End-of-life management of oil and gas offshore platforms: challenges and opportunities for sustainable decommissioning[1]

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Abstract

Purpose of the paper: *The decommissioning of offshore platforms represents a significant and controversial challenge that has gained attention over the years due to its environmental, social, and economic impact. This work aims to investigate stakeholders' perceptions regarding the future of offshore platforms and to explore dimensions of sustainability related to decommissioning.*

Methodology*: An analysis was carried out based on two rounds of empirical inquiry, a range of primary data collected through multiple-choice questionnaires and in-depth interviews.*

Findings*: The analysis shows that stakeholders perceive reuse as an opportunity to minimise the impacts according to an environmental, economic, and social perspective. While the multipurpose platform represents an opportunity for the future, it also presents challenges.*

Research limitations: *The study relies only on qualitative analysis techniques and on a limited sample and geographical area.*

Practical implications: *The analysis offers several insights into the decommissioning scenario according to a sustainable and circularity perspective and contributes to the decommissioning debate by providing information about decommissioning programs, stakeholders' impacts, and future planning considerations.*

Originality of the paper: *The study contributes knowledge to the field and useful managerial insights, highlighting stakeholders' perception in the Italian context and exploring dimensions of sustainability and main SDGs related to the issue.*

Key words: sustainable development; circular economy; decommissioning; offshore platforms; end life management

1. Introduction

In recent years, national and international attention to global issues affecting the environment has increased, including attention to the decommissioning of offshore platforms, which is a multi-disciplinary issue. The industry has been increasingly interested in evaluating the environmental impact of decommissioning, as well as increasing public awareness about it. Decommissioning is also a key pillar of the

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global energy system and, as such, is a driver of economic and social development. More than 7500 offshore oil and gas structures have been built in over 53 countries (Parente *et al.*, 2006; Lakhal *et al.*, 2009; Techera and Chandler, 2015). Moreover, a growing number of oil and gas platforms and facilities have come to the end of their expected life, having exhausted the extractable oil reserves (Day and Gusmitta, 2016). Decommissioning activity represents a significant investment, without a possibility of return on investment (ROI). A relatively new challenge to most producer countries and energy companies, decommissioning aims to balance the sensitive threshold between minimizing financial and human costs and protecting well-being and the environment (Fam *et al.*, 2018).

In this context, adopting sustainable methods involving a circular approach to decommissioning programs represents a game-changing opportunity to manage resources within planetary limits. The actions set out in the oil and gas decommissioning sector through a circular economy (CE) approach can contribute to the fulfilment of the sustainable development goals (SDGs). Understanding the circularity of products and services (or their contribution to the CE) is indeed crucial in designing policies and business strategies in the oil and gas industry. Key features of circularity include lifecycle thinking and the elimination of waste. In recent years, programs oriented towards reusing obsolete facilities for marine research, aquaculture, renewable energy technologies, or leisure or towards recycling materials from the structure have emerged (Techera and Chandler, 2015; Chandler *et al.*, 2017; Buck and Langan, 2017). Reducing the harms associated with decommissioning of oil and gas offshore platforms allows for the creation of new economic opportunities and environmental improvements. Although in the past the environmental impact of decommissioning has lacked visibility, in recent years, thanks to greater general awareness, stakeholders have become more interested.

Decommissioning of offshore platforms is currently a highly relevant topic in Mediterranean regions. It is proposed as a priority topic for the next biennium 2022-2023. An examination of the technical evaluation of removal methods, sustainability implications, environmentally sound management, and optimal treatment is needed. In Italy, there are numerous offshore installations, and the decommissioning of several structures is expected soon. In the national regulations, decommissioning includes structural dismantling, removal of platforms, and restoration of the area's original condition. However, the considerable cost of social and economic decommissioning has led to a gradual change in regulations in favour of a sustainable and circular approach.

In this context, this research aims to investigate stakeholders' perceptions regarding the future of offshore platforms and the opportunities and challenges related to the sustainable and circular approach to decommissioning. By leveraging the dimensions of sustainability, scenarios of platforms' reuse through sustainability pillars have been discussed. The paper is structured as follows. Section 2 provides an overview of the end-of-life management of platforms and explores the literature on sustainability and circularity, highlighting the importance of sustainable development and the application of circular principles in oil and gas decommissioning programs. Section 3 presents the research methodology, and Section 4 presents the research results; Section 5 discusses the main findings. Conclusions are drawn in Section 6, which identifies practical and managerial implications and research limitations and suggests further research directions.

2. Theoretical background

2.1 The end-of-life management of oil and gas offshore platforms

The typical oil and gas project lifecycle includes acquisition, exploration, drilling, production, and decommissioning phases. Decommissioning is the final stage of the life cycle of assets in the oil and gas supply chain. Decommissioning activity is projected to grow significantly by 2040 (EIA, 2018). It includes all activities necessary to manage and dispose of installations and platforms and to restore the environment, in particular:

- pre-abandonment surveys, development of a decommissioning plan and submission for regulatory approval, plugging and abandonment of wells, dismantling and removal of topsides, subsea structures and pipelines, and disposal of associated waste;
- reverse engineering structures to dismantle them safely and efficiently;
- destruction or recycling of substantial waste products, including hazardous chemicals;
- substantial environmental remediation, which can have important economic, social, and environmental implications in the context in which it is realised.

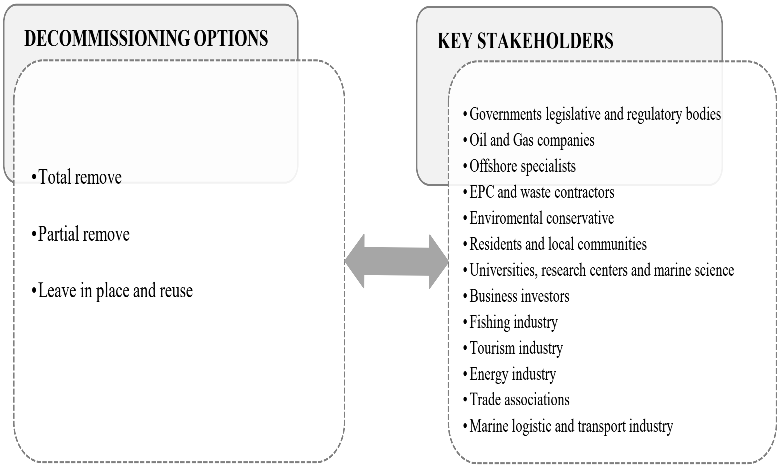
Each offshore platform structure is different and therefore requires a customised approach to be decommissioned. Generally, the end-of-life options for offshore infrastructure include (I) total removal, (II) *in situ* decommissioning (by leaving the infrastructure in place either completely intact or with its topsides removed and legs toppled), (III) removal and relocation offshore (for example, as a dive site or fishery), and (IV) partial removal (removing parts of the infrastructure while leaving others *in situ*) (Ekins *et al.*, 2005).

Different strategies for decommissioning derive from complex and intercorrelated environmental, technical, economic, and safety aspects. Policies of removal, which are generally adopted in regulation frameworks, assume that the seabed is left unaltered and can represent the most environmentally sound decommissioning option, but disposal is expensive. As an alternative to total removal, other decommissioning options are characterised by their impact on the environment, costs, and socioeconomic and security aspects. Martins *et al.* (2020) have reviewed how a multicriteria analysis has been used in oil and gas decommissioning decisions, investigating the main aspects and methods of this analysis.

According to the literature (Schroeder and Love, 2004; Sommer *et al.*, 2019), the major environmental issues arising in decommissioning regard the potential effects on the marine ecosystem, the appropriate use and containment of hazardous substances, including naturally occurring radioactive material, and waste management, which includes finding a destination for the debris accumulated over the life cycle of a piece of equipment (Cripps and Aabel, 2002; Almeida *et al.*, 2017). Scholars have observed that the structure of the oil and gas platform may provide important habitats to ensure population connectivity: marine ecosystems evolve below the surface on and around offshore oil and gas structures throughout their operational life. Hence, these platforms present great ecological opportunities for marine ecosystem enhancement or restoration and offer both ecological and economic opportunities (Van Elden *et al.*, 2019). Over the past 50 years, global guidelines and regulations have emerged as decommissioning activities have risen significantly, calling for guidelines for the protection of the marine environment and the rights of other parties (local communities, industries, etc.). Global conventions and guidelines have been purposely introduced in the oil and gas industries to minimise the risk and threats induced by decommissioning operations. The Article n. 60 of the United Nations Convention on the Law of the Sea and Resolution A.672 adopted in 1989 as part of the International Maritime Organization provided guidelines and a framework for decommissioning; however, there is a range of alternatives to be exploited case by case in the national and international contexts (Fowler *et al.*, 2014).

Whether an offshore structure is to be fully or partially removed or left in place, decisions about oil and gas decommissioning have attracted considerable interest from a large number of different local, regional, and global stakeholders. Over the last decades, international and national regulatory, technological, and ideological frameworks have changed significantly, encouraging a new way to consider decommissioning. Social movements, which are pressing for ecological modernisation and sustainable development, have emphasised the importance of reducing waste and sharing resources (Arts and Leroy, 2006). As currently required by legislative bodies, oil and gas decommissioning activities must involve stakeholders extensively (Sommer *et al.*, 2019). However, certain stakeholders are not physically close to, nor directly involved in, the decommissioning process but can feel indirect impacts. In the literature and in practice, it has emerged that the process of decision-making about the future of offshore platforms has involved several direct and indirect stakeholders: oil and gas companies, national and local governments, regulators (nuclear and environmental protection regulators, etc.), offshore specialists, procurement and construction (EPC) contractors, waste supply chain contractors, port authorities, trade associations, local communities and residents, business investors, universities, research centres, and marine scientists (IAEA, 2009; Love, 2012; Invernizzi *et al.*, 2017; OECD/NEA, 2018; Sie *et al.* 2018; Genter, 2019). The main key stakeholders are included in Fig. 1.

Fig. 1: Stakeholders involved in decommissioning options



Source: Authors.

2.2 Integrating sustainability and circularity in decommissioning programs

In the last twenty years, the concepts of sustainability and sustainable development have generated increased interest not only from economics and business management scholars but also by policy-makers (Kates *et al.*, 2001; Komiyama 2006; Lang, 2012; Schoolman *et al.* 2012; Gore, 2015). Although these concepts were first introduced in response to environmental concerns, the sustainability paradigm has expanded to encompass the notion of "economic development", which includes not only economic growth (increase in material wellbeing and distribution of wealth) but also environmental and social outcomes. Sustainability and sustainable development are important concepts in the oil and gas industry for several reasons: they not only potentially make companies wealthier (e.g., economic prosperity), but they also foster social justice and environmental protection. In a world that has become more connected and interdependent than ever before, sustainability is not an option: it is essential.

The contemporary sustainability literature has centred on the UN's various sustainable development goals (SDGs) in which the three pillars of sustainability have been explicitly embedded (UN, 2012). The 2030 Agenda for Sustainable Development and its framework of 17 Sustainable Development Goals (SDGs) adopted by the United Nations General Assembly in September 2015 agree to "*protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations*". (UNEP, 2015). The SDGs aim to address the world's pressing environmental, economic, and social challenges (Colglazier, 2015). The sustainable development concept is frequently connected to the oil and gas industry, which considers sustainability aspects in its strategic decision-making processes. The oil and gas industry can contribute to the realisation of different SDGs whether it enhances its positive actions towards the environment or avoids or mitigates its negative impacts. The oil and gas industry's operations and products can have positive and negative impacts on a range of topics covered by the SDGs, including communities, ecosystems, and economies. Recently, the United Nations Development Programme (UNDP), the International Finance Corporation (IFC) and the global oil and gas industry association for environmental and social issues (IPECA) have partnered to publish "Mapping the oil and gas industry to the Sustainable Development Goals: An Atlas". The oil and gas decommissioning program can act towards SDGs 3 (health), 6 (water), 8 (sustainable economic growth), 9 (industrialization and innovation), 11 (cities), 12 (sustainable consumption and production), 13 (climate change), 14 (oceans), 15 (terrestrial ecosystems), 16 (peaceful and inclusive societies) and 17 (means of implementation) (Fig. 2).

Fig. 2: Sustainable development goals in the decommissioning program

Source: Authors, based on UNEP (2015).

Many challenges, including health and well-being, pollution, global climate change, and biodiversity, have emerged in the oil and gas industry and in the end-of-life management of platforms. Table A1 in the Appendix indicates the main SDG dimensions and the opportunities to integrate SDGs into decommissioning programs. Recent studies have demonstrated a sustainable decommissioning approach in the energy industry (Topham *et al.* 2017; Invernizzi *et al.*, 2020; Zawawi *et al.*, 2012; Capobianco *et al.*, 2021). To integrate sustainability in decommissioning programs, social, environmental, and economic dimensions must be considered, as well as the ways in which these interconnect. The "Three Pillars" approach or "Triple Bottom Line" (Elkington, 1997) can be adopted to distinguish the three dimensions of sustainability: economic viability, social equity, and ecological integrity. When the three dimensions are separated, it is easy to operationalise the approach and to highlight trade-offs, especially in accounting and evaluation practices; therefore, policy-makers have widely accepted the three pillars approach, which has been included in many soft law documents and promoted within companies' business management (Bosselmann, 2016). As a source of renewable natural loops, offshore platform end-of-life management should integrate the three dimensions of sustainability (environmental, economic, social) for sustainable decommissioning.

The circular economy has recently been popularised as a driver for sustainability (Geissdoerfer *et al.*, 2017; Schroeder *et al.*, 2019). In step with sustainable development, awareness is growing that we need to move from a linear to a circular economy. The current economic and industrial model, called the produce-use-dispose model, is a linear model. In this model, resources used are lost, which constitutes a waste of resources and money. The CE is based on three key activities, reduction, reuse, and recycling (the so-called '3R's principles'), in the processes of production, consumption and circulation (Feng and Yan, 2007; Yong, 2007; Benton, 2015). The CE has relied on the restorative capacity of natural resources and has aimed to minimise - if not eliminate - waste, utilise renewable energy sources, and phase out the use of harmful substances (Ellen MacArthur Foundation, 2015). Such an economy goes beyond the "end of pipe" approaches of the linear economy (Chamberlin *et al.*, 2013) and seeks transformational changes across the breadth of the value chain to retain materials in the "*circular economy loop*" and preserve their value for as long as possible (Ellen MacArthur Foundation, 2014, Vanner *et al.*, 2014). The definition of the circular economy makes explicit the increasing pressure on our resources: the CE is "*an economy in which stakeholders collaborate to maximize the value of products and materials, and as such contribute to minimizing the depletion of natural resources and create positive societal and environmental impact*" (Kraaijenhagen *et al.*, 2016, p. 15). Additionally, Kirchherr *et al.* (2017) have proposed a definition of the CE that links the circular economy concept to the goal of sustainable development in all three dimensions (society, economy, and environment): "*an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro-level (products, companies, consumers), meso level (eco-industrial parks) and macro-level (city, region, nation and beyond), to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity, and social equity to the benefit of current and future generations. It is enabled by novel business models and responsible consumers*" (Kirchherr *et al.* 2017, p. 229).

In a contest of decommissioning decisions, a circular approach can be implemented along a variety of strategies under four main categories in order of priority:

1. narrowing resource flows to reduce the number of materials going around in the economy (e.g., waste reduction, dematerialisation);
2. slowing the flow of resources between the point of manufacturing and disposal (e.g., repair and maintenance, lifetime extension, component reuse and refurbishment, remanufacture, disassembly);
3. closing the loop of resource flows (e.g., recycling, decommissioning);
4. safely integrating material flows back into natural processes (e.g., rigs-to-reefs, remining, and controlled landfill storage).

The circular approach contributes to sustainability by minimizing natural resource extraction and waste while optimizing environmental, social, technical, and economic values throughout the lifecycles of materials, components, and products (Velenturf *et al.*, 2021).

3. Methodology

3.1 Research design

To investigate stakeholders' perceptions about the future of offshore platforms and the opportunities and challenges related to the sustainable and circular approach in decommissioning, we conducted an empirical analysis.

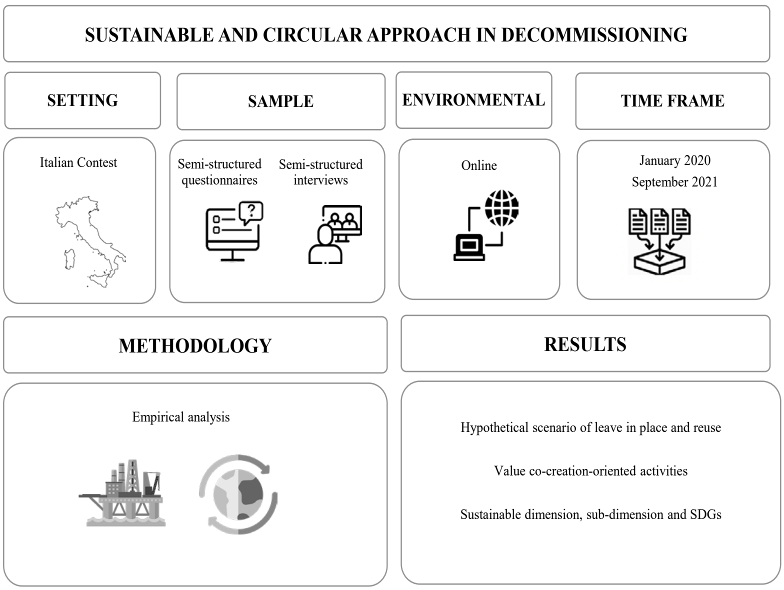
The Italian context was selected for the analysis. Italian oil and gas installations are reaching the end of their economic life, and a program of decommissioning is underway. The oil and gas offshore structures in Italy include 138 platforms, which mostly extract gas, and out of which 12 are inactive and 34 will have to be decommissioned in the coming years (UNMIG, 2020). National legislation relating to the abandonment or decommissioning of physical structures used in oil and natural gas production has been developed. The abandonment of facilities and related infrastructures is forbidden. When a licence-holder wishes to decommission physical structures that have either become sterile, have exhausted a deposit, can no longer be used, or are not capable of further assuring production in commercial quantities, details of the shutdown must be provided with an authorization request from the National Mining Oce for Hydrocarbons and Geo-resources (UNMIG) Section of the MiSE. The official list of offshore platforms being decommissioned is published by UNMIG on the Ministry of Economic Transition website and updated every year.

This study is based on a qualitative approach,Surveying key stakeholders' opinions and perceptions can contribute to the understanding of oil and gas decommissioning.

In this study, the data were collected from January 2020 to September 2021. Data collection was divided into three rounds of empirical inquiry.

First, multiple-choice questionnaires were used to investigate people's perception about the challenges and opportunities generated by offshore platforms decommissioning in relation to sustainability and the circular economy. The final dataset included 33 answers To ensure a high response rate, the multiple-choice questionnaires were brief and easy to complete (taking respondents less than 15 minutes to fill). Second, in-depth semi-structured interviews focused on the multipurpose approach in hypothetical scenario of leave in place and reused of the platform. Third, explorative interviews were conducted with consultants involved in the decommissioning industry to validate the primary interviews and explore managerial visions about the future of offshore facilities. During the first round of data collection, topics of discussion included the decommissioning hypothetical scenario, the main purpose of the decommissioning program, key partners, and value cocreation-oriented activities in the leave in place and reuse scenario. Additionally, secondary data were collected from government publications, official websites, and news articles related to the industry, as well as reports and documents produced by regulatory agencies, oil and gas companies, EPC and waste contractors.

Fig. 3: Research framework



Source: Authors.

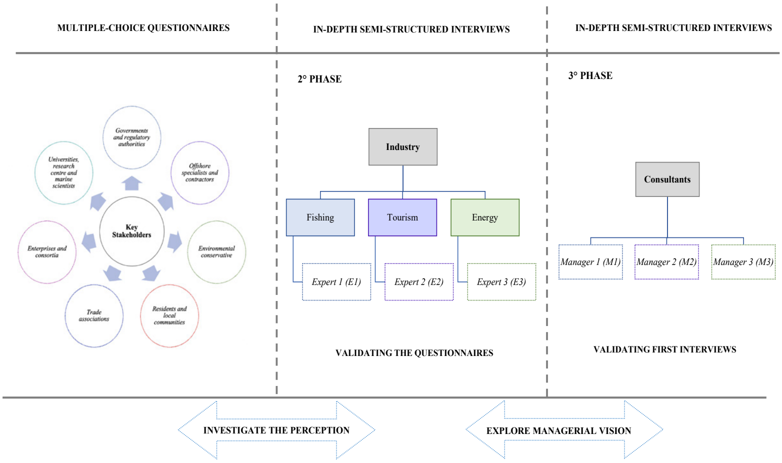
3.2 Data collection and analysis

Semi-structured questionnaires were conducted online between January and April 2020 among a list of stakeholders identified within the Italian community (i.e., governments and regulation authorities, offshore specialists and contractors, trade associations, enterprises and consortia, environmental conservation organisations, residents and local communities, universities, research and marine science centres). Based on their activities, the key stakeholders were chosen through desk research on decommissioning oil and gas platform-related activities. Each questionnaire included several sections: respondents' social demographic profile, evaluations of decommissioning scenarios, individuation of main partners and relevant activities in terms of value creation proposition in the hypothetical scenario of reuse, and prominent approaches enabling platform reuse. The data were entered into a database, coded, and processed for qualitative analysis. The authors used Excel as their qualitative data analysis tool (Meyer *et al.,* 2009).

In keeping with the purpose of the study, a number of in-depth semi-structured interviews were conducted with three experts related to the different industries (fishing, tourism, energy) that had emerged in the literature and the multiple-choice questionnaires and were considered relevant in terms of value creation proposition from the perspective of sustainable decommissioning. The interviews were conducted from March to September 2021 and focused on the perspectives of sustainable and circular challenges related to the hypothetical scenario of leaving in place and reusing Italian offshore platforms. Following the initial analysis of the first three interviews, specific lines of enquiry emerged around the reuse of platforms. To validate the first interviews and generate a deeper understanding of the phenomenon and explore managerial vision about the future of offshore facilities, the interview sample was broadened purposively to include consultants who were involved and linked to the decommissioning project. It was anticipated that, through their respective roles, these interviewees would provide different perspectives on oil and gas decommissioning.

The interviews were guided by a flexible interview protocol and supplemented by follow-up questions, probes, and comments. Since the interviews contained open-ended questions and discussions diverged from the interview guide, the experts were encouraged to interact. The interviews were transcribed manually, as well as recorded to guarantee a more consistent transcription (Creswell, 2012). Interviews were conducted by the researchers over the internet using Microsoft Teams. Following the transcription of all interviews, the transcripts were shared with the participants for accuracy and to determine whether they wished to add anything to their responses. As the study focused on a new phenomenon, the transcripts were initially analysed individually by all researchers, using a constructivist perspective. Following the initial analysis, the research team engaged in extended dialogue to refine the key themes that had emerged. Each interview lasted an average of 45 minutes, and the interview protocols were transcribed.

Fig. 4: Data collection and analysis



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4. Findings

This section describes the results of the multiple-choice questionnaires and in-depth exploratory interviews on the general perspective of sustainable decommissioning in the broader framework of the circular economy.

Primarily, the demographic profile of the study was analysed. The respondents mainly worked in the public sector; for instance, some were involved in local government. Among the 33 respondents, most were between 51 and 60 years-old. Additionally, most had degrees and a high level of education (Table 1).

Tab. 1: Respondents' profile

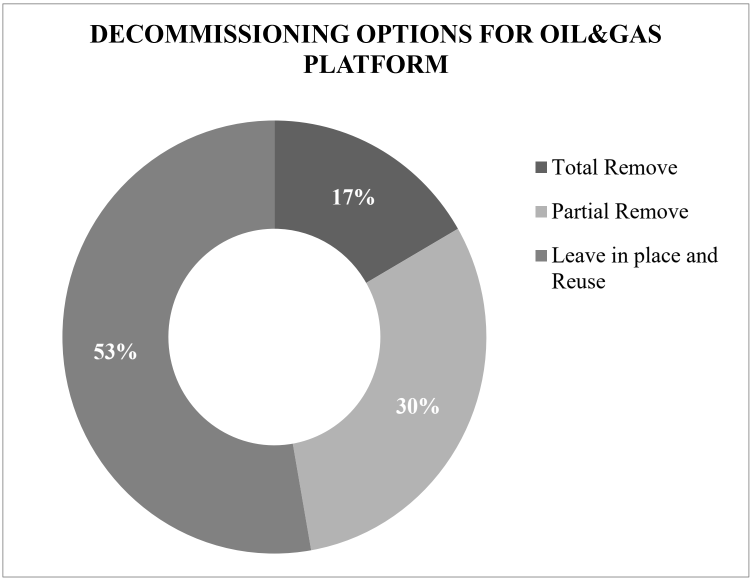
Characteristics	Participants N = 33 (%)
Sex	
Male	23 (70%)
Female	10 (30%)
Age range (years)	
18-25	1 (3%)
26-35	3 (9%)
36-50	10 (30%)
51-60	17 (52%)
>60	2 (6%)
Education level	
High School	6 (18%)
Msc	12 (36%)
Postdegree/Master/PhD	15 (46%)
Professional affiliation	
Public sector	17 (52%)
Private sector	11 (33%)
Associations and NGOs	5 (15%)

Source: Authors.

Decommissioning hypothetical scenarios

Considering that the impact of decommissioning decisions and end-of-life management goes beyond the industrial environment, it is essential to properly consider the perspectives of distinct stakeholders about different courses of action. As such, these decisions are politically sensitive and multidisciplinary in nature. Each offshore platform structure is different and therefore requires a customised approach to decommissioning. Generally, the end-of-life of offshore infrastructure includes total removal, partial removal, leave in place, and reuse. The analysis shows the high potential of leaving in place and reusing offshore platforms. For 53% of respondents, the scenario of leaving the platform in place and reusing it appears to be the most appropriate in terms of environmental and socioeconomic aspects (Fig. 5).

Fig. 5: Responses to questions about the decommissioning scenario



Source: Authors.

The interviews revealed the importance of searching for innovative solutions, processes and products aimed at applying the circularity principle, as well as the reuse and enhancement of waste materials to make the economic system more efficient while minimizing both resources and energy consumption: "*In the last decades, oil and gas industry investing in R&D activities to implement innovative technologies to protect offshore platforms from corrosion and so on, to reduce environmental impact […] and to increase energy efficiency with low-carbon and climate-resilient technologies*" (M2). The interviewees were aware of the possibility of applying circularity principles and underlined that "*Materials can be* *retained and reused in a different context, instead of being disposed of as waste […] structures can be reutilised with new functions, thus reducing the need for new investments as well as demolition costs […]*". (E3).

Protection strategies for reducing the risk to the health of employees and local communities are incorporated into the decommissioning process. An interviewee underlined that "*Decommissioning includes different needs to measure impacts systematically to reduce the risks of pollution and contamination as well as to use performance indicators to reduce the impact on the environment [...] in a scenario of reusing and sustainable development technologies and innovative system of measurement that can reduce health hazards limit environmental and social impacts*". (M3). The implementation of decommissioning is usually undertaken by an oil and gas installation operator in consultation with the regulatory agencies. National guidelines for decommissioning offshore platforms and related infrastructures are approved and adopted to ensure the quality and completeness of the environmental impact assessment. Regarding best practices, one interviewee said, "*Regarding the sharing of best practices on decommissioning and reuse, it must be considered that the Italian panorama has not reached a level of maturity such as to develop its own best practices; these are instead present in other contexts (UK, Norway), which stand as references for the Italian context*" (M1).

Key partners in the hypothetical scenario of leave in place and reuse.

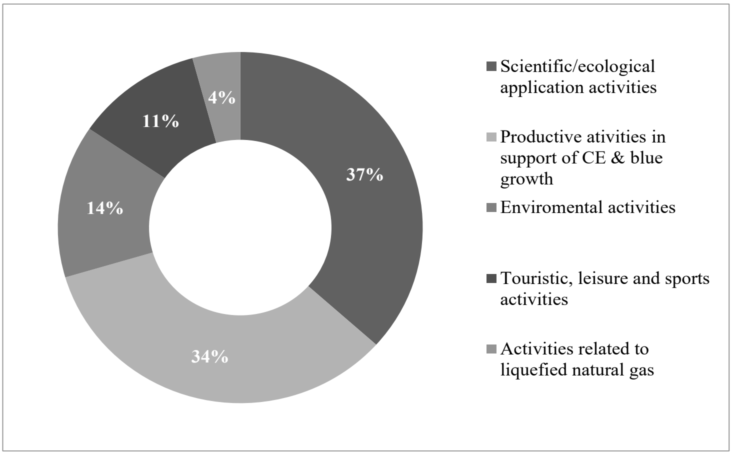
The platforms represent a high-value asset not only based on the existing infrastructures but based on their nontangible features. These may include a strategic location, typically characterised by the proximity of large cities or touristic and cultural landmarks, access to coastal water or existing infrastructures, and an existing network of social and economic relationships established during the period of plant operation. These nontangible features enhance the possibilities for end use or conversion strategies. The results of the study highlight the important role of partners, such as international authorities (22%), national and local governments (15%), academia, and research centres (18%), in the scenario of leaving in place and reusing and in guiding the sustainable decommissioning program. EPC contractors (5%) and shipowners and naval cooperatives (5%) are considered marginal partners. Additionally, to implement the reuse of facilities, considerable attention is given to environmental organizations involved in the protection of the marine ecosystem (14%). Trade associations (12%) and business investors (9%) are also considered key partners in developing new business opportunities related to the reuse of facilities. In terms of social impact on local communities, "*a circular approach to decommissioning could create a positive impact in terms of job creation and minimise the negative impact in terms of job losses*" (M1). This trend is also reinforced by the possibility of applying strategies for the reuse of platforms and repurposing of materials. Regarding the main actors involved in Italy, the interviewees underlined that "*[…] the reference is the Ministerial Decree of 15.02.2019 on the national guidelines for the mining* *decommissioning of platforms and for the cultivation of hydrocarbons at sea and related infrastructures […]. The main stakeholders are UNMIG, the Port Authority, the Environmental Protection Agency, and competent local administrations*" (M2).

Approaches to decommissioning

Strategies based on the circularity approach to decommissioning might result in a significant increase in value for the asset compared to a linear approach. The oil and gas industry contributes to sustainable development in different ways (e.g., generating direct and indirect jobs, contributing tax and other types of revenue for governments, developing new technologies and products through investment in R&D, encouraging local entrepreneurship, investing in the long-term social and economic success of the communities in which they operate, and managing the impacts of its operations by emphasizing environmental protection, health, and safety). In the hypothetical reuse of a platform, respondents (70%) consider that a sustainable and circular approaches play a crucial role, followed by change and innovation in the culture of the industry (30%). In line with sustainable development and circular approaches, the interviews highlight the extension of the lifetime of (infra)structures through their conversion in the context of the energy transition. According to one *interviewee, "sustainability and circular approaches are becoming increasingly important. […] think also about the possibilities offered in reusing waste from other production processes and biomass to produce renewable energy. […]. There are contractors' companies that install structures to produce renewable energy on offshore platforms". Furthermore, "the circular approach is intertwined with the future challenge of adopting more low-carbon energy systems*" (E3).

Reuse constitutes a life extension program for the whole structure or part of the structure. Obsolete platforms could be transformed into strategic hubs that could host valuable and sustainable activities in terms of renewable energy, blue growth, and tourism, as well as a combination of value cocreation-oriented activities. Fig. 6 shows the results of the multiple-choice questionnaires that asked about which activities were considered more relevant for the territory and stakeholders involved in terms of value creation propositions during the offshore platform decommissioning process.

Fig. 6: Responses to questions about applying the leave in place and reuse strategy in platform decommissioning in terms of value cocreation-oriented activities



Source: Authors.

Reusing platforms within the scientific-ecological hub is considered a relevant activity (37%); as reported by one expert, "*the platforms are optimal sites because they are in the open sea away from underwater currents […] the platforms act as a shelter for fish, and this amplifies the underwater microenvironment*" (E1). Some oil and gas platforms should be reused with the energy transition in mind to enable their infrastructures to be repurposed and integrated in sustainable energy systems. For example, their infrastructures could be used for blue and green hydrogen production, carbon capture and storage, and offshore wind production. According to the interviewees, "*in terms of sustainable and blue growth initiatives, a multidisciplinary research centre should be created to develop and combine different reuses of offshore platforms. […] European funds for a sustainable and circular economy and financial incentives for reuse initiatives are crucial […] a fund system for reuse may even be established to provide financial incentives or compensation to keep installations in place that can be reused*" (E1). On one hand, the use of offshore platforms as a base for a single activity is uneconomic; on the other hand, the combination of aquaculture systems with wave energy devices or tourism-recreational activities can generate value. The interviewees explained that "*aquaculture is also one of the blue growth sectors, and synergies have been found with tourism*", adding that "*in areas where 'sustainable' forms of aquaculture are practised, these can provide good-quality seafood to tourists, etc. […] shell and fish farmers can enhance the area's attractiveness by offering tours on their vessels for tourists to visit their farms, creating educative and recreational poles*" (E2). Moreover, the platform can be left in place and reused for recreational activities (such as tourism, leisure, and sports activities): "*the platforms are optimal sites because they are in the open sea, away from underwater currents; then, interesting opportunities for leisure and sports activities (e.g.,* *diving sport, snorkeling, etc.) can be created along the bottom structures of the marine ecosystem sheath*" (E2). Tourism development policy is usually delegated to the regional and local levels of government and rarely carried out at the national level. An important driver of conflict is the diversity in the tourism sector and the variety of needs associated with different types of tourism. One of the interviewees explained that "*there is a tendency towards tourism diversification, meaning more sustainable forms of tourism are emerging*" and that "*experience-based tourism with a focus on scenic, cultural and environmental assets and local traditions and production attracts more affluent and discerning types of tourists*" (E2). The reuse of facilities for different activities can increase their socioeconomic value; according to interviewees, "*the possibility of reusing offshore platforms could undoubtedly be an opportunity for the revitalisation of coastal areas […] socioeconomic value can be created through the reuse of the facilities for touristic-recreational uses*" (E2). The national government and authorities control what types of infrastructure may be available to support the redevelopment of a site and can often provide resources from the jurisdictional budget or through their access to regional or national economic development grants. One interviewee underlined that "*productive reuse of facilities being decommissioned, especially when attracting new industries, could offset the decline in employment*" (M3). In the face of cocreation-oriented activities, multistakeholder engagement is needed: "*To create social and economic value is important for a collaboration and complementary partnership across government, civil society, and the private sector […] current initiatives around sector integration and coupling envisage the reuse of existing assets for new purposes such as hydrogen, carbon dioxide or biogas transport*" (E1).

Thus, the findings suggest that the reuse of platforms may significantly contribute to environmental, social, and economic benefits and provide potential evidence that platforms can remain in place and be reused to create value through multipurpose use. Alternative uses range from aquaculture and tourism to alternative energy production and the establishment of scientific and ecological hubs, which are intended to preserve the biological communities that are supported by the platforms and to enhance biological production or fishing opportunities. The results highlight that the reuse of unprofitable or discontinued facilities, which are given a new life and a sustainable and low-carbon future, is part of a sustainable strategy that the Italian stakeholders who were interviewed share widely. However, although the energy transition has gained momentum, many oil and gas platforms continue to be commissioned.

5. Discussion

The analysis reveals that a sustainable and circular approach has emerged in the decommissioning process as a value cocreation that drives the future of these structures. Concepts and processes of CE aim to minimise waste and to make efficient use of available resources (e.g., through design considerations, careful operation, and the recovering and regenerating of products at the end of a facility's life cycle). In a perfect circular or closed cycle, all waste products are reused. If decommissioning incorporates CE approaches, it is possible to reduce the need for disposal and create long-term, more economical and ecological waste management solutions with added value for society. Therefore, CE strategies deliver a wide range of benefits, including reduced waste, lower costs, and greater sustainability.

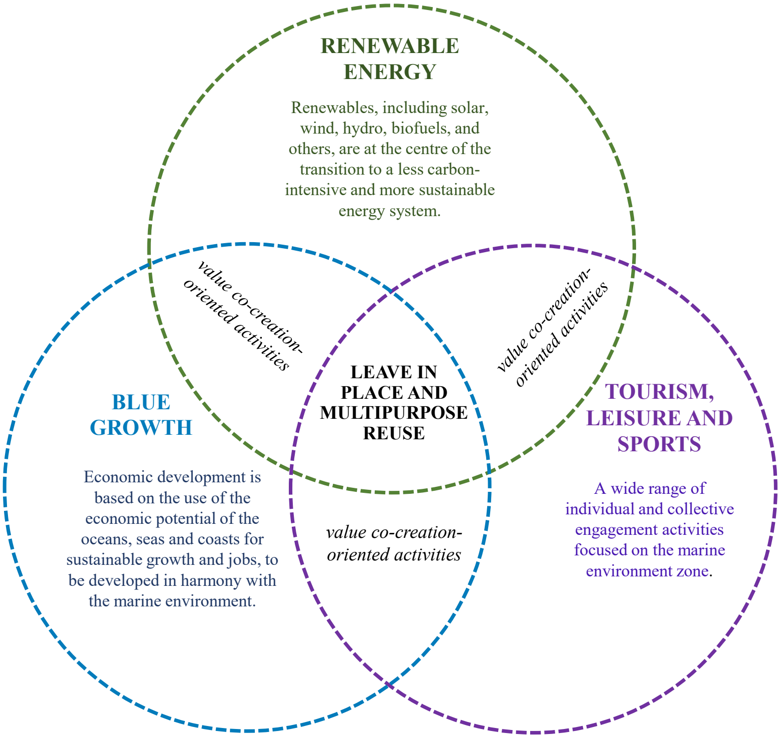
When applying CE strategies to decommissioning, experts face two different situations: first, the sustainable decommissioning of older facilities that were designed and operated with little consideration for sustainability poses specific challenges. Second, to achieve a meaningful circular economy in decommissioning, project managers need to balance the cost of decommissioning and correlated efforts with social and environmental concerns such as radiological risks and the treatment of specific waste streams. In both cases, they rely on technical, regulatory, and social innovations to find the best possible solutions.

Several alternatives that are in line with sustainable development and show awareness of the circularity approach have emerged from the literature and have been proposed for the complete removal of decommissioned offshore oil and gas platforms:

- Platforms for photovoltaic farms (Pimentel Da Silva *et al.* 2018);
- Offshore wind energy projects, either as sites for wind turbines or as offshore maintenance and logistics areas (Smyth *et al.*, 2015; Topham and Mcmillan, 2017);
- Offshore wave energy projects, either as sites for anchoring wave energy generating equipment or as offshore maintenance and logistics areas (Smyth *et al.*, 2015);
- Offshore wind hydrogen projects (Leporini *et al.*, 2019);
- Liquefied natural gas (LNG) terminals (Gondal, 2019);
- Marine farming that includes farming finfish, shellfish and aquatic plants (Buck and Langan, 2017);
- Installation of sea instruments or other equipment into and out of wells;
- Marine protected areas or artificial reefs, either left in place or relocated to a designated reefing location (rigs-to-reefs) (Techera and Chandler, 2015);
- Offshore structures for tourism, leisure, and sports activities (Sommer *et al.*, 2019).

The scenario of leaving in place and reusing obsolete platforms, which leads to value cocreation-oriented activities, has emerged from the data analysis (Fig. 6), including multipurpose uses that combine synergies and compatibilities across platforms. In Italy, multiple sectors coexist in the maritime economy (i.e., commercial fisheries, aquaculture, coastal and maritime tourism, shipping, port activities, oil and gas extraction, and environmental protection). Based on our findings, we consider this multipurpose use a valuable perspective to understand the opportunities of platform decommissioning in Italy and future challenges (Fig. 7).

Fig. 7: A framework of platform multipurpose reuse in light of value cocreation



Source: Authors.

Some of these platforms could become diving bases and strategic sites for the monitoring of the marine environment. Hence, the reuse of facilities could support blue growth initiatives by sustaining growth in the maritime industry as a whole and by harnessing the potential of Europe's oceans, seas, and coasts for the creation of blue jobs and the development of local economies.

In the sustainable reusing of platform equipment, a proactive and innovative solution lies in the development of multi-use platforms at sea (MUPS) that integrate different activities within a specific marine area, for instance, energy production and aquaculture (Vona *et al.*, 2022). The reuse of facilities on multipurpose islands presents several advantages for economic development and ecotourism initiatives (Zawawi *et al.*, 2012). MUPSs are maritime areas that can be designated for a combination of integrated or parallel activities linking spatial (supporting a more sustainable use of marine space) and process efficiency to promote a blue economy in line with recent European strategy and policy (Stuiver *et al.*, 2016; Klinger *et al.*, 2018).

In the MUPS scenario, when platforms are at the end of their service life and become heavy assets whose decommissioning is burdensome from an environmental and economic stand, they could instead become profitable assets thanks to the application of innovative eco-sustainable strategies in multipurpose use. The platforms represent a high-value asset not only for their existing infrastructures but also for their nontangible features. These may include a strategic location, typically characterised by their proximity to large cities or touristic and cultural landmarks, and access to coastal water or existing infrastructures, as well as proximity to the existing network of social and economic relationships established during the period of plant operation. These nontangible features increase the number of possible end uses or conversion strategies.

Decommissioning programs involve multiple actors with diverse interests and means to achieve decommissioning planning alternatives. Achieving sustainable development requires multisectoral and multidisciplinary approaches. Sustainable decommissioning projects should consider regulatory, environmental, health and safety, and financial criteria to maintain a good reputation for all direct stakeholders involved. To realise fully their contribution potential towards the achievement of the SDGs, government bodies, national authorities, and oil and gas companies should engage in meaningful multistakeholder dialogue with relevant actors locally and nationally, with whom they could identify joint SDG priorities and collectively define potential coordinated responses to the SDGs in the local context. Current regulations do not provide sufficient guidelines on how decommissioning should be carried out to minimise the risk of environmental damage, and they do not foresee potential platform reuse or recycling, which is instead left to the voluntary effort of individual companies. The legislation must provide sufficient incentives to enable reuse projects: reviewing policies and laws for enabling reuse of oil and gas installations is a highly necessary and strategic step for countries with maturing petroleum areas and facing the energy transition.

The authors linked, the literature and their results about the environmental, economic, and social subdimensions that emerged out of their hypothetical scenario of platform leaving in place and reusing. Finally, the authors linked of SDGs relevant in sustainable decommissioning of the oil and gas offshore platforms, as shown in Table 2.

Tab. 2: Sustainable pillars and SDGs in the scenario of leaving in place and reusing

Sustainable Development Goal (SDG)	Description	Actions set out in the oil and gas decommissioning program
SDG 3 (Health)	Ensure healthy lives and promote well-being for all at all ages	Oil and gas activities, particularly those in remote or underdeveloped areas, can contribute to health challenges, including indirect impacts due to changes to the local environment and communities. Identifying potential challenges requires understanding the complex social, economic, geographical, and biological dynamics of a given area. Management of decommissioning operations enables mitigation of potential health risks (e.g., exposure to air and water emissions, fires, etc.) Protection strategies for the health of employees and local communities are incorporated in the different stage decommissioning process.
SDG 6 (Water)	Ensure availability and sustainable management of water and sanitation for all	Oil and gas industry manage large land areas and can be responsible for water related ecosystems both within their concession and as part of engaging in landscape-level cross-sectoral management of ecosystems. A water strategy also includes integrated approach with local stakeholder how the oil and gas company protect and restores water-related ecosystems to address water quantity and quality in and around the area of decommissioning operations.
SDG 8 (Sustainable economic growth)	Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all	Foster full and productive local employment and workforce development. Direct employment in oil and gas operations can often be limited, and the local workforce can lack the technical and managerial capacity necessary to meet a company's standards. The incorporation of local businesses into the supply chain, either through the direct procurement of goods and services by the company or through indirect procurement via contractors, contributes to local inclusive economic growth. However, the communication of different stages and economic opportunities of decommissioning project to local communities, educational organizations, and government.
SDG 9 (Industrialization and innovation)	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Complexity of decommissioning operations requires a high level of technology and expertise and could be promotes inclusive industrialization. Oil and gas industry investing in new technologies that increase energy efficiency and conservation and are low-carbon and climate-resilient in nature. Technological advancements and efficient infrastructure are paths to meeting energy demand while avoiding or reducing environmental and social impacts and related risks. Additionally, by applying innovative and more efficient techniques and for decommissioning program, can improve the environmental and social stewardship of their entire value chain.
SDG 11 (Cities)	Make cities and human settlements inclusive, safe, resilient, and sustainable	Oil and gas industry recognize that its activities can potentially affect the urban environmental, culture and traditions of local communities During the decommissioning process management may also necessitate the implementation of enhanced protect and safeguards, social and cultural plans can be developed, and investments could be made in support of risks connected. During the decommissioning the strategic environmental assessments are implemented to incorporate protect and safeguard cities, and human, cultural heritage into environmental, social and health impact assessments in full compliance with international norms and standards and industry good practice.
SDG 12 (Sustainable consumption and production)	Responsible consumption and production - ensure sustainable consumption and production patterns	Relevant stakeholders involved in decommissioning program (e.g., oil and gas companies, governments bodies, etc.) are helping to meet sustainability challenges by mitigating the impacts and improving the efficiency of their operations and by supporting energy efficiency through a variety of methods. These include implementing sustainability and circular principles in a decommissioning program such as efficient chemical and waste management (recycle materials, reuse facilities, etc.). Coordinate approaches to sustainability thought combined effort of multiple stakeholders is required to improve decommissioning process.
SDG 13 (Climate change)	Take urgent action to combat climate change and its impacts	Climate change may impact a company's infrastructure, assets, operations, and supply chains. To improve the resilience of facilities and local infrastructure need to consider, identifying, and evaluating a wide variety of risks, including those that may be influenced by climate change. Based on those efforts, sustainable decommissioning management strategies can be developed, implemented, and monitored. An enabling policy environment is needed to support the technology innovation, development and deployment needed to transform the energy system and to pursue sustainable development.
SDG 14 (Oceans)	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	Decommissioning operations must support ecosystems and biodiversity. Mitigating potential impacts on the environment in the areas around offshore operations requires integrating local environmental and social considerations into the baseline surveys and environmental impact assessments. Environmental management plans built on those assessments can be implemented to cover an operation's entire life cycle, incorporating each marine ecosystem potentially affected. During decommissioning operations, the established standards and operations integrity, combined with a culture of safety and risk management, are important tools for accident prevention.
SDG 15 (Terrestrial ecosystems)	Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Oil and gas activities affect surrounding environments, the industry manages and mitigates potential impacts through application of the mitigation hierarchy, which emphasizes preventing negative impacts first (avoid, minimize) before considering remediation efforts (restore, offset as a last resort). In decommissioning program need seek opportunities for conservation of the natural environment, it is possible consider biodiversity "offsets" (recreating affected habitats in a new location) for achieve no net loss, and preferably net gain, of biodiversity. Decommissioning option of leave in place and reuse a platform is a useful mechanism for balancing economic development and environmental conservation and can sometimes lead to net conservation gain and help to preserve marine ecosystems, communities, and economies.
SDG 16 (Peaceful and inclusive societies)	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels. Respect the rights of communities potentially affected by decommissioning and avoid conflict that might otherwise arise from a lack of support and participation. To that end, need to ensure timely and responsible management of community queries and concerns, adhering to any formal grievance-handling procedures required by the regulatory authorities.
SDG 17 (means of implementation)	Strengthen the means of implementation and revitalize the global partnership for sustainable development	Energy is a critical pre-condition for achieving the SDGs. In decommissioning program need enhance the global partnership for sustainable development, complemented by multistakeholder partnerships, with stakeholders at global, national, regional, and local levels to achieve the SDGs. Promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships represent an important strategy to determine how to apply the SDG indicator framework in decommissioning program.

Source: Authors.

6. Practical and managerial implications

Decommissioning encompasses an interdisciplinary agenda that is of interest to many fields in contemporary research and industry. Recently, a sustainable approach to decommissioning has emerged based on principles of safety, circular economy, sustainability, and ecological integrity. This study contributes to the literature and practice. First, it expands the academic and grey literature on sustainability by examining a hypothetical scenario of decommissioning and considering SDG actions. Second, the analysis provides evidence about the perceptions of selected stakeholders (i.e., governments and regulatory authorities, offshore specialists and contractors, trade associations, enterprises and consortia, environmental conservationists, residents and local communities, universities, research centres, and marine scientists) on decommission and the factors influencing practices and value cocreation-oriented activities in the reuse scenario. More importantly, the findings contribute to oil and gas decommissioning practices by providing policy-makers, oil and gas companies, and project managers with information to consider when making decisions about decommissioning programs, stakeholder impacts, and future planning. Third, the study extends the literature on the sustainable life cycle management (SLCM) (Brent *et al.*, 2004; Parente *et al.*, 2006; Sommer *et al.*, 2019; Bull *et al.*, 2019; Basile *et al.*, 2021) by revealing the essential features of oil and gas decommissioning, offering insights about different decommissioning scenarios. Moreover, by unveiling the stakeholders' perspectives, the study shows that considerable attention should be placed on them in decisions about decommissioning and reuse to ensure that, as decommissioning, reuse, planning, and implementation proceed, stakeholders' needs and concerns are properly addressed, thus improving the probability of success. In the end-of-life management of Italian offshore platforms, the adoption of a sustainable perspective and the consideration of the opportunities derived from the application of CE principles can preserve the environment and create new economic and social value (Loia *et al.*, 2021 a,b; Capobianco *et al.*, 2021). In the complex context of platform end-of-life activities management, a circularity approach aims to use resources more efficiently, keep resources in use for as long as possible, and minimise waste. Keeping materials circulating in the economy at as high a value level as possible creates environmental and economic gains. This is particularly relevant to the decommissioning sector, where most of the materials can be recycled, and where national authorities can drive sustainable decommissioning based on reuse and remanufacturing. Therefore, national governments can adopt regulations to drive decommissioning programs towards the leaving in place and reusing of platforms, according to a sustainable and circular vision. In the future, it might be interesting to implement a sustainable business model canvas (SBMC) for offshore platforms where a viable business model is developed that follows a holistic approach that includes all stakeholders and the three dimensions of sustainability (Purnell *et al.*, 2018; Basile and

Vona, 2021). Therefore, in addition to economic criteria, decommissioning programs focus on the ecological and social consequences of the activity and aim at maximising positive externalities and avoiding negative impacts on society and nature. The potential value inherent in leaving in place and reusing structures is significantly higher than that in recycling. The key to sustainable resource management is to develop a decommissioning strategy that involves different stakeholder categories that work together to ensure that the circularity approach is embedded into decommissioning contracts and that consideration is given to innovation and creativity in the reuse of facilities, materials, and energy. The oil and gas industry has the responsibility of raising awareness about concepts related to sustainability in ways that provide energy efficiency as well as contribute to economic and human growth. Organizations such as IPIECA, API, and OGP actively organise sustainable development management standards in the oil and gas sector and encourage oil and gas companies and their shareholders to provide voluntary reports as one of their priorities, thereby consolidating and adhering to sustainable development strategies (Schneider *et al.*, 2013).

7. Limitations and future research

The main limitations of the present work suggest paths for future research and indicate directions that scholars could take to further investigate decommissioning in the oil and gas industry. The first limitation concerns the qualitative approach adopted for investigating the stakeholders' perspectives on the end-of-life management of offshore platforms, which provides preliminary understandings that pave the way for a deeper examination of sustainability questions related to the decommissioning process. The second limitation concerns the sample and the geographical area: the study is focused on Italian stakeholders involved in the decommissioning process. Thus, the research design could be applied in other countries and stakeholder categories could be extended. Analysing other contexts and fields of renewable energies, such as onshore wind farms or bioenergy projects, should enhance the generalizability of our findings. Since the impact of decommissioning decisions and end-of-life management goes beyond the industrial environment, it is essential that industries properly consider the perspectives of distinct stakeholders about different courses of action, which are politically sensitive and multidisciplinary in nature.

Additionally, in line with the objectives of the 2030 Agenda, the interviews with different categories of stakeholders could be repeated and expanded by comparing the latest developments in governmental decommissioning strategies. To explore how the hypothetical scenario of leave in place and reuse integrates the main sustainability pillars, future research could investigate decommissioning options through a more integrative approach, such as a multi-criteria decision analysis (MCDA) including qualitative and quantitative variables. The impacts of decommissioning alone involve a large number of interest groups in a variety of sectors with conflicting interests (e.g., the fishing industry, the tourism industry, shipping companies, civil society organisations, etc.); thus, the problem is to find a framework to guide the decision-maker to a sound decision: multicriteria methods are particularly suited to this purpose (Kiker *et al.*, 2005; Fowler *et al.*, 2014; Henrion *et al.*, 2015; Na *et al.*, 2017).

Finally, future research could analyse best practices within the sector to share knowledge and experience about using innovative solutions that apply CE principles to reusing, remanufacturing, and recycling waste.

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