	1965	9	1	1992	P
Ravenna mare a alloggi	1967	10		1995	T
Ravenna mare a	1968	10	10	1995	T
Porto Corsini w prod	1968	12	8	1995	T
Porto Corsini wa alloggi	1968	12		1995	T
Porto Corsini wb alloggi	1968	13		1995	T
Porto Corsini 25	1976	23	1	1996	T
Porto Corsini 25bis	1976	23	1	1996	T
Narciso 2	1985	21	1	1997	T
Lavinia	1981	90	1	1997	T
Ravenna mare sud 1	1961	9	1	1999	P
Porto corsini a	1967	25	4	1999	P
Porto corsini 1bis	1968	25	8	1999	P
Ravenna mare sud 5	1968	9	1	1999	P
Porto Corsini b	1968	25	8	1999	P
Ravenna mare 4	1960	10	1	2000	T
Ravenna mare 7	1963	12	1	2000	P
Anemone 2	1973	22	1	2000	T
Porto Corsini 26	1978	25	1	2000	P
Porto Corsini 27	1979	24	1	2000	P
Porto Corsini 30	1982	24	1	2000	P
Cervia 25	1986	27	1	2000	P
Flavia	1981	10	1	2001	T
Fulvia	1981	12	1	2001	T
Mila 5	1980	52	1	2003	T
Mila 4	1985	45	1	2003	T
Mila 6	1985	45	1	2003	T
Mormora mare 1-4	1985	15	2	2005	T
San Giorgio mare 4	1973	18	1	2005	T

T = transport to shore; P = reuse as artificial reef.

guro» (now a Site of Community Importance – SCI). The remaining 26 decommissioned platforms were removed and treated in dedicated onshore areas for final disposal (Assomineraria, 2016).

In Italy, according to DGS-UNMIG studies (Grandi, 2017; Caliri *et al.*, 2017; Antoncecchi *et al.*,2017) at least 20 offshore platforms (mainly extracting natural gas and located in shallow waters) will come to the end of their useful production lifetime between 2017 and 2021 and more are expected to be decommissioned by 2030 and later.

Over the last decades, international and national regulatory, technological and ideological frameworks have changed significantly, therefore a need for refreshing the decommissioning approach is of the essence. In particular, current international and regional regulatory frameworks (i.e. the Geneva Convention 1958; the Barcelona Convention 1976, the UNCLOS Convention 1982, the IMO Guidelines 1989, the OSPAR Convention 1992) are in favour of a complete removal at the end of the useful life of offshore Oil&Gas platforms, pipelines and other ancillary offshore infrastructure provided that maritime shipping, fishing and environmental protection are taken into account (see Table 2).

Tab. 2. International and regional regulatory framework for the decommissioning of offshore platforms.
Quadro regolatorio internazionale e regionale per la dismissione mineraria delle piattaforme offshore.

Convention/Guideline	Objective	Date	Internal reference
Geneva	Convention on the Continental Shelf	1958	Art 5 1 and 5 5
Barcelona	The Convention for Protedjon of the Mediterranean Sea against Pollution	1976	Art. 20
UNCLOS	United Nations Convention on the Law of the Sea	1982	Art. 60.3
IMO (International Maritime Organization)	Guidelines and Standards for the removal of offshore installations and structures on the continental shelf and in the exclusive economic zone	1989	Art. 3.1 and 3.2
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic	1992	Decision 98/3

With reference to the Italian law, it should be noted that although there is currently no systematic and homogeneous regulatory framework for decommissioning Oil&Gas extraction plants, the most recent indications are in the Legislative Decree no. 145 of 18 August 2015, which transposes European Directive 2013/30/EU ("Offshore Directive"), article 2, paragraph 1, point gg, as well as article 25, paragraph 6 of the Legislative Decree no. 104 of 16 June 2017 ("Environmental Impact Assessment"), which says that the Ministry of Economic Development, in agreement with the Ministry for the Environment, Territory and Sea and with the Ministry of Cultural Heritage, will adopt national guidelines for the decommissioning of the offshore platforms in order to ensure the quality and completeness of the assessment of their environmental impact.

This provision also aims at tackling the issue that a significant number of the platforms entering in the decommissioning phase did not undergo an Environmental Impact Assessment (EIA) procedure because it was not applicable at the time.

On the basis of the current Italian legislation, decommissioning projects, regardless of the total or partial removal hypothesis for further alternative uses, must certainly take place in total safety, must respect the environment (the marine ecosystem), maritime navigation, not forgetting social impact (labour for instance) and financial duties on companies.

The results of the above mentioned elements highlight that to carry out this sensitive and complex activity in the years to come, it is necessary that the competent authorities and operators have:

1. a relevant regulatory framework,
2. criteria and methodologies that make the assessment of technological options from safety, social, economic and environmental viewpoints possible.

These points are also relevant considering that as alternative to total removal, there are other decommissioning options (see Figure 1), each one characterized by its own impact on the environment, costs, socio-economic and security aspects; i.e. bearing in mind the growing sensitivity to aspects of sustainability (economic, environmental and social) and safety in the broader sense. In addition, the application of the principles of the so-called Blue Economy (European Commission, 2017) should be considered as well.

In order to choose the best decommissioning option from sustainability and safety standpoints, appropriate decision-making tools should be available to allow an objective, traceable and transparent assessment of the various possibilities. In particular, this paper aims at presenting a first overview of the study performed on decision support system methodologies with focus on Multi-Criteria Analysis (MCA) that can back up decision making among all possible options to be followed in the decommissioning phase developed within the "Safe and Sustainable Decommissioning (SSD)" project (see Figure 2).

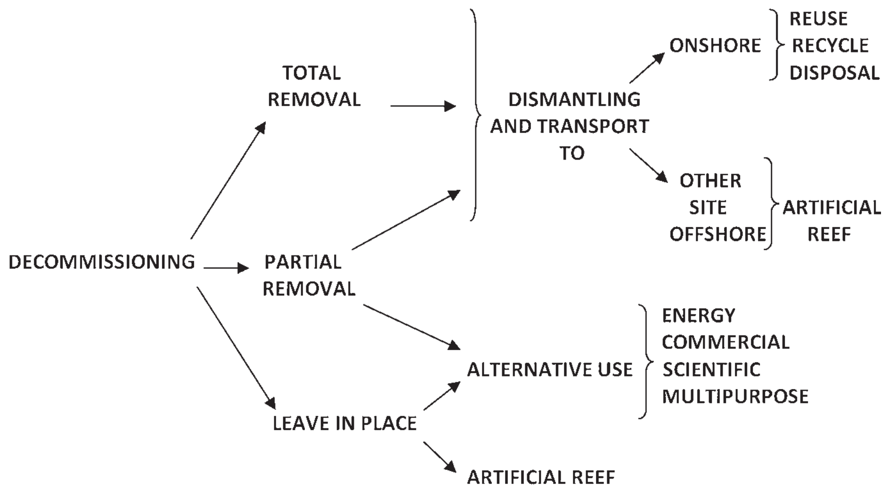

Fig. 1. Decommissioning options.
Opzioni di dismissione mineraria.

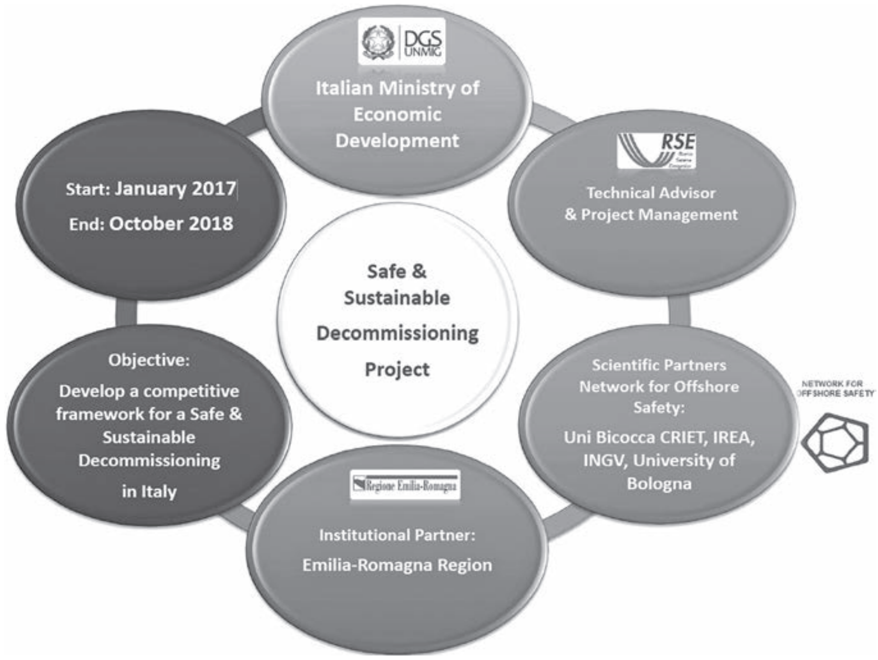

Fig. 2. The "Safe and Sustainable Decommissioning (SSD)" project.
Il progetto "Safe and Sustainable Decommissioning (SSD)".

2. The Multi-Criteria Analysis approach

Multi-Criteria Analysis (MCA) can be helpful to solve a decision problem whenever multiple conflicting objectives are present. In general, every decision choice or process, taken by either a single decision-maker or a stakeholder group, involves environmental, social and economic effects that need to be assessed. In particular, the more and more importance gained by the Multi-Criteria methodologies as a decision support tool is due to the failure of classical economic/monetary analysis in handling multidisciplinary aspects required in the comparison of different design and planning alternatives. It is important to shed light on the fact that MCA techniques do not define the optimum solution among a set of alternatives, but can be used to identify a single most preferred option or to rank options with a transparent, explicit and reproducible process. There are several different methodologies that are part of the MCA general approach. Among these we adopt the methodological framework proposed by Keeney and Raiffa (1993). The method consists of 4 main phases:

- identification or generation of a set design of alternatives and options;
- assessment of the identified options and impacts over time, through a series of measurable criteria to assess the extent to which the decision making group objectives have been achieved; the result is a performance matrix in which each row describes an option and each column describes the performance of the options against each criterion;
- normalization of criteria, by means of utility functions that express the satisfaction of the decision maker on the basis of a single criterion and translate them into a unique unit of measurement;
- weight assignment, expression of the relative importance of each criterion.

Because the decommissioning of offshore platforms involves high costs and a series of potential environmental impacts, the choice about what is more suitable to do when platforms reach the end of their useful oil and gas production, can become an issue of public controversy. In this framework, we are outlining a method of MCA for evaluating and comparing alternative decommissioning options across key selection criteria, including environmental, economic, societal, technical feasibility and safety considerations.

3. The Multi-Criteria Approach to Oil&Gas platform Decommissioning

As aforementioned, the MCA offers a well-structured and objective framework for evaluating and comparing the performance of multiple options across numerous selection

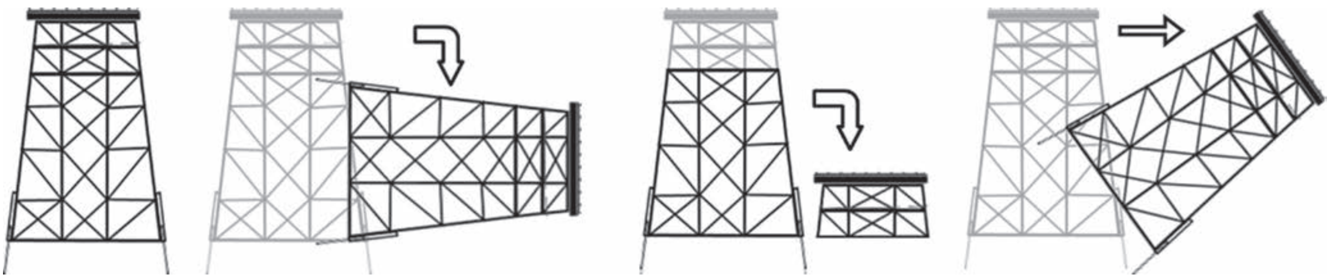

Fig. 3. Different decommissioning options: (a) leaving the rig unaltered in its current location; (b) toppling the entire structure in its current location; (c) partially dismantling the rig through "topping" – the removal of only the upper portion of the rig; (d) transport the rig to shore (Macreadie *et al.*, 2011).
Opzioni di dismissione: (a) "abbandono" della piattaforma nella sua posizione attuale; (b) ribaltamento in loco dell'intera struttura, "toppling"; (c) taglio della porzione superiore della piattaforma, ed abbandono in situ; (d) trasporto della piattaforma a terra (Macreadie et al.*, 2011).*

criteria (Fowler *et al.*, 2014). The proposed method follows a well-defined process that in general includes:

1) definition of the decision objectives to achieve and set up the selection criteria that reflect the objectives;
2) identification of the decommissioning options suitable for the rig (or a group of platforms) under consideration;
3) performance evaluation of each disposal alternative for each criterion;
4) assigning a weight to each criterion according to their level of importance;
5) combination of the criteria evaluation and weights into an overall performance estimate for each decommissioning option;
6) selection of the best disposal alternative based on overall performance.

Perhaps an example can shed some light on the method proposed. Criteria – e.g. decommissioning costs, impact on water and air quality, impact on fish production, technical feasibility – represent the objectives to be maximized (or minimized) by the decision makers and by all stakeholders involved in the decision, reason for which the criteria list should be refined in consultation with all of them. Generally, every stakeholder chooses their own criteria set to better represent their own interests, according to specific situation requirements. The disposal options can range from leaving the platform in place intact, with a conversion to a reef or with a reuse for other purposes, to the complete removal (see Figure 3).

In this regard, it should be noted that in Italy, current legislation excludes the possibility of leaving the rig unaltered in its current location. The elaboration of an alternatives list to consider in the analysis should take into account site-specific conditions: distance of the platforms from shore, water depth, local stakeholder interest for the reuse of the oil rig and regulatory restrictions. The following step after the decision criteria and decommissioning options selection is the construction of a performance matrix in which each row describes a decommissioning alternative and each column describes the performance of the alternative against each criterion (see Table 3). The performance assessment can be both quantitative (cardinal number) and qualitative (dimensionless ranking). It is not easy to find quantitative indicators influenced by the different options, but when feasible to use them it is preferable.

The scientific literature in this area offers different examples of criteria quantitative assessment. For instance, Bernstein *et al.* (2010) described a method to quantitatively estimate the criterion "production of exploitable biomass" for different decommissioning options. The total biomass B populating a platform can be estimated by the sum of the following terms:

1) bottom biomass B_b, defined as the fish biomass in the lowest 2 m of a platform;
2) middle B_m, biomass from 2 m off the bottom to the partial removal depth;
3) upper B_u, fish biomass populating the part of the platform that will be removed in case of partial dismantling through "toppling".

This means that the total biomass B is equal to $B_b + B_m + B_u$. The "complete removal" decommissioning option entails the entire loss of biomass B, while for the "partial removal" option with upper jacket relocated to shore, the adjusted biomass will be: $B_{adj} = B_b + B_m$. In case the upper jacket is disposed of on sea floor as a reef, under the hypothesis that the new habitat will have a similar fish community to the nearby platform, the biomass is calculated adding an adjusted (i) bottom and midwater value scaled to the size of the jacket

Tab. 3. Example of performance matrix.
Esempio di matrice di performance.

	Costs (€)	Fish production (kg)	Greenhouse gas emissions (kg CO_2)
Complete removal	I_{11}	I_{12}	I_{13}
Rig to Reef	I_{21}	I_{22}	I_{23}

placed on the bottom, according to the formula: $B = B_b + B_m + B_{bi} + B_{mi}$.

To compare these various assessments, it is necessary to proceed with a normalization process (see Table 4).

This process converts the criteria assessments into dimensionless values, making them comparable to each other. This transformation is done by means of utility functions (a different one for each criterion), that assign each value of the criteria assessments a corresponding dimensionless preference score, ranging between a minimum value (normally 0) and a maximum value (1, 10 or 100) (Dodgson *et al.*, 2009). The general formula for the utility functions is $U_i = f(I_i)$ for the indicator I_i.

Generally, the decision criteria are characterized by different levels of importance that would be appropriate to include in the overall evaluation. Therefore, a "weight" is assigned to each criterion that expresses its relative importance in relation to the other criteria considered. The weights assignment to the criteria reflects the preference structure of the decision maker, in this sense the choice is completely subjective. The MCA process allows managing this subjectivity in a transparent way. Commonly, the sum of the weights is equal to 1, and their value is allocated by the decision makers involving the stakeholders.

The vector of weights should be stated by the stakeholder, because it should be representative of his/her structure of preferences. This is not always simple or immediate, because the rigorous procedure to obtain the vector of the preferences requires a certain degree of interaction between the technician and the stakeholder. A way to simplify this process is organizing criteria and indicators in a so called decision tree (Figure 4).

In this way it is possible to assign the coefficients for every group of nodes that are children of the same node, for every level of the tree. Inside each group, the sum of the coefficients must be equal to 1.

This process is called hierarchic allocation of the weights and an example is shown in Figure 4. The weights associated to each leaf of the hierarchy are calculated as product of the coefficients assigned from the leaf to the root of the tree.

For example, referring to Figure 4 the weights of SO_2 criterion is given by the product of the coefficients assigned to SO_2 itself, air and environment.

Lastly, it is possible to calculate the overall performance V of each decommissioning alternative, using the formulas reported below (1) (2), and make a comparison among them: the option with highest performance value will be the best one according to the proposed MCA method.

This kind of allocation has the advantage that coefficients are assigned to homogeneous elements and so it is possible for different groups of experts to work on the definition of coefficients linked to their own expertise.

In general, coefficient allocation on the leaf can be done by experts of the sectors involved. While going back up in the hierarchy, it is necessary that politicians suggest the values to adopt (e.g. a technician who is an expert of water quality could suggest the values of the coefficients for organic pollution and non-organic pollution, that belongs to the "Water" criterion, leaving the politician with the task of defining the coefficients for the economic and the environmental sectors).

$$V_{complete\ removal} = w_1 U_{11} + w_2 U_{21} + w_3 U_{31} \quad (1)$$

$$V_{rig\ to\ reef} = w_1 U_{13} + w_2 U_{22} + w_3 U_{32} \quad (2)$$

Given the controversial nature of decommissioning decisions, participation to the MCA process of both technical experts and stakeholder groups is highly recommended.

Tab. 4. Normalization process by means of utility functions.
Processo di normalizzazione tramite le funzioni utilità.

	Costs (-)	Fish production (-)	Greenhouse gas emissions (-)
Complete removal	U_{11}	U_{12}	U_{13}
Rig to Reef	U_{21}	U_{22}	U_{23}
Weight	w_1	w_2	w_3

5. Forward research: options and criteria selection with the stakeholder involvement

As discussed above, an important step of the methodology is the selection of the evaluation criteria and their organization in a decisional tree. Although this step should involve decision makers and relevant stakeholders, it is worth starting with a literature-derived decision tree. The criteria selection is based on past studies related to MCA application to the decommissioning of Oil&Gas platforms. In particular, the following papers have been analyzed in detail:

– A *Multi-criteria decision approach to decommissioning of off-shore oil and gas infrastructure* (Fowler *et al.*, 2014).
  The article underlines that, although the complete removal is considered the most environmentally-sound option, there are examples in the world where oil structures are now habitats to diverse marine communities. For all these reasons a case-by-case approach to decommissioning is re-

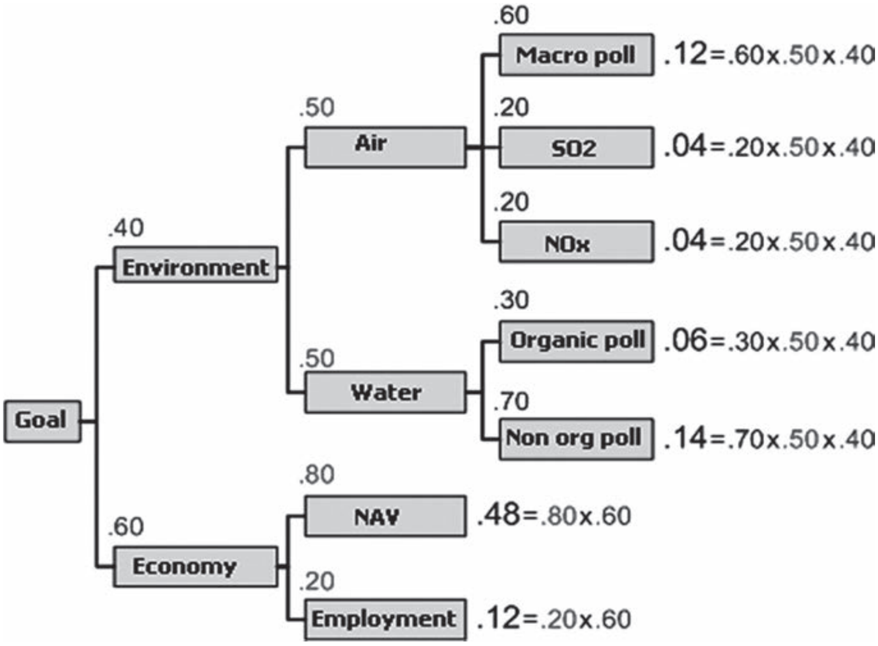

Fig. 4. Example of weights assignment following the decision tree hierarchy.
Esempio di assegnazione dei pesi seguendo la gerarchia dell'albero delle decisioni.

quired. In this study, the authors proposed a generic list of criteria applicable to most offshore decommissioning decisions. The criteria are 39 and are grouped into 5 major categories (environmental, financial, socioeconomic, health and safety, additional stakeholder considerations) to help comprehension of the decision-making problem.

– *Using Comparative Assessment Methods to Determine Preferred Options in Pipeline and Jacket Decommissioning (Ferris and Tjea, 2015)*.
This study proposed a comparative assessment method to evaluate decommissioning options. The comparative assessment was applied for the decommissioning of the Murchison platform in the Northern North Sea (156 m water depth). Murchison was one of the biggest platform in the North Sea, with its jacket weighing in total more than 26000 tonnes. For this reason it was necessary to evaluate a possible derogation to the Convention For The protection of The Marine Environment Of The North-East Atlantic (OSPAR 98/3). The two options assessed are the *partial jacket removal* and the *complete jacket removal*. The criteria are 12 and they are grouped into safety, environment, technical, societal and economic.

– *A multi-attribute decision analysis for decommissioning off-shore oil and gas platforms (Henrion et al., 2015)*.
In the near future, California will face decommissioning of 27 oil and gas platforms located offshore to the South of the region. For this reason the State of California requested the California Ocean Science Trust (an independent non-profit organization) a comprehensive policy analysis to better understand the decommissioning issue. The definition of the attributes on which the analysis is based required a big effort. First, an initial list was created from a literature review and the history of this topic. Then the list was refined according to the results of a working group of experts. In the end the objectives were organized in the following 8 attributes (criteria): economic costs, air quality, water quality, impact on marine mammals and birds, marine resources fish biomass, benthic impacts, ocean access impacts, compliance.

The final list of criteria takes into account the results from the literary review, Italy's specific conditions as well as the availability and reliability of data for indicator quantification. The 26 evaluation criteria are grouped into 4 major categories: Environmental, Economic, Societal and Technical and they are shown in Figure 5.

Of course, the criteria list and the decommissioning alternatives should be refined with the support of key stakeholders and experts, to be engaged in specific round tables, bearing in mind that the success of the proposed methodology is based on a wide and active participation of all stakeholders.

6. *From studies to structured planning*

Current Italian and international regulatory frameworks favour complete removal at the end of the life cycle of offshore Oil&Gas platforms, sealines and other ancillary offshore infrastructures. However, social, environmental and economic benefits of total removal policy may not be always warranted because other options (such as leave in place, partial removal, reuse for other purposes or nearby relocation) may be a better choice.

The adoption of these alternative solutions is stimulating a lively debate among stakeholders in order to tackle challenges and opportunities in the short and longer terms.

To reinforce the MCA model, a consultative approach has been started in order to further collect possible scenarios, information about public opinion perceptions, tests and validate indicators and criteria. In particular, some sessions have been carried out via the "Forum of the Future of Offshore Platforms" launched at the Offshore Mediterranean Conference & Exhibition (OMC 2017). Coupling

Fig. 5. Decision tree with the selected objectives and criteria.
Albero decisionale in cui si riportano gli obiettivi ed i criteri selezionati.

MCA and consultation processes can be said to be a methodological innovation, at least in this sector. However, further studies and development of SSD project steps are needed.

In all cases, it seems that key to a sustainable choice between the various decommissioning options is to ensure availability of information along with the right decision-making tools. Thus, the "Safe and Sustainable Decommissioning" project could be an important base to develop suitable decommissioning programs that will assist regulators, operators and stakeholders in ensuring awareness, best available technologies, defining indicators, objective criteria and implementing shared decommissioning programs for offshore platforms and their infrastructures in Italy. In particular, the development of the MCA tool is going to be an added value policy instrument in line with other approaches found in the literature for California (Bernstein *et al.*, 2010; Henrion *et al.*, 2015) to decide whether removing or converting offshore hydrocarbon platforms.

The MCA can be helpful to assist problem analysis and decision processes, especially when multiple conflicting objectives are present.

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