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Coordination and Support Action

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"Start-up Action: SEALINES Mediterranean Safety Network"

THE FEASIBILITY STUDY FOR A SCIENTIFIC RESEARCH HUB ON AN INTEGRATED GREEN ENERGY SYSTEM
Re-use of offshore infrastructures for energy transition

A work carried out by the partners of Sealines Start-up Action:

Italian Ministry of Economic Development – DGS UNMIG; Rosetti Marino S.p.A., Basis Engineering; National Research Institute of Astronomy and Geophysics (NRIAG); Hellenic Hydrocarbon Resource Management (HHRM); Croatian Hydrocarbons Agency (AZU); Ministry of Transport, Communications and Works Department of Public Works - Republic of Cyprus; Ministry of Labour, Welfare and Social Insurance – Department of Labour Inspection – Republic of Cyprus; Ministry of Agriculture, Rural Development and Environment – Department of Environment – Republic of Cyprus; National Institute of Oceanography and Applied Geophysics (OGS); University of L'Aquila – Department of Industrial and Information Engineering and Economics; Institute National des Sciences et Technologies de la Mer (INSTM), Laboratoire Milieu Marin (LMM); Polytechnic of Turin, Department of Applied Science And Technology (DISAT); National Research Council – Institute of Marine Sciences – Institute of Marine Engineering (CNR-ISMAR; CNR-INM)

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Executive Summary

This feasibility study represents the outcome of the multi-disciplinary approach of Sealines Start-up Action, created by the strong interaction at international level between research centers, stakeholders, and policy makers to achieve results for blue growth according to Research Strategic Agenda goals.

Whit this aims, the feasibility study considers an abandoned platform, otherwise decommissioned, as the best case to test a hub for scientific research on an integrated “green energy” system.

AZALEA A, as one of the platforms that in Italian regulatory framework is available for repurposing projects (see Official Italian Hydrocarbon and Georesources Bulletin, BUIG of August 2019), was chosen as a real case study because its features fit reasonably well to run a demo that may be later apply to other cases.

Given a small description of the Start-up Action initiative, the document provides more elements about the project idea and lists AZALEA A technical features: position, structural status, linked facilities. The energy potential from renewable resources (wind, solar, wave) is evaluated from literature data.

The study proposes the installation of solar panel, wind turbine and wave energy production systems. 100% of the electric power produced by photovoltaic and/or turbine systems and/or wave systems may feed the electrolyzer and may be converted to produce H_2 thanks to the use of Proton Exchange Membranes – PEM.

Once a green energy is produced and converted in H_2 also a possible transport system needs to be evaluated. For this reason, the feasibility study investigates a repurposing process involving linked sealines as well. Two different options are contemplated: energy inland transport and H_2 storage and transport.

Three ideal business cases associated to this project idea have been studied to identify the budgetary investment costs:

- option 1: hybrid electric power generation integrated into the power system of the nearby platforms in operation (it is not the option linked to case study of AZALEA A);
- option 2: direct H_2 injection into the existing gas sealine of the nearby platforms in operation and sold at the same price of the natural gas (same case of AZALEA A);
- option 3: inland transportation through abandoned sealine and sold as H_2 technical gas (it is not the option linked to case study of AZALEA A).

Referring to the second option the same case of AZALEA A considering the power generation of 270,000 kWh/year by solar and wind, and H_2 injection into the existing natural gas sealines a total investment costs is estimated about 0.8 million of euro. Although the amount of renewable sources estimated in the study area (as defined by literature) may not be

enough for an economic investment in the current economic frame, the use of existing offshore infrastructure for power generation, included the reuse of sealines for energy storage and transport of H_2, seems to be a good solution from an economic point of view considering decommissioning costs. Furthermore, the results from the analysis of reuse of existing sealines for hydrogen storage and transport highlight the possibility to store hydrogen until 1,852 kg at maximum pressure of 330 bar (considering the safety threshold defined by API standards). The proposed technical study demonstrates how the integration of the existing offshore infrastructures with the new hybrid power generation systems is feasible and can be envisaged as a positive example of “Blue Economy”. However, it is important at this stage to test the technological and scientific improvements. A further scale-up of the SEALINES Start-up Action may provide a good solution proposing a scientific research hub and an integrated green energy system on a disused platform.

In this case also innovative methods to ensure the proper monitoring activities of both platform structural integrity (existing structures to evaluate the health state and their usability, for their re-use in several scenarios) as well as the environmental aspects will be carefully investigated. In addition, the current existing gaps in common best practices on the matter will be studied and suggestions for improvement will be proposed, where possible.

Description of partners and partnership

Ministry of Economic Development – General Directorate for Safety of Mining and Energy activities (MISE – DGS UNMIG) is the Competent Office for cartography, statistics, publication, surveillance, controls, inspections and chemical and mining analysis in the field of mining and energy production safety. In 2014 the DGS UNMIG launched the CLYPEA Italian network to promote research and innovation in offshore Oil&Gas safety with significant national funding and endeavor. The collaborations undertaken so far have led to significant results also recognized by other Med-Countries as useful to share.

University of MILANO "BICOCCA" – Department of Business and Law (DISEADE), for the partnership, has cutting-edge knowledge in economic, business and legal items. The Department focuses its research, teaching and third mission to offer a qualified contribution to the development of useful economic and legal knowledge regarding the management of abiotic natural resources.

ROSETTI MARINO S.p.A. represents in this partnership the leadership role of high-tech SME in the project. It is an integrated Contractor providing Engineering, Procurement, Construction and Installation services to Energy Industry worldwide. It has consolidated relationships with several national and international Oil and Energy Companies in the world and holds knowhow, experience, references, capacity, production facilities and operating presence.

National Research Institute of Astronomy and Geophysics (NRIAG) is an Egyptian public research institute belonging to the Ministry of Higher Education and Scientific Research. It is dedicated to the exploration of the Earth and the planets. NRIAG has managed to build a worldwide cooperation network at the highest level with international institutions and universities.

Hellenic Hydrocarbon Resources Management SA (HHRM) is a member of the EUOAG Group. It is a State-owned Company controlled by the Hellenic Ministry of Environment and Energy which manages on behalf of the Hellenic Republic its exclusive rights to explore and exploit hydrocarbons in Greece. HHRM is the Competent Authority within the meaning of Law 4409/2016 transposing Directive 2013/30/EU.

Croatian Hydrocarbon Agency (AZU) is a member of the EUOAG Group. It is a public regulatory body responsible for the supervision of all aspects of hydrocarbon exploration and exploitation, ensuring a balance between energy and environmental policies. In addition, one of its tasks is the operational and administrative management of the national Competent Authority for offshore oil and gas safety.

The **Cyprus** participation involved the main authorities related to offshore safety:

Department of Public Works is operating under the Ministry of Transport, Communications and Works. It is also the Competent Authority for any subsea pipeline license within the Cyprus Exclusive Economic Zone and Continental Shelf (Regulations as of 2014). The Department of Public Works was designated as the chair of the Committee on Submarine Pipelines.

Department of Labour Inspection of Ministry of Labour, Welfare and Social Insurance, is the Competent Authority according to Offshore Safety Directive 2013/30/EU. It is also a member of the committee for assessing the Environmental Impact Assessment reports and the Committee for the licensing of offshore activities under the Barcelona Convention. Cyprus is also member of EUOAG Group.

Department of Environment of the Ministry of Agriculture, Rural Development and Environment is the National Focal Point for the Offshore Protocol of the Barcelona Convention and the Competent Authority for the implementation of Article 29, of the Directive 2013/30/EC.

National Institute of Oceanography and Applied Geophysics (Istituto Nazionale di oceanografia e geofisica sperimentale, OGS) is a public research institute operating in a wide area of the Mediterranean Sea. It is a pioneer in the fields of Earth Sciences, Geophysics, Oceanography, Marine, Maritime and Inland Waters, Seismology and Infrastructures to contribute to environmental protection, sustainable economic development and societal inclusion.

University of L'Aquila, Department of Industrial and Information Engineering and Economics studies the energy and environmental planning of the territory, with expertise in mechanical, energy, electrical, civil, infrastructure, ICT and management. It is involved in several industrial collaborations, national and international projects, also concerning the Oil&Gas sector (e.g. for the energy assessment of offshore platforms; energy production efficiency and climate change mitigation, etc.).

National Institute of Marine Sciences and Technologies (INSTM) is a Tunisian national research institution expert in marine sciences and technologies; it contributes to the national economy (fisheries, aquaculture) and to the practical solution of the marine environmental issues.

Polytechnic of Turin, Department of Applied Science and Technology (DISAT) focuses its research and training activities on energy, transformation and engineering applications. The Department is at the forefront of physics, nanotechnology, chemistry, materials science, from the conception of new materials/processes to the development of new devices.

National Research Council (Consiglio Nazionale delle Ricerche, CNR) is Italy's largest public research body and leader in technology and knowledge transfer in various scientific disciplines. The **Institute of Marine Sciences** (CNR-ISMAR) conducts research in Mediterranean, oceanic and polar regions, focusing on the evolution of oceans and their continental margins (studying submarine volcanoes, faults and slides and their potential impacts onshore), the influence of climate change on oceanic circulation, acidification, bio-geochemical cycles and marine productivity and submarine habitats and ecology. The **Institute of Marine Engineering** (CNR-INM) pursues, among others, the following research areas: marine vehicles and robotics, marine renewable energy, environmental acoustics, underwater acoustics, and geo-acoustics.

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Authors of the Sealines Start-Up Action feasibility study

This document has been developed with the contribution of the participants of the workshops in Ravenna (March 28th, 2019), Athens (June 24th, 2019) and Milan (September 30th-October 1st, 2019). During the workshop in Milan, the key topics of the document and its structure were defined. It was also decided to divide the participants into working groups based on their technical specializations; each working group was entrusted with the drafting of one or more chapters of this document.

The lead authors of each chapter (**in bold**) and the contributing authors are listed below:

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2. <u>ACTION AND RESULTS OF SEALINES START-UP ACTION</u>

Giada Rossi - Italian Ministry of Economic Development
Ilaria Antoncecchi - Italian Ministry of Economic Development
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3. <u>DEFINITION OF THE IDEA AND FINAL OBJECTIVES TO BE ACHIEVED</u>

Ilaria Antoncecchi - Italian Ministry of Economic Development
Marzia Bevilacqua - Italian Ministry of Economic Development
Giada Rossi- Italian Ministry of Economic Development

4. <u>TECHNOLOGIES FOR POWER PRODUCTION FROM RENEWABLE ENERGY ON AZALEA A</u>

Nicola Mondelli - Basis Engineering, Rosetti Marino Group of Companies (technologies for power production from renewable energy on AZALEA A, business cases)
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8. CONCLUSION

1. INTRODUCTION

1.1 BlueMed framework and Sealines Start- Up Action: a comparison with Strategic Research Innovation Agenda

Based on the results of the Sealines Start-up Action workshops in Ravenna, Athens and Milan, the final deliverable of the Start-Up Action consist of a feasibility study of a platform (AZALEA A) located in the northern Adriatic Sea, for the realization of a scientific research hub.

The proposal is in line with the BlueMed Research & Innovation Initiative which - through the implementation of its Strategic Research and Innovation Agenda, BlueMed SRIA – aims at promoting the Blue Economy in the Mediterranean region, through cooperation and the creation of sustainable growth in the marine and maritime sectors.

Sealines Start-up Action addressed the challenge of the Strategic Research and Innovation Agenda (SRIA) majorly focusing on offshore platforms, marine spatial planning, climate change, aquaculture and transport, exploring innovative knowledge-based pathways and forward-looking visions with a multidisciplinary and mission-oriented approach (Table 1).

Table 1. Key challenges of SRIA tackled by Sealines Start-Up Action

Challenge of SRIA, 2018	***Challenge tackled by Sealines Start-up Action***	***Action***	***Future steps***
E – Governance of maritime space and marine resources in the Mediterranean	E1 – strengthening synergies among stakeholders	International network starting from CLYPEA and EUOAG	Enlarge network to other group, EU and non-EU Countries with best practices
E – Governance of maritime space and marine resources in the Mediterranean	E2 – effective maritime spatial planning in the Mediterranean Sea,	Proposal of reusing an offshore infrastructure to a different scope (research hub) according to existing activities in the area	Considering advantages and disadvantages of the reuse of the infrastructure for a scientific research purpose
E – Governance of maritime space and marine resources in the Mediterranean	D1 – from traditional maritime economic to blue growth activities;	Support the transition from fossil fuel to green energy production	Testing and study the technical feasibility to make a transition to a green energy system (from production, to storage and transport)
A – Mediterranean Sea ecosystems: characterize present dynamics, services, resources, vulnerability and resilience to natural and anthropogenic pressures	A2 – Understanding pollution impacts, mitigation, and remediation in the Mediterranean Sea	Proposal of a monitoring program using innovative technologies and solutions	Test innovative technologies to perform environmental and infrastructure monitoring
B – Mediterranean Sea: forecast changes of the basin under climate and anthropogenic pressures and develop services in the field of sustainable adaptation to climate change and plants for mitigation	B1 – forecasting Mediterranean Sea dynamics and climate	Study of the principal environmental parameters in the framework of an environmental and geohazard assessment	Define a common methodology to monitor and mapping sealines and create a common knowledge of the Mediterranean
A – Mediterranean Sea ecosystems: characterize present dynamics, services, resources, vulnerability and resilience to natural and anthropogenic pressures	A4 – Building capacity, blue skills and blue professionals	Possibility to improve existing initiative for Blue growth advance training school in Trieste	Create a common program for the training on the initiative of Sealines program

1.2 Mediterranean Sea Peculiarities

AZALEA A is located in the Adriatic Sea, in the central Mediterranean Sea.

The Mediterranean Sea expands up to 2.6 million square kilometers with an average depth of 1,460 meters, and a maximum depth of 5,267 meters, making it the largest semi-enclosed sea on Earth (UNEP, 2017[1]).

The Mediterranean has narrow continental shelves and a large area of deep sea where bottom temperatures vary from 12.8°C–13.5°C in the western basin to 13.5°C–15.5°C in the eastern and high salinity of 37.5–39.5 psu (UNEP, 2017).

The net evaporation exceeds the precipitation, driving an anti-estuarine circulation through the Strait of Gibraltar, contributing to very low nutrient concentrations (UNEP, 2017). It acts like an ocean system in which several temporal and spatial scales (basin, sub-basin and mesoscale) interact to form a highly complex and variable circulation. It is one of the few locations in the world where deep convection and water mass formation take place. The Mediterranean is also an important marginal basin to the North Atlantic outflowing saline water, through the Strait of Gibraltar that the deep circulation of the North Atlantic (UNEP, 2017).

The Mediterranean is considered one of the top biodiversity hotspots in the world. The rate of endemism is exceptionally high both on land and in the sea.

The Mediterranean Sea, although not a very productive sea it nevertheless harbors a tremendous diversity of marine organisms, many of which are endemic to the region. It is estimated that the Mediterranean Sea contains 8–9% of all the world's marine creatures. Sponges, sea squirts, crustaceans and other species found their habitats in the *Posidonia oceanica* meadows in shallow coastal waters (EC, 2009).

1.3 Energy transition and fossil fuels

Since the signing of the Kyoto Protocol, the European Union and its Member States have committed themselves to actions oriented at tackling climate change through the adoption of Communitarian and national policies. The 21st Conference of the Parties in the Framework Convention on Climate Change, held in Paris in 2015 adopted the Paris Agreement by Decision 1/CP21. The Agreement establishes the need to limit the global average temperature increase to well below 2°C and to pursue efforts to limit the increase to 1.5°C, compared to pre-industrial levels.

In March 2007 the European Council, for the first time, envisaged an integrated approach between energy and climate change policies, with the Climate-Energy Package 2020. The objectives of the Package have been transposed as national legislations in 2009 among Member States. As far

[1] https://www.medqsr.org/mediterranean-marine-and-coastal-environment

as the promotion of renewable energy sources is concerned, Italy has the objective of reaching by 2020 a share of 17% of energy from renewable sources in Gross Final Energy Consumption and a sub-objective of 10% of energy from renewable sources in Gross Final Energy Consumption in transport.

Italy has drawn up the National Integrated Plan for Energy and Climate 2030. The Plan is structured in five lines of action, which will be developed in an integrated way: from decarbonization to energy efficiency and security, through the development of the internal energy market, research, innovation and competitiveness. The objective is to contribute to current energy policies that ensures the full environmental, social and economic sustainability of the national territory and accompanies this transition.

1.4 Partial Conclusion and future step

The BlueMed initiative, funded by the European Commission, has hence the opportunity to act on both sides of the Mediterranean, promoting Euro-Mediterranean collaboration, fostering Blue Growth-related research and innovation activities. The feasibility study is a conclusive outcome of the Sealines Start-Up Action which proposed the repurposing of a disused offshore platform to test technologies for renewable energy production.

2. ACTIONS AND RESULTS OF SEALINES START-UP ACTION

Throughout 2019, the Start-up Action held three workshops in Ravenna, Athens and Milan during which it was observed:

- re-use of offshore hydrocarbon platform seems to be a good option in terms of costs/benefits and environmental impact, but this has never been verified on a real case study;
- some studies have been carried out on the re-use of sealines for transport of H_2 and CO_2 that have to be tested (case study presented by Basis Engineering and Rosetti Marino Group of Companies);
- most Mediterranean countries do not have specific regulations on re-use, although they have different internationally certified standards and procedures for maintaining and monitoring existing infrastructures; best practices should thus be implemented;
- new innovative technologies have been developed for monitoring and maintaining the integrity of offshore infrastructures (AUV, ROV, IoT, etc.);
- mapping of and information regarding sealines is a sensible matter.

It was decided to address the feasibility study on the re-use of an offshore platform considering the engineering, technological and environmental issues. Considering the expertise and involvement of both partners and stakeholders, during the Sealines 3rd workshop the content of the feasibility study has been drafted as it follows:

- Innovation and technology;
- Infrastructure monitoring systems;
- Geohazard assessment;
- Environmental and infrastructure monitoring;
- Regulations;
- Communication plan and social engagement.

2.1 Innovation and Technologies

During the Sealines workshops technologies and methods of reuse of offshore infrastructure were presented, such as the proposal of the University of L'Aquila:

1. Carbon Capture Storage (CCS): the most promising technology to meet the need to maintain the current level of energy demand and, at the same time, reduce the concentration of CO_2 in the atmosphere. The proposed idea is to recovery the CO_2 on land, to reuse the existing sealines backwards to the offshore platform and to re-inject the CO_2 into the depleted reservoir;
2. transportation of liquefied products like LPG and LNG to shore. Studies for thermal modelling required for planning and monitoring of the sealines re-use at the new operating conditions. In fact, the fluid must be transported in thermal condition well below the

environmental temperature, requiring cryogenic pipelines with proper insulation layers;
3. hydrogen gas transportation of either mixed to natural gas, or as an electricity vector, or as such for technical gas usage inland.

Among these three solutions, however, only the third one has been considered by the project partners and it has been deepened by Basis Engineering (Rosetti Marino Group), which presented a case study for the transport of hydrogen from a platform located in the Italian offshore, identifying three technical alternatives. Each of them involves the production of H_2 on the platform by electrolysis of seawater using a hybrid generation of electricity.

The alternative solutions were the following:

- case 1: hybrid electric power generation to integrate the power requirement with the nearby platform in operation;
- case 2: injection of the produced H_2 into the existing natural gas sealines of the nearby platforms still in operation. The produced H_2 is sold at the same price of the natural gas;
- case 3: injection of the produced H_2 into an abandoned sealines and stored onshore before being sold as technical gas or utilized for CO_2 abatement through the methanation process;
- case 4: same as above, to use the sealines as storage facilities.

2.2 Infrastructures monitoring systems

Best practices and innovative solutions for infrastructure monitoring systems have been developed.

The decommissioning of offshore platforms at the end of the useful life of oil reservoirs may require the identification of alternatives other than the removal of existing installations. According to the principles of the "Blue Economy", such infrastructure could be reused. However, before a platform can be reused, monitoring campaigns should be carried out to verify both the integrity of the structure and the condition of the marine environment in its surroundings.

The technological improvements in recent years have allowed the evolution of autonomous marine systems, including submarine gliders and Autonomous Underwater Vehicles (AUVs). The Polytechnic of Turin is developing, within the CLYPEA Network, monitoring techniques for acoustic mapping of the reflectivity of seabed and geochemical testing of the water column based on the use of customized AUVs that have many potential and applications in the energy field.

2.3 Geohazard assessment

Knowledge of geohazard is essential for the installation of sealines on the seabed.

OGS explained the main marine geological hazards: seismogenic faults, submarine landslides, coastal erosion, volcanic eruption, tsunamis and fluid flows. Seabed mapping is the first step to carry out a census of the geohazard-bearing features present in a specific offshore area.

2.4 Environmental assessment & monitoring

An innovative technology for the marine environmental monitoring around the sealines is developed by CNR-INM (Italian National Research Council – Institute of Marine Engineering) and it is called MATRAC-ACP (Figure 1). It is a technology to enhance the protection of harbor waters, improving monitoring procedures through highly automated robotic technologies and new adaptive sampling. The MATRAC-ACP provides an accurate and repeatable spatial-temporal measuring action of the water column.

Figure 1. MATRAC-ACP (INTERREG project)

2.5 Regulation

During the second workshop, the regulatory framework was discussed by four speakers from Croatia, Cyprus, Italy and United Kingdom. The discussion showed that each country has a certified engineering testing procedure on the sealines and that these practices should be shared.

2.6 Communication plan

Referring to the communication activities a lot of initiatives were taken during the Sealines Start-Up Action:

- News online (on website of the Italian Ministry of Economic Development and the Hellenic Hydrocarbon Resource Agency https://unmig.mise.gov.it/index.php/it/informazioni/notizie-e-faq/it/198-notizie-stampa/2036065-dgs-unimg-al-secondo-workshop-dedicato-alla-start-up-action-sealines; https://www.greekhydrocarbons.gr/news_en/PR_REL_240619_EN.html);
- Technical reports for BlueMed CSA;
- News on www.bluemed-initiative.eu;
- Twitter pages @BluemedMed @SealinesA;

- Ecomondo 2019, 5-8 November, Rimini:
    1. presentation of the results of the Sealines project at Circular economy for the definition of sustainable integrated blue growth strategy;
    2. a poster at the booth of BlueMed, CNR.
    3. Drafting of a scientific paper about the results of SEALINES Start-Up Action (SuA).

The communication strategy with these few steps achieved good results and the total stakeholder engagement considering the three workshops grew up to 151 participants (Figure 2).

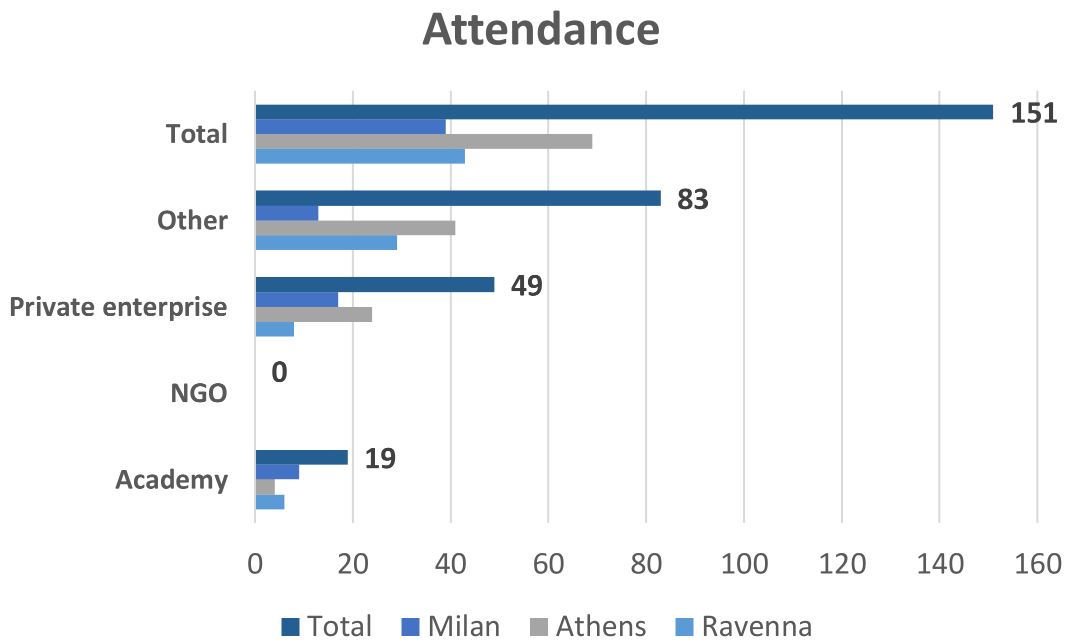


Figure 2. Bar chart of attendance at Sealines international workshops in Ravenna, Athens and Milan

2.7 Partial conclusion

The Sealines Start-up Action workshops have tackled the following topics: innovation and technology; infrastructure monitoring systems; geohazard assessment; environmental assessment and monitoring; regulation; communication plan.

3. DEFINITION OF THE IDEA AND FINAL OBJECTIVES TO BE ACHIEVED

Following the approval of "*The national guidelines for the mining decommissioning of offshore hydrocarbon platforms and related infrastructures*" by the Ministerial Decree 15th February 2019[2], a list of platforms to be decommissioned has been published on the Italian Official Hydrocarbons and Georesources Bulletin[3] (BUIG; [https://unmig.mise.gov.it/index.php/it/informazioni/buig;](https://unmig.mise.gov.it/index.php/it/informazioni/buig) Figure 3).

BUIG - Bollettino ufficiale degli idrocarburi e delle georisorse - Anno LXIII N. 8 - 31 Agosto 2019

ELENCO DELLE PIATTAFORME E INFRASTRUTTURE DA DISMETTERE MINERARIAMENTE
Aggiornamento al 31/08/2019

Parte a) - Elenco delle piattaforme e infrastrutture da rimuovere senza possibilità di riutilizzo

Nome piattaforma	Concessione mineraria	Coordinate	Tipo piattaforma	Rimozione senza possibilità di riutilizzo	Possibilità di riutilizzo
ADA 3	A.C9.AG	Lat.45,183361 N Long. 12,591176 E	Monotubolare	SI	NO

Parte b) - Elenco delle piattaforme e infrastrutture da dismettere minerariamente ma con possibilità di riutilizzo con scopi diversi dall'attività mineraria di estrazione di idrocarburi

Nome piattaforma	Concessione mineraria	Coordinate	Tipo piattaforma	Rimozione senza possibilità di riutilizzo	Possibilità di riutilizzo
AZALEA A	A.C8.ME	Lat. 44,171769 N Long. 12,714258 E	Bitubolare a portale	NO	SI
PC 73	PORTO CORSINI MARE	Lat. 44,385037 N Long. 12,579101 E	Monotubolare	NO	SI

Figure 3. List of platforms and facilities for decommissioning. AZALEA A was chosen as the case study for this feasibility study proposal

For the definition of the methodological approach, the AZALEA A platform, a bitubular platform located in the offshore area of Rimini in the northern Adriatic Sea, is considered to have technical features that fit a feasibility study for a research pole and the development of a green energy system.

The feasibility study concentrated on the idea to reuse a disused platform as a scientific research hub to test system, technologies and method to support energy transition from fossil fuel to green energy.

For this reason, the idea here analyzed, both from technical and economical point of view, considers the possible reuse of a platform for power generation from renewable resources (available in the study area), the power conversion in H_2 as an energy vector, and H_2 transport or storage options (Figure 4).

[2]DM (2019), Ministerial Decree of Italian Ministry of Economic Development of 15 February 2019 and Annexes, on Italian National guidelines for the mining decommissioning of offshore hydrocarbon platforms and related infrastructures, Official Gazette, n.57 of 8 March 2019. On line at: https://unmig.mise.gov.it/index.php/it/informazioni/normativa-di-settore/fonti-secondarie/2036038-decreto-ministeriale-15-febbraio-2019

[3]BUIG, (2019), Official Bulletin for Hydrocarbon and Georesources, Ministry of Economic Development, 31 August 2019, Italy. On line at: https://unmig.mise.gov.it/images/buig/63-8.pdf

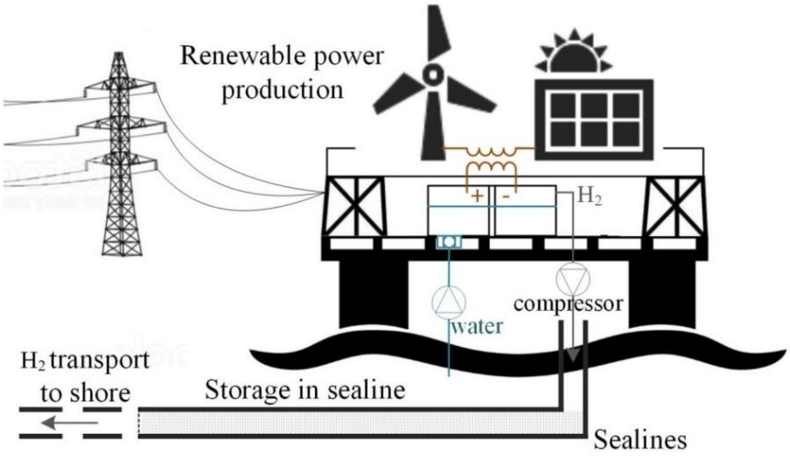


Figure 4. Scheme of the project proposal about the reuse of an offshore oil and gas platform to support scientific research in energy transition focusing on new technology to reuse of a sealines as transport or storage system

3.1 Description of the case study: AZALEA A

The engineering solutions to convert the inactive offshore infrastructure into a hybrid system to produce renewable energy is investigated.

The production of solar and wind energy (and their storage and transport) is combined with a seawater hydrogen production system.

The case studies proposed are all related to the reuse of the offshore platform (AZALEA A) and its sealines and ancillary infrastructures (Figure 5).

Figure 5. GIS representation of the AZALEA A platform (blue star) and the connection by sealines (orange line) to the nearby platform Anemone Cluster (orange cross). Others orange cross: active platforms; red cross: active platforms connected to land by sealine; pink polygon: concessions for the production of hydrocarbons; green line: 12- nautical mile limit

The AZALEA A Database consisted in all data collected by Eni S.p.A. since 1984 when platform started in A.C8.ME License Block.

The general characteristics of the AZALEA A platform are briefly described and available on the website of the Italian Ministry of Economic Development (https://unmig.mise.gov.it/images/dati/piattaforme.pdf):

- is part of the mining concession A.C8.ME in the Adriatic Sea (WGS 84 coordinates: Lat. 44.171769 N; Long. 12.714258 E);
- it is a bitubular (19*4 meters) platform installed in 1984 by Eni S.p.A.;
- is a gas extraction platform;
- is 16 km off the coastline;
- the height above sea level is 17 meters;
- the seabed is 19 meters deep;
- it is connected to the Rubicone central (Forlì-Cesena, Italy);
- the platform is within the 12- nautical mile limit.

AZALEA A is connected to the nearby Anemone Cluster platform by a sealine (Figure 6) that is no longer in operation. The end points of the sealines are available from the WebGis of the Italian Ministry of Economic Development, as well as information about the name of the sealines and their lengths (km; Figure 6; Figure 7; Figure 8). Other important information about the sealines position, fluid, length, diameter, and thickness are in Table 2.

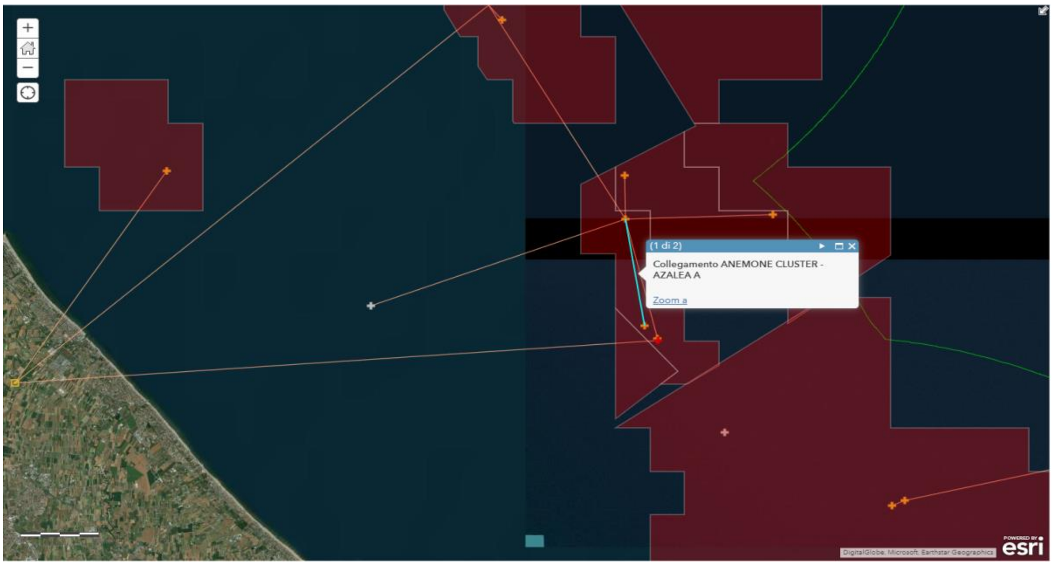


Figure 6. Sealine connection from AZALEA A to Anemone Cluster in GIS representation[4]

[4]https://www.arcgis.com/home/webmap/viewer.html?webmap=13fee4db46bd40a7a0113faf8cf1812e&extent=9.0555,42.3802,17.1689,45.8339

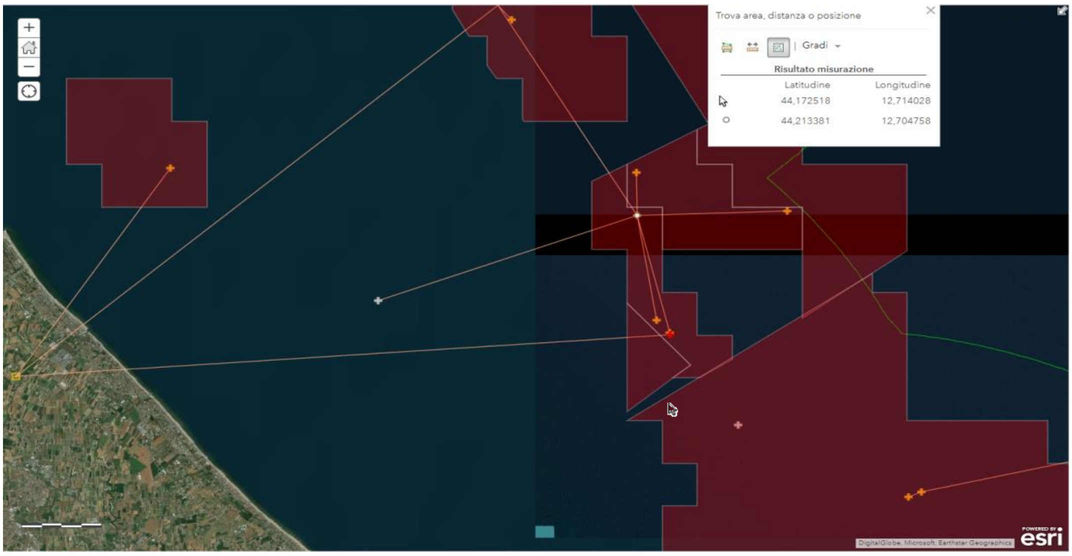


Figure 7. Endpoints coordinates in GIS representation[4]

Figure 8. Sealines length from AZALEA A to Anemone Cluster[4]

Table 2. Summarized data of sealines from Azalea A to Anemone Cluster. From the left: Ref. Terrestrial central, Denomination, Coordinates of Azalea A, Coordinates of Anemone Cluster, Type, Carried fluid, Operative state, Year of installation, Length, Diameter in inches, Thickness

Center	Line name	Start point	Start point	End point	End point	Type	Fluid	Year	Offshore length (m)	Nominal diameter (")	Thickness (mm)
		Coord-1	Coord-2	Coord-1	Coord-2						
Rubicone	Azalea 1-2 - Anemone Cluster	44°10'16.229"	12°42'52.329"	44°12'43.694	12°42'19.862	Rigid	GLICOLE	1978	4580	3	4.78
Rubicone	Azalea 1-2 - Anemone Cluster	44°10'16.229"	12°42'52.329"	44°12'43.694	12°42'19.862	Rigid	GAS	1978	4580	6	10.97

In the database of the Italian Ministry of Economic Development all the information related to AZALEA A platform is available (location, project plan, size and dimensions, vertex coordinates, wind, solar and marine resources) provided by Eni S.p.A. and the local Nautical Map provided by IIM (Istituto Idrografico della Marina).

3.2 Evaluation of potential renewable resources for AZALEA A

RSE S.p.A., in the framework of CLYPEA Innovation Network for future Energy, supported by the Italian Ministry of Economic Development in 2014, published a preliminary assessment of the potential of renewable resources near the offshore oil and gas platforms located in the Italian Seas. The results for AZALEA A are summarized in the table below, with a brief description of the dataset considered for each type of renewable resource (wind, solar and marine; Table 3).

Table 3. Summary table about the potential renewable resources around Azalea A platform (source RSE S.p.A., 2017 on Mise website database)

PLATFORM NAME	**AZALEA A**		
MiSE Link	https://unmig.mise.gov.it/images/docs/schede_ita.pdf		
Emerged part dimensions [m]	**19*4**		
Height m a.s.l.	**17**		
Distance from the shoreline [km]	**16**		
Seabed depth [m]	**19**		
WIND RESOURCE			
Annual mean wind speed at 25 m a.s.l. [m/s]	**3.8**	Specific annual energy production at 25 m a.s.l. [MWh/MW]	**632**
Annual mean wind speed at 50 m a.s.l. [m/s]	**4.1**	Specific annual energy production at 50 m a.s.l. [MWh/MW]	**891**
Annual mean wind speed at 75 m a.s.l. [m/s]	**4.3**	Specific annual energy production at 75 m a.s.l. [MWh/MW]	**992**
Annual mean wind speed at 100 m a.s.l. [m/s]	**4.4**	Specific annual energy production at 100 m a.s.l. [MWh/MW]	**1083**
SOLAR RESOURCE			
Optimal tilt angle of PV plant [°]	**34**		
Incident solar radiation on the horizontal plane [kWh/m²]	**1463**		
Incident solar radiation on the plane with optimal tilt angle [kWh/m²]	**1681**		
MARINE RESOURCE			
Annual mean power available from waves [kW/m/year]	**2.8**		
Marine current power flow [W/m²]	**2.3**		

Wind

Availability of wind data in the area near AZALEA from three different public databases are as follow:

- long-term annual wind speed map and estimated annual energy production (RSE Wind Atlas);
- data collected from the non-operative AZALEA B platform equipped with a sonic anemometer and a Lidar - Light Detection and Ranging device (Eni Report, 2013);
- mesoscale modelling RAMS (Regional Atmospheric Modelling System performed by RSE).

Considering the information contained in the Wind Atlas for a fixed wind turbine model, the average expected annual production at altitudes higher than 50 meter a.s.l. are 4.1 - 4.5 m/s with a peak production at 100 m a.s.l. of about 1,000 MWh/MW (Figure 9).

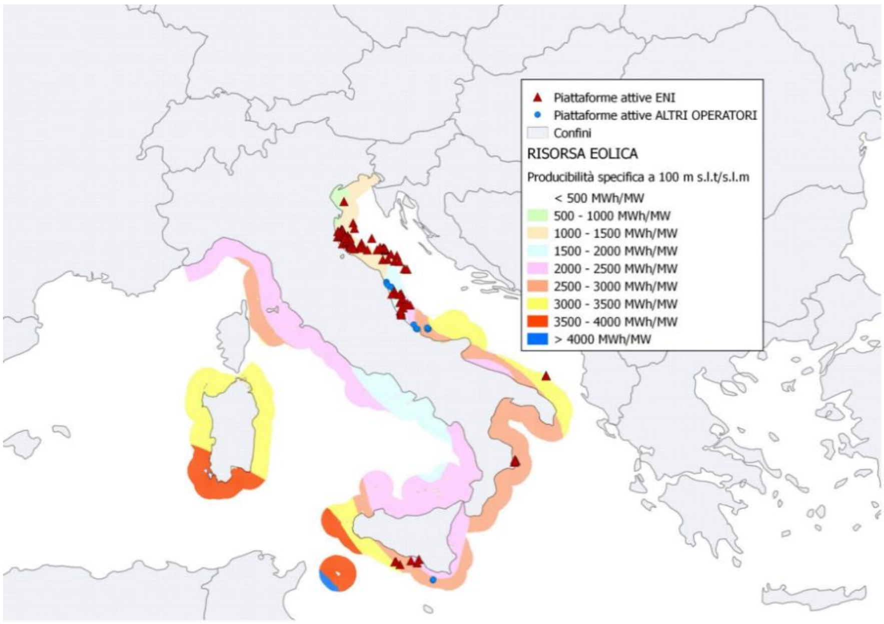


Figure 9. Map of annual energy production (MWh/MW) at a 100 m a.s.l. This map is one of the eight available for different altitudes considered in the wind Atlas of RSE S.p.A. (source Report of agreement between Italian Ministry of Economic Development and RSE S.p.A., 2014)

Solar

Historical data on solar radiation, mediated by a timeframe, are the base to assess solar energy in a specific area. The accurate availability of solar energy in each area depends heavily on climate fluctuations data, as compared to historical data. Available historical data generally cover solar radiation rank on a horizontal surface (expressed as kWh/m^2) and are provided by different organizations on daily, monthly or yearly basis.

Among the most acknowledged database:

- Photovoltaic Geographical Information System (PVGIS);
- Resource and Performance of Photovoltaic Technology[5];
- Italian Atlas of solar radiation[6];
- Database RADSAF of global solar radiation on Italy[7];
- PVSYST Meteonorm[8].

Considering the RSE database (RSE, 2017) for the study area of AZALEA A, close to AZALEA B site (at the same latitude 44°N), it is possible to calculate a preliminary rough estimation of solar radiation available considering AZALEA B average value equal to 1,500 kWh/m² per year (Figure 10).

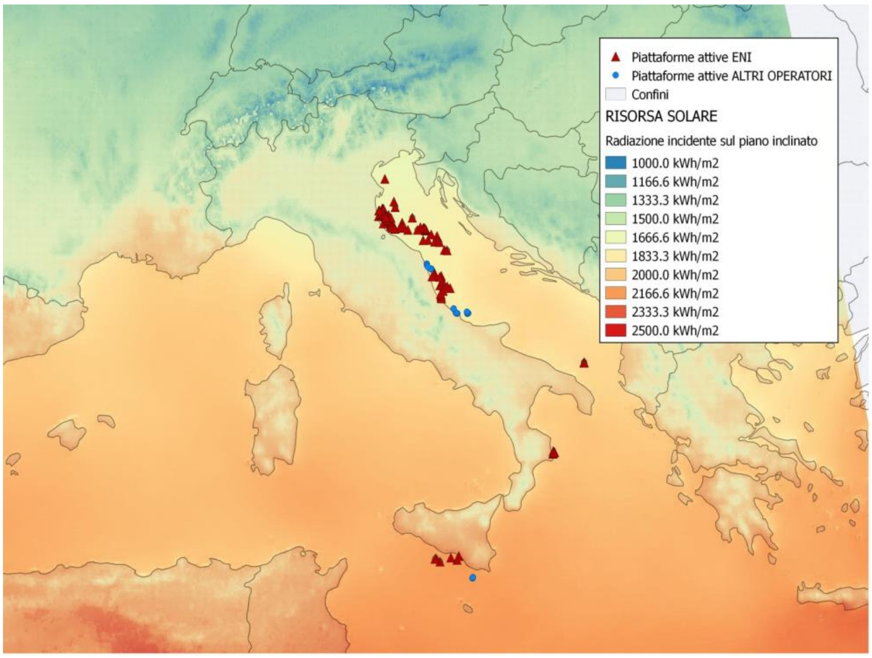


Figure 10. Map of solar radiation on Inclined plane elaborated in GIS environment (source PVGIS)

Wave and currents energy

Wave energy production evaluation in the AZALEA A area per year has been carried out starting from data on chart (Figure 11).

Estimated values come from the TRITONE database provided by RSE S.p.A.:

- Average power per year from wave energy per linear meter of wave front: 2.75 kW/m;
- Average year available power flow from marine currents: 2.28 W/m².

[5] (http://re.jrc.ec.europa.eu/pvgis) EC, Join Research Centre (JRC)
[6] (http://www.solaritaly.enea.it/) – ENEA renewable resources
[7] (http://sunrise.rse-web.it)
[8] (www.pvsyst.com; www.meteonorm.com)

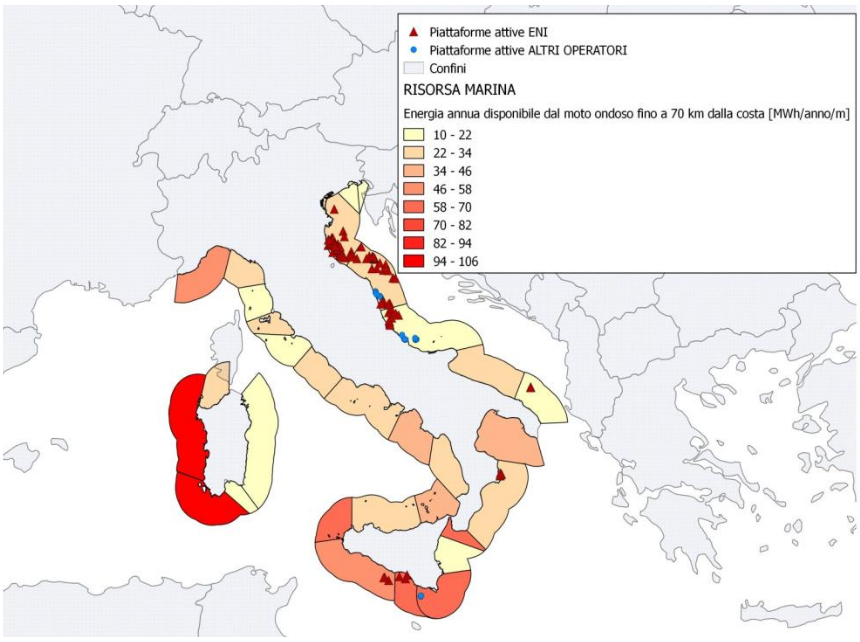


Figure 11. Map of energy available from waves motion with a buffer of 70 km of distance from the coast

3.3 Partial conclusion

*Technical description of AZALEA A is given as well as renewable energy potential from literature data. AZALEA A is a bitubular (19*4 meters) platform installed in 1984 by Eni S.p.A. for gas extraction and is connected to the nearby Anemone Cluster platform by a sealine that is no longer in operation.*

Considering the information from literature, for a fixed wind turbine model, the average expected annual production at altitudes higher than 50 meter a.s.l. are 4.1 - 4.5 m/s with a peak production at 100 m a.s.l. of about 1,000 MWh/MW.

About the solar radiation, for the study area of AZALEA A (at 44°N latitude), it is possible to calculate a preliminary rough estimation of solar radiation available equal to 1,500 kWh/m2 per year.

About the marine energy instead:

- *Average power per year from wave energy per linear meter of wave front: 2.75 kW/m;*
- *Average year available power flow from marine currents: 2.28 W/m^2.*

4. TECHNOLOGIES FOR POWER PRODUCTION FROM RENEWABLE ENERGY ON AZALEA A

According to available renewable resources at AZALEA A site the following engineering reconversions are investigated:

- Wind turbines;
- Photovoltaic power generation;
- Aquaculture and subsea garden;
- Hydrogen generation;
- Hydrogen storage;
- Sealines as power line or hydrogen transport.

4.1 Wind up to Energy

At present, wind and photovoltaic (PV) power are among the most cost-effective renewable technologies. The interest towards offshore applications has experienced a spike during the last decade, mostly due to the extensive Research and Development activity, resulting in higher efficiency of components (e.g. turbines, gearbox components for wind; solar cells material, behavior at high operating temperatures for photovoltaic) and eventually in a higher attainable power output for the plant. This feature, along with an increased components durability, fail-safe, is key for a growing confidence of investors and stakeholders, on both the private and public scale. Nonetheless, a major hurdle to the full development of offshore wind and PV technology is represented by the lack of a concerted regulatory framework on an international basis. Despite the general trend towards more rational and expedite decommissioning and licensing process, the need to comply with maritime spatial planning and guidelines for marine environment and landscape protection still prevent the offshore wind and PV technology from succeeding on a large-scale. In this regard, the re-use of existing structures will simplify the installation process, as well as the facilities implementation and management.

The base components of a typical offshore wind farm include one or more wind turbines located on the platform, connected by a series of cables to an offshore transformer station, connected by an undersea cable to an onshore transformer station linked to the existing power grid. For the case at hand, one wind turbine is considered for installation, hence no turbulence and wake effects, resulting from possible interactions between contiguous turbines in case of a wind turbine field, needs to be considered.

To dimension wind turbine for the exploitation of wind energy, a crucial step would be assessing the structural integrity of the selected platform as well as the allowable loads of the steel structures.

A verification through the data available by the last inspection report shall be required.

For a good dimensioning of installations, the following technical characteristics are considered:

- wind conditions as reported in Paragraph 3.2 with average wind velocity of 4.3 m/s,
- turbine nacelle height of 75 meter above the sea level
- electric power production from wind up to 99,200 kWh/year.

Estimating the available loading capacity of the deck to 300 kg/m^2 (about 60% of the design condition) and 10 ton. maximum load it can be assumed that a 100 kW nominal wind turbine power may be installed.

4.2 Solar Energy

In this study, solar energy is one of the key opportunities to be exploited. As observed before, the technological maturity of solar application gives a degree of easiness of engineering and installation in an existing structure. Considering the available area of the Azalea platform, three options have been evaluated: traditional photovoltaic (PV), concentrated photovoltaic panels (CPV) and concentrated solar power plants (CSP; Figure 12). After this first evaluation, concentrated solar technologies have been excluded, for economic reason. In fact, although they can have higher specific energy for required area, the costs related to the concentration of radiation (through parabolas or lens) and to ancillary technologies (solar tracking, vacuum management for evacuated ducts, smart control devices, cooling circuits, etc.) are still so high to justify its installation in a limited space, such the one of the current platform. In other words, the marginal cost associated to the concentration technologies does not produce a significant marginal energy increase. Hence, conventional photovoltaic has been considered for the low ratio between costs and expected energy production.

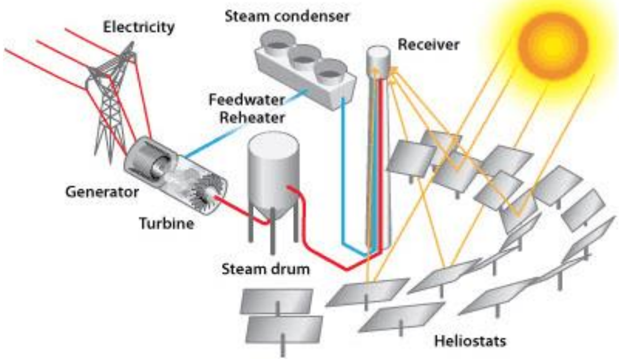
Photovoltaic	Concentrate Solar Plant (Tower)
	
Concentrated Solar Panels (Parabolic)	

Figure 12. Representation of solar technologies considered

As previously observed, the photovoltaic (PV) technology is a mature and economically feasible renewable energy source, whose economic feasibility strongly depends on scale benefits and, ultimately, on space constraints. Moving solar to the space-abundant seas allows large scale projects, in which the absence of the shading effects - that usually characterize on shore projects-and the large solar source availability compensate the low energy density of the PV technology.

Assuming AZALEA A has an available space to allocate solar panels of about 100 m^2 and an electric power yield of about 1,680 kWh/year/m^2 (at the North Adriatic latitudes), production estimated could be about 168,000 kWh/year by about 60 modules (330 Wp each and 1.6 m^2).

The available space, and then the electric power production, could be increased by providing deck extension through cantilever design solution.

However, notwithstanding the available plot area to install photovoltaic panels on this platform is rather small, testing this technology is anyway suggested to investigate its production in conjunction with other technologies.

Floating photovoltaic systems has not been evaluated due to lacking installation on open sea in the test area.

4.3 Aquaculture, artificial reefs and subsea gardens

Aquaculture is the most rapidly expanding food industry given the declining wild fisheries stocks and profitable business. In 2008, aquaculture provided 45.7% of the fish produced worldwide for human consumption, increasing at a mean rate of 6.6% a year since 1970. Offshore aquaculture is an emerging approach to mariculture, or marine farming. The farms are positioned in deeper and less sheltered waters, where ocean currents are stronger providing more oxygen and nutrients. Moving aquaculture offshore offers a larger area, culture lots can be expanded order to meet the increasing product demand. In Europe, aquaculture accounts for about 20% of fish production and it directly employs around 85,000 people. The sector is mainly composed of SMEs or micro-enterprises in coastal and rural areas. EU aquaculture is well-known for its high quality, sustainability and consumer protection standards. The European Commission has launched several campaigns to promote sustainable aquaculture in the EU. Most recently, these include the Tapping Into Blue Growth conference, the Farmed in the EU campaign and the aquaculture schools project. These campaigns aim to highlight the role of aquaculture for EU citizens, and to raise awareness on the matter. Self-sustaining hubs for deep-sea fishing, is an idea that could make both financial and environmental sense.

In the UK North Sea, around 470,000 tons of offshore assets will need to be dismissed and recovered between 2013 and 2022. The cost for decommissioning for the mentioned time span has been estimated around £10.4bn. Despite the UK government's commitment to cushioning the industry from the costs of decommissioning through a 50% tax break, new methods to reuse decommissioned oil platforms – reducing decommissioning costs and eliminating the need to tear down offshore structures – are beginning to emerge. Some old platforms have already been used or considered for offshore diving centers, rigs-to-reefs projects are picking up steam in the US, where platforms could even play host to luxurious resort hotels.

Converting old rigs into hubs for mariculture, or deep-sea fish farming, seems indeed an ideal repurposing procedure. Laws require that a platform at the end of its production life be totally removed unless the submerged jacket section continues as a reef under state sponsorship[9]. Consideration of the eventual fate of the populations of fishes and invertebrates beneath platforms has led to global reefing of the jacket portion of platforms instead of removal at the time of decommissioning. Reefing option for platforms begins in the mid-20th century as effort for artificial reefs to provide both fishing opportunities, and increase production given the burgeoning U.S. population demand.

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[9] Guidelines on application of the Water Framework Directive and the Marine Strategy framework Directive in relation to aquaculture (2016) and a new impetus for the Strategy for the Sustainable Development of European Aquaculture - COM/2009/0162 final

The Sealines feasibility study will be evaluating the possibility to reuse the decommissioning platform AZALEA A for offshore aquaculture, artificial reefs and/or subsea gardens in order to provide a sustainable use of the seafloor. It will therefore be necessary to carry out targeted analyses to verify the environmental conditions around the platform to determine which of the solutions listed above is best suited to the case in question.

4.4 Energy conversion: power to gas (P2G) – H_2 generation

New dedicated infrastructures connecting produced energy to the electric grid inland have not been considered due to the very low return on investments, nor to adjacent platforms as there are no contiguous active platforms.

An innovative solution proposed foresees the energy conversion in H_2 by electrolysis. This solution allows the leveraging of the attributes of the existing natural gas infrastructure for integration of energy generation from renewable sources and conversion system to produce hydrogen. The conversion system by electrolysis is based on the Proton Exchange Membranes (PEM) technology. PEM may couple wide range of load, fast response to transient conditions, and produce H_2 at higher pressure.

100% of the electric power produced by photovoltaic, and/or turbine systems, may feed the electrolyzer to produce H_2.

The system power consumption is in the range of 4.5 to 7.5 kWh/Nm^3 H_2, while about 1 liter of demineralized water is required.

Assuming the electric power produced by the system, in order of 200,000 kWh/year, electrolysis will generate about 30,000 Nm^3/year of H_2 or about 2,700 kg/year.

4.5 Business Cases

To identify the budgetary investment costs three ideal business cases have been considered, of which only one is applicable to the case study of AZALEA A:

1. Hybrid electric power generation integrated into the power system of the nearby platforms in operation;
2. Direct H_2 injection into the existing gas sealine of the nearby platforms in operation, and sold at the same price of the natural gas (same case of AZALEA A);
3. Inland transportation through abandoned sealine and sold as H_2 technical gas.

1. **Business Case 1 - Power generation integrated with the nearby platforms in operation**

Photovoltaic:

Modules and required area: 60 x 330 Wp/100 m^2

Electric power yield: 1,680 kWh/year/kWp

Total installed peak power: 20 kWp
Electric power production: 168,000 kWh/year
Investment costs: €0.1 million

Wind Turbine:
Installed power: 100 kWp
Running hours at peak: 2,500 h/year
Electric power production: 99,200 kWh/year

Investment costs:
Turbine: € 0.2 million
Balance of plant el.: € 0.1 million

Total Electric Power Production: 270,000 kWh/year
TOTAL EQUIPMENT INVESTMENT COSTS: € 0.4 Million

2. Business Case 2 - H_2 injection into the existing natural gas sealines

From Business Case 1 Hybrid Power Generation with the solution "Photovoltaic plus Wind Turbine"

Total electric power production: 0.27 MWh/year
Power generation investment costs: €0.4 million

For H_2 Conversion:
Electrolyzer installed power: 100 kWp
Electrolyzer yield: 6.7 kWh/Nm^3
H_2 production: 40,000 Nm^3/year

Investment costs:
Electrolyzer: € 0.3 million
Auxiliaries: €0.1 million

TOTAL EQUIPMENT INVESTMENT COSTS: €0.8 Million

3. Business Case 3 - H_2 injection into the existing natural gas sealines and onshore storage

Hybrid power generation from the solution "Photovoltaic plus Wind Turbine" as for Business Case 2.
Total electric power production: 0.27 MWh/year
H_2 production: 40,000 Nm^3/year

Total investment costs for €0.4 million

Power generation and H_2 conversion:

- H$_2$ Storage Case a): n°1 module, 12 bottles x 1.6 m^3 each
  Storage capacity/ Pressure: 19.2 m^3/200 bar
  Storage and auxiliaries investment costs: €0.9 million

- H$_2$ Storage Case b):
  by existing sealines: 20 km; Nominal Diameter (ND): 200 mm, volume: 630 m^3
  Auxiliaries investment costs: € 0.5 million

TOTAL INVESTMENT COSTS:

Case a): €1.3 million

Case b): €0.9 million

4.6 Sealine as power line or hydrogen transport or storage

Sealines as power lines

The submarine power transmission technology already represents an effective solution for bulk electric power transmission across large distances, encompassing wide and deep-water bodies, and features a peculiar operating reliability in the range of decades. Further developments have occurred at a high rate during last years, pushed by the increasing number of both planned, and deployed submarine power lines. High voltages allow efficient transmission of large quantities of electric power over long distances, for higher is the voltage lower are the losses.

The type of conductor, along with the length and the cross section of the line, and the type of current (AC or DC) affect the transmission process (e.g. the skin effect in presence of AC) and can result in an increased resistance to the current flow.

Whereas High Voltage Direct Current (HVDC) cables only require one power line to transport electricity, a High Voltage Alternate Current (HVAC) link needs three power lines to carry the same power. HVDC lines need lesser space for their right of way on land than HVAC lines. Given the case HVAC cable is too long, the reactive power consumed by the cable would absorb the entire current carrying capacity of the conductor and no usable power would be transmitted.

As the distance to cover shifts towards larger scales (i.e. hundreds of kilometers), the bulk transmission of electricity is done by HVAC. HVDC for power transmission usually applies in presence of (i) large quantities of electric energy where HVAC would be uneconomical or impracticable, (ii) interconnection between two AC systems that operate at different frequencies or that are non-synchronous and (iii) enhanced stability of an

AC system. Two main configurations are possible for a HVDC interconnectors:

- monopolar interconnectors comprise a single conductor line while the return path is made through the ground or sea using electrodes. This configuration reduces the costs of a power line, due to lower material use and reduced work for cable lay-down.
- bipolar interconnectors consist of two poles with opposite polarities. The direction of power flow can be controlled by switching the polarities of both poles. In normal functional conditions the current flows in a loop. In case of a failure of one of the poles the other can still function in a monopolar configuration with ground path return.

In case of a HVDC configuration, since power grids operate almost exclusively with alternate current, converter stations are needed, according to a scheme in which one transforms AC into DC to be used in cable (rectifier) and one that transforms DC from cable back to AC to be used in the transmission and distribution grid (inverter).

In case Line Commutated Converters (LCC) are used, active power control is only possible. They are equipped with AC filters but no black start capability and allow high capacity values. When the power flow is reversed, also the polarity on the HVDC cable is reversed. The LCC is the oldest and most-established technology, used for the last 40 years in HVDC transmission. Its performance, though, depends on the good functioning of the AC grid, i.e. voltage drops in the AC grid should be avoided as they could affect the inverter functioning by triggering a short circuit.

Voltage Source Converters (VSC), allow both active and reactive power control, and can be turned on and off sequentially allowing commutation processes in the power converter to run independently of the grid voltage. VSC have black start capability but no AC filtration, and while the capacity is lower than LCC, they assure higher flexibility and do not require to reverse the polarity when the power flow is reversed. VSC technology is relatively new, and both more complex and expensive than LCC, although its performance does not depend on the AC good functioning.

Reusing the existing sealines as power lines bears the great benefit to avoid shoring approach operations of the lines. The reuse can be easily done introducing the power lines in the duct, that can act as a cover for the line itself, protecting it from the sea. The diameter of the sealine should be verified, but the power line can be easily adapted at the existing one. Duct diameters of 3 inches can allow the allocation of conductor in 380 kV lines (which the highest voltage in Italian grid). The voltage depends mainly on the source of the power that it should carry: electrical energy produced on the platform has to be brought to the shore, its voltage and maximum current availability would not be so high to require big lines: it can be estimated a medium-low voltage (< 1000 V), so it is reasonable to consider this reuse opportunity as a real option.

Sealines as lines for Hydrogen transport and storage

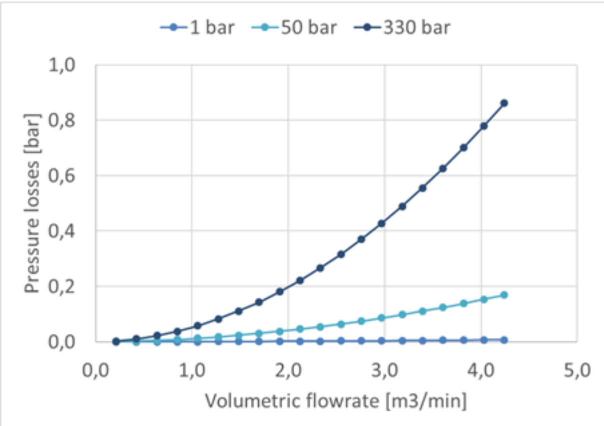
At present, NG transport network mainly consists of pipelines, compression stations and pressure-reduction stations. This network assures at once the transport of enough energy – more precisely, a power flow – to cover the demand by end users and the possibility of a short-term storage of NG – also known as linepack - whenever the gas supply exceeds the demand. The linepack allows an almost continuous supply of NG into the network, despite a strongly fluctuating demand pattern and the storage capabilities are regulated through the line pressure. When it comes to assess the actual margins for the reuse of sealines for hydrogen transport purposes, it is worth observing that: whereas the higher heating value (HHV) of natural gas equals approximately 40 MJ/Nm^3, the HHV of hydrogen amounts to 13 MJ/Nm^3. Consequently, the same energy demand calls for a volume of hydrogen three times that of NG; the density of hydrogen is nine times smaller than that of NG. Hence, a flow rate of hydrogen three times larger than that of NG results in approximately the same pressure drop; the achievable linepack in a pipeline is strongly influenced by the flow rate. The lower the flow rate, the more storage becomes possible. The maximum volume linepack with hydrogen is usually 60%-70% the linepack with NG. Such figure becomes even more critical when looking at the energy content of the linepack, i.e. the actual ability of the line to satisfy the energy demand: the linepack energy of hydrogen can be more than four times smaller than the NG one, which may eventually undermine the short-term security of supply during one day.

Besides energetic considerations, also several material issues require some attention: e.g., the use of the existing compression and pressure-reduction stations, hydrogen embrittlement and leakages that may occur in existing pipelines, already suffering from a stress history and fatigue damage, induced by pressure fluctuations. This further confirms the importance of an intensive testing of pipelines and welds. In addition to this, the material of the pipeline also affects volumetric losses differently, as the working gas shifts from NG to hydrogen, calling for a proper preliminary analysis of actual volumetric losses under normal operation, at different flowrates. The incidence of leakage and diffusion through the material of the pipeline is a further element that drives the selection of the material and the assessment of actual feasibility of the re-conversion of existing pipelines: cast iron and fibrous cement pipelines are particularly incline to leakage phenomena, whilst polyethylene present large risk of diffusion of hydrogen.

As far as the compression stations are concerned, piston compressors seem to be the most easy-to-adapt technology, as they are not sensitive to the working gas. Centrifugal compressors working with hydrogen, on the other hand, have to face a volume three times the one of NG and in order to obtain the same pressure ratio, the rotational speed must be increased with respect to the NG case.

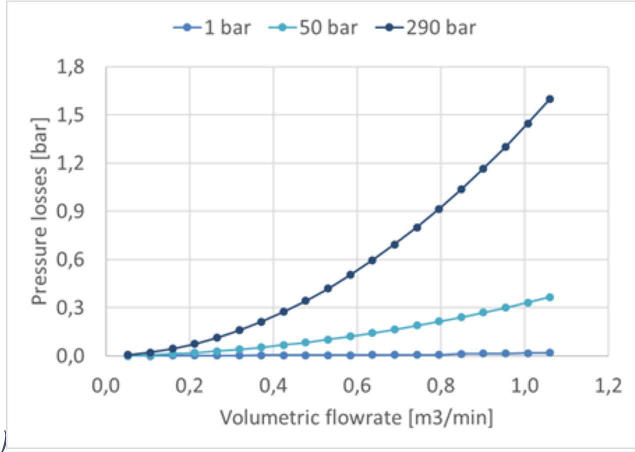
A proposal for the reuse of sealines to transport the energy produced by renewable resource in form of hydrogen (according to the option 1 of the three solutions proposed) is evaluated taking into account the condition of the sealines infrastructure provided briefly in the previous paragraphs ("description of the case study"). Indeed, having the geometry of the existing sealine (diameter and length), it is possible to evaluate the flow rate of the gas in the duct. It surely depends on the thermodynamic condition of the gas transported (i.e. density, pressure and temperature). Since the actual sealine was used to transport natural gas, it can be surely used to transport hydrogen in the same ranges of pressure and temperature of the previous transport.

The actual thickness of the sealines assure a maximum allowable pressure of about 33 MPa for a diameter of 6 in. and 29 MPa for 3 in., according to ASME Boiler & Pressure Vessel Code, section B31.1. These high values consent to state that the ducts can be used for gas transportation. In any case, a checking procedure could be planned to verify the thickness, making use of non-intrusive sensors, in order to verify the ageing and corrosion conditions. In the two following figures (Figure13a and 13b), the evaluation of possible flow rate of hydrogen has been done, and respectively pressure drop associated. The first figure is related to 6 in. sealine, while the second one is related to 3 in. one. The bigger sealine (6 in.; Figure 13a) can easily allow a flow rate of about 4 m^3/min with a maximum pressure loss along the line of approximatively 0.9 bar. Negligible pressure drops are accounted for the case where the transport pressure is 50 bar, equal to the production pressure. Higher pressure drops and lower flow rate are obviously experienced for the smaller pipe (3 in.; Figure 13b).



a)

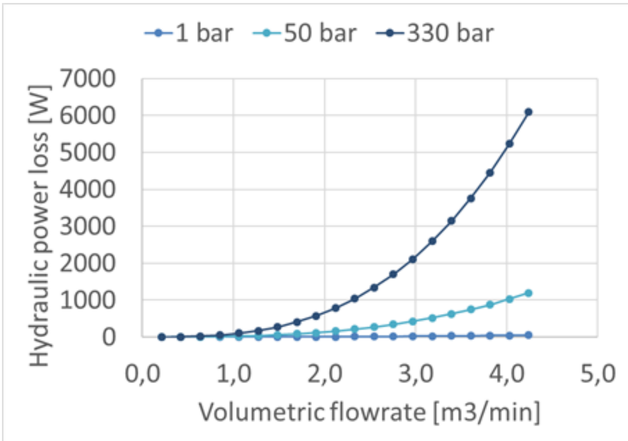
Figure 13a. Calculated pressure losses along the first sealine (6") for different H_2 transport pressure



b)

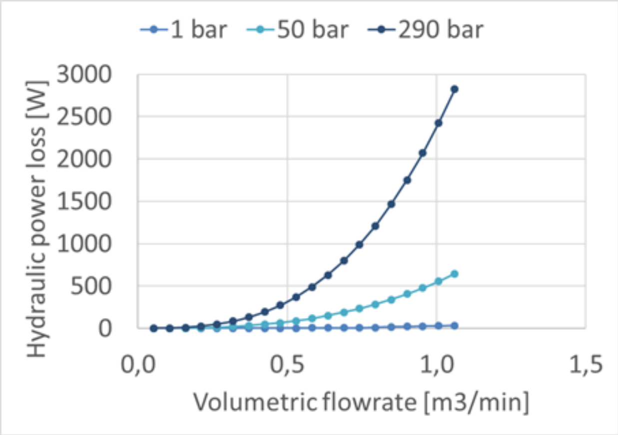
Figure 13b. Calculated pressure losses along the second sealine (3”) for different H_2 transport pressure

Thanks to the evaluation of the pressure drops, the hydraulic power needed to move the fluid can be calculated (Figure 14a and 14b): the first one is always related to the bigger pipe (6 in.; Figure 14a), while the second one is the smaller pipe (3 in.; Figure 14b). It is demonstrated that a compressor of about 6 kW and 3 kW (6 in. and 3 in. respectively) can be used if the maximum allowable pressure is used for H_2 transportation. However, if a more suitable pressure of 50 bar is considered, the power needed by the compression is in the range of 500 W - 1 kW, which can be realized with very common commercial machines.



a)

Figure 14a. Calculated hydraulic power required to transport H_2 along the first sealine (6”) for different operating pressure



b)

Figure 14b. Calculated hydraulic power required to transport H_2 along the second sealine (3") for different operating pressure

In case the transport was done in a liquid state, the sealine should be coated with proper insulation layers, in order to keep the temperature in a cryogenic condition. The technology can be easily taken from the liquefied petroleum gas - LPG and liquefied natural gas - LNG sectors and the thermal field across the layers calculated by a mathematical model of the duct, aimed to verify the inner temperature of the gas in worst external conditions of the sea (low temperature and high convective heat transfer conditions).

A very interesting opportunity is represented by using the existing sealine as a storage volume of hydrogen. In fact, the sealine can be closed at one end, in order to create a bounded volume that can be used as a storage, where a gas can be accumulated. The storage pressure is the main parameter for evaluating the amount of gas storable and it is surely higher than the one used to transport operation, so the thickness of the duct should be verified with more accuracy or eventually reinforced.

The preliminary assessment of the maximum gas pressure inside the pipe is key to evaluate the potential of the existing sealine for storage. In line with the common practice in pipelines design, the maximum shear stress criterion is selected for calculating the actual mechanical stress due to the pressure regime the pipe is subjected to. As a matter of fact, the boundary conditions for the system at hand are the (i) storage pressure of the gas inside the pipe, (ii) the hydrostatic pressure of sea water and (iii) the temperature of the sea water. The sea water pressure and temperature are both referred to the given 19 m depth and rank to 3 bar and 15°C approximately (this value of temperature can be surely lower in winter conditions, but in that case the density of the inner fluid would be higher and so we are in safety condition underestimating the mass storable). The hydrogen temperature is kept constant and equal to such value, under the assumption that no thermal insulation is performed on the pipeline. For the pipe with a 6 in. inner diameter, and 10.97 mm thickness, length of 4,580 m (compliant with the API SPEC 5L standard), the volume of the sealine is about 80 m^3. The common practice suggests lowering the yield strength through a 1.5 coefficient of safety, resulting in a 240 MPa admissible tension of the used steel. To meet such a specification, the maximum storage pressure of the Hydrogen turns out to be 330 bar. The Table 4 reports some scenarios in terms of storage pressures, densities and mass of hydrogen shown in Figure 15 (6 in. pipes). It suggests that:

- at a 3 bar pressure, the hydrogen density is 0.25 kg/m³ (superheated vapor), corresponding to a 20 kg stored mass. In such condition, the pressure inside the flowline and outside the pipe balance each other, which leads to a minimum stress on the pipeline material. Such a scenario, though, corresponds to a minimum storage inside the pipe, to be checked against both (i) the actual hydrogen producibility on the timescale of interest (e.g. daily, weekly, monthly, etc.) and (ii) the demand profile of hydrogen;
- at a 13 bar pressure, the hydrogen is beyond its critical state. The density tops 1.1 kg/m³ and 88 kg Hydrogen can be stored, before the pipeline capacity is saturated;
- the upper limit pressure (330 bar) corresponds to a 23 kg/m³ density and 1,852 kg hydrogen stored.

Table 4. H_2 mass storable in the first sealine (6") for different storage pressure

H_2 Pressure (bar)	3	7	13	20	100	200	330
H_2 Density (kg/m³)	0.3	0.6	1.1	1.7	7.9	14.9	22.9
H_2 Mass Storage (kg)	20	47	88	135	642	1209	1852

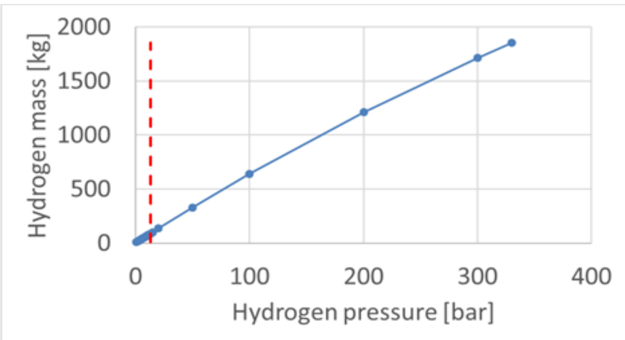


Figure 15. H_2 mass storable in the first sealine (6") for different storage pressure

The same analysis can be performed, accounting for the second pipe (3 in. and 4.78 mm thickness), compliant with the API SPEC 5L standard.

In this case, the volume is reduced and the storable hydrogen is shown in Figure 16 as a function of storage pressure.

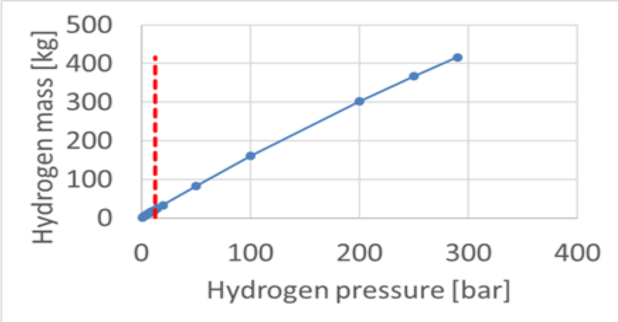


Figure 16. H_2 mass storable in the second sealine (3”) for different storage pressure

When glycol is considered as fluid, it remains in the liquid state, its density is relatively unaffected by the storage pressure variations. In the case of the 3 in. pipe, the maximum admissible pressure inside the pipe is 290 bar, to which a 1,110 kg/m^3 density corresponds. Hence, the maximum mass that could be stored in the pipeline would be 22,460 kg.

4.8 Partial conclusion and future step

Reuse options for AZALEA A infrastructure are investigated. Installation of wind turbines, solar panel and energy conversion by electrolysis for hydrogen production and storage, are considered.

Floating photovoltaic systems has not been evaluated due to lacking installation on open sea in the test area.

To identify the budgetary investment costs three ideal business cases have been contemplated. Reuse options regarding the platform linked sealines, transport and H_2 storage are outlined.

The proposed study highlights that a new hybrid power generation system on an existing offshore infrastructure is a worthwhile opportunity to embrace “Blue Economy” principles, as well as a sustainable use of the sea.

A future step should be the assessment (e.g. check of documentation) of the platforms and the connected sealines that should include:

- *check on conformity of formal documentation available;*
- *check of validity of certificates for equipment and systems;*
- *environmental assessment;*
- *check on validity of data used for original design;*
- *site survey to check conformity of current status of assets with documentation available;*
- *gap analysis between current status of assets and documentation available.*

The result of the analysis should lead to identify the remaining lifetime of the platform along any required strengthening of the steel structure to endure new design conditions and loads. A conformity survey is thus essential to assess the actual reliability of the structure. Evaluation of the available last platform inspection reports is also very important to evaluate structure life expectation through past fatigue analysis, current corrosion status so to perform necessary strengthening of the steel structures. Hence, *a gap analysis should be performed in order to evaluate the distance between literature and real conditions of the site under investigation. Life expectation estimation could be particularly important for the sealine that connects the platform to the adjacent one: recognition of the status of a submerged pipeline could be not so easy and it needs dedicated instrumentations. Furthermore, it is advisable to assess the availability of the potential resources in the site area to validate the estimates coming from literature data. Significant imbalance could restraint some of the technologies considered.*

5. ENVIRONMENTAL AND INFRASTRUCTURE MONITORING

The Adriatic Sea is a semi-enclosed sea connected to the Ionian Sea at its southern end through the Strait of Otranto. It forms an elongated basin, approximately 800 km long and 200 km wide, which can be divided into three distinct regions generally known as the northern, middle, and southern Adriatic. Its northern section is very shallow and gently sloping, with an average bottom depth of about 35 m (Figure 17).

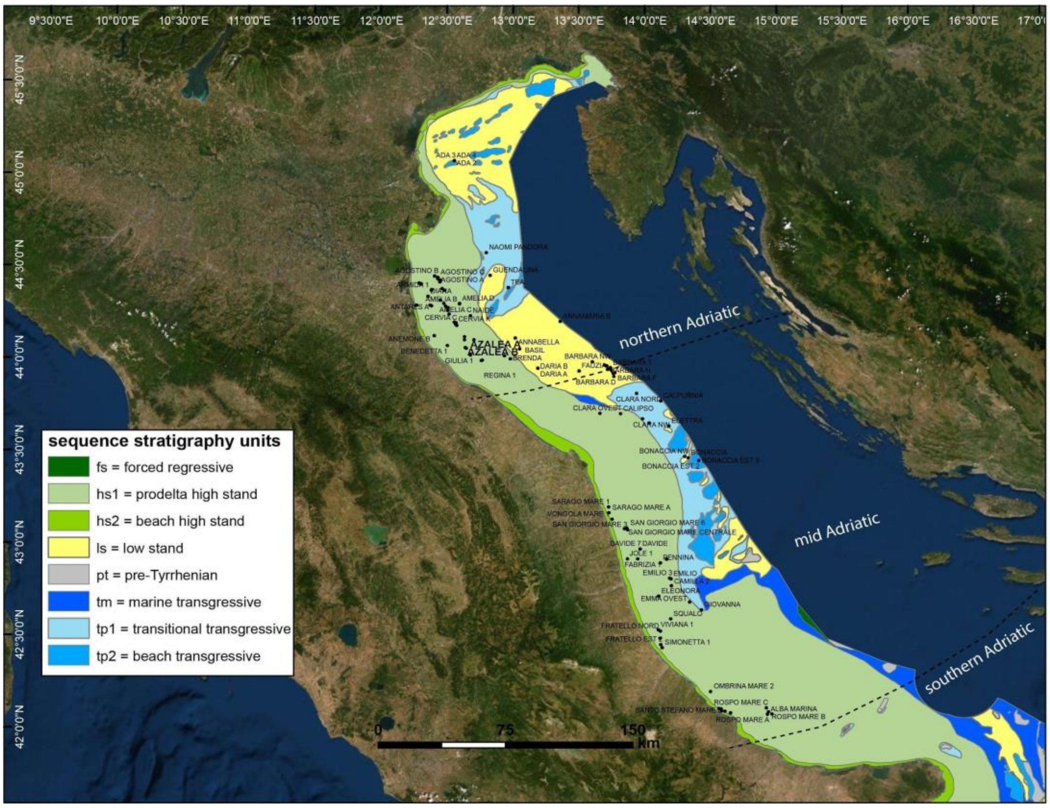


Figure 17. Map of the Adriatic Sea which highlights its internal subdivision into 3 basins. The surface sediment classification is displayed in color

5.1 Winds, waves, tides and general ocean circulation

The most intense winds in the region include the northeasterly Bora blowing off the Balkan peninsula, the southeasterly Sirocco and northwesterly Mistral, the latter two winds blowing along the main axis of the basin (Cavaleri et al., 1997). The Bora is a dry, cold katabatic and gusty wind, particularly strong during the winter season over the northern and middle Adriatic Sea (up to 15 m s-1 for several days, with gusts up to 50 m s-1), causing enhanced local cyclonic flow. Like the Sirocco, the Bora may be both cyclonic (the dark Bora) and anticyclonic (the light Bora). The Dark Bora comes with depressions crossing the Adriatic and rise in the rear part of the cyclone. Generally associated with cold temperatures, it is also related to unstable weather with showers and storms. If the cyclone passes quickly, it blows over just as quickly; if a depression lingers over the Adriatic, it may last up to several days. The Light Bora: typically blows in winter when the Siberian anticyclone (from NE) reaches.

The Sirocco and Mistral are more efficient in modulating the wave field, compared to the Bora (Bignami et al., 2007). The meso-scale pattern, leading to the surge in the northern Adriatic Sea, are explained by a deep low-pressure system induced a south-eastward pressure gradient along the basin, which, because of the channeling due to the long coastal mountain ridges, produces a strong Sirocco wind. Both wind and, to a lower degree, the inverse barometric effect contribute to surge in the northern part of the basin (Lionello et al, 2006).

The Mistral generally blows from NW on sunny days, stable days in the form of a summer breeze. It starts blowing late in the morning and lasts until sunset, with its peak in mid-afternoon. The most frequent synoptic winds are the Bora and the Sirocco. They can both arise in low and high pressure (cyclonic Bora/Sirocco and anticyclonic Bora/Sirocco respectively) but their presence is, in most cases, linked to weather shifts.

The Sirocco is the weather front-announcing wind. In most cases its onset is not sudden it starts faintly and gradually builds up. So, despite being responsible for the roughest seas, the Sirocco can be managed in time and safely. A 10.8 m wave was once measured in Northern Adriatic during a Sirocco gale, in 2019 crest heights of > 9 m were measured during a storm caused by a very strong Sirocco wind in the Adriatic Sea (Cavaleri et al., 2019). Waves can reach considerable heights as they have much room (fetch) at their disposal; that is because the Sirocco blows along the sea longitudinal axis. The Sirocco rarely blows in summer – when it does, it never lasts longer than 2-3 days and hardly ever exceeds force 7. Between October and May, it blows more often, for longer periods and with greater intensity, up to force 9. Its onset is often preceded by thickening cirrus clouds, a rise in temperature and drop in pressure. During the summer the Sirocco normally blows over with the arrival of a storm, when the wind abruptly changes and blows NE.

The area has experienced a regime of mixed wind pattern due to Sirocco and Bora winds (Schweizer et al., 2016). Wave conditions have been established on the basis of the data collected by the "Nausicaa" directional wave buoy installed by the Emilia-Romagna Regional Agency for Environmental Protection (ARPA) at a depth of 10 m below the sea level, about 8 km offshore, from 23 May 2007 to 24 March 2016 (Schweizer et al, 2016), which represents the only wave observation set currently available for the entire coast of Emilia-Romagna (Figure 18). The wave climate is characterized by low wave energy conditions, with HS < 0.5 m for about 70% of time, and 0.5 6 HS < 1 m for about 20% of observations. The most frequent marine storms are mainly caused by Sirocco (SE) winds while the dominant storms are associated with Bora (NE) winds. The significant wave height rose is given in Figure 19, with calm referring to values of wave heights below 0.25 m.

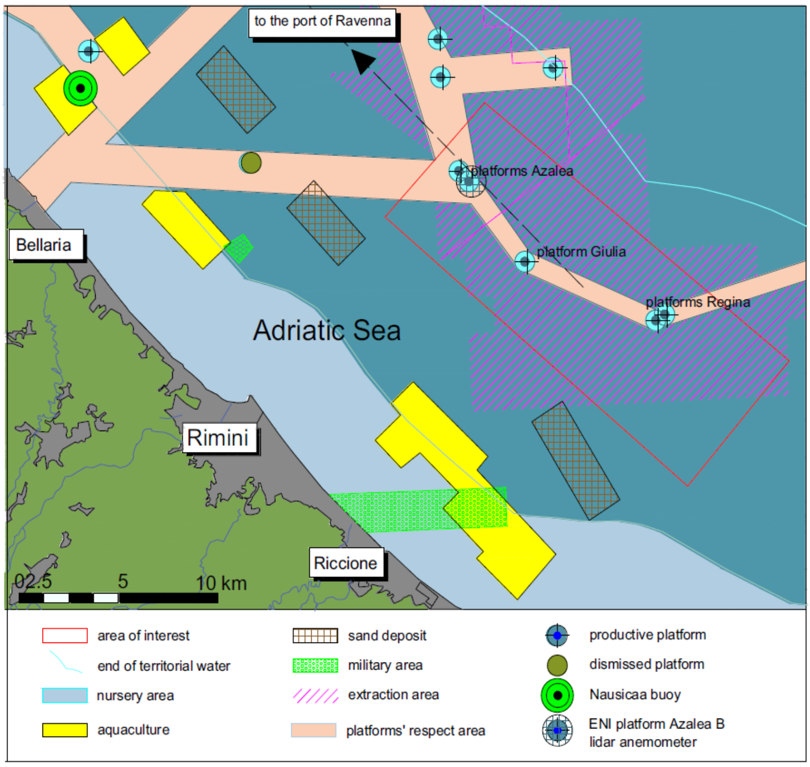


Figure 18. Feasibility study of an offshore wind farm in the Northern Adriatic Sea by Schweizer et al. (2016). The selected area is approximately 8 km wide and 20 km long, 12 km far from the coast, and overlaps a district for gas extraction, including platform AZALEA A. Military zones are also present in the proximity, though located distant enough, as well as sand deposits for beaches nourishment. Aquaculture is practiced sufficiently far away, along the boundary of the nursery area, next to the coast. The industrial port of Ravenna is located north of the area, approximately 60 km from Rimini

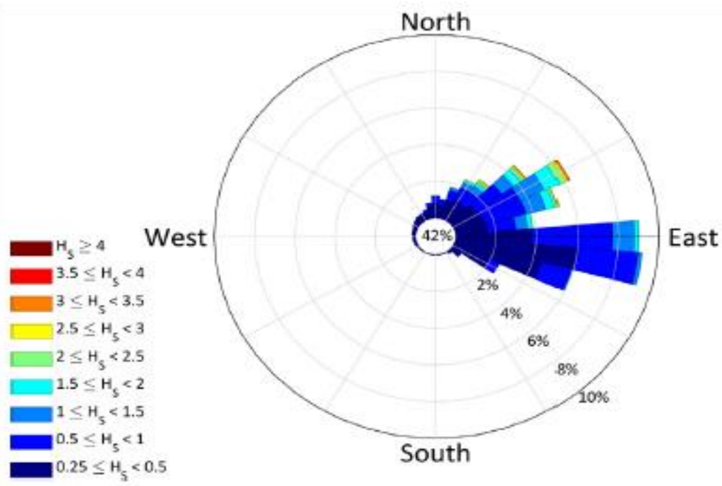


Figure 19. Rose of the significant wave height, at the "Nausicaa" directional buoy (values in meters) from Schweizer et al. (2016)

The Adriatic has moderate tides, with the highest amplitudes reaching 26.6 cm at the M2 frequency (12.421 h) and 20.1 cm at the K1 frequency (23.934 h), both in the Gulf of Trieste (Cushman-Roisin and Naimie, 2002) other highest velocities/heights of the residual currents occur in the vicinity of high-curvature points along the coastline.

The wind system is indeed one of the main forcing agents of the Adriatic circulation. The northern Adriatic circulation is substantially affected by cold Bora winds that penetrate to the bottom; a cold deep water (NAdDW) with density > 29.2 kg m^3 is produced in the Gulf of Trieste and its salinity is greatly affected by river discharges (Artegiani et al., 1997), it travels southward along the coast on the outer shelf. The Western Adriatic Coastal Current (WACC), a coastal current originated as a geostrophic response of the river runoff mostly in the Northern Adriatic, travels with an intensity of some 0.30 m s^{-1} (Poulain, 2001).

5.2 Biogeochemistry of the water column

Due to river runoff waters, the surface layers of all three regions of the Adriatic Sea are freshened during the spring–summer seasons. The vertical distributions of dissolved oxygen vary quantitatively in the three regions showing a spring–summer subsurface maximum due to the balance between phytoplankton growth in the euphotic zone and low vertical mixing in the water column. This behavior can be reconciled with open ocean conditions except for the northernmost part of the Adriatic where well-mixed oxygen conditions prevail throughout the year.

The basin exhibits a generally decreasing trend of nutrient concentrations from North to South, due to the nutrient input by rivers, occurring particularly in the northern Adriatic, enabling intense phytoplankton developments in winter and autumn. In the northern basin the dominant cyclonic circulation determines a southward nutrient flow along the western coast; however, the resulting horizontal nutrients distribution can be strongly affected by phytoplankton uptake, as in the case of the winter bloom. Strong bacterial regeneration of the organic matter occurs in spring–summer, with a sensible oxygen depletion and nutrient increase at depth (Zavatarelli et al., 1998).

Principal components analysis reveals a strong influence of the Po River discharge on the spatial and vertical distributions of metal species. Almost all the metal fractions globally decreased following the salinity gradient. Metal concentrations are far below (at least one order of magnitude lower) the Environmental Quality Standard established by the Italian law (Illuminati et al., 2019).

An environmental impact study was conducted 30 km SE from the Azalea A platform in 2013, commissioned by Eni S.p.A. and carried out by GAS S.r.l. Main outcomes indicate a scarce visibility (< 3 m) of the water column, no chlorophyll, dissolved oxygen and pH influenced by the thermocline depth (24 m) ranging respectively 4.9-5.3 mg/L and 7.6-7.4. Low concentrations of nutrients were recorded, with increase of ammoniacal nitrogen at the seabed interface with water. Hydrocarbons were not detectable, organic carbon oscillating 1.6-5.6 mg/L, microbiological tests indicate max 38 UFC/mL.

5.3 Fisheries

In the northwestern Adriatic Sea, the high biological productivity determines a rapid growth of many young individuals, generating seasonal trophic concentrations, before they leave the Italian coasts. The main fishing activities are artisanal fisheries and trawling. Bottom trawling together with purse-seining and pelagic pair-trawling has the largest impact on the Adriatic ecosystem. Additionally, bottom and pelagic long-lines, trammel nets and other forms of artisanal fisheries reduce the overall fish biomass.

The northern Adriatic represents a hot spot of Mediterranean biodiversity, especially taking into consideration the endemism of fish species. In fact, the study area includes important high commercial value fish breeding and growth areas (Essential Fish Habitats). Distribution models on recruitment and spawning areas of economically relevant species like anchovy (*Engraulis encrasicolus*), mud mullet (*Mullus barbatus*), red seabream (*Pagellus erythrinus*), sardine (*Sardina pilchardus*), atlantic chub mackerel (*Scomber colias*), atlantic mackerel (*Scomber scombrus*), sole (*Solea solea*), Mediterranean horse mackerel (*Trachurus mediterraneus*) were developed as part of the MEDISEH project (Mediterranean Sensitive Habitat, 2013). In particular, the areas of recruitment of sole (*Solea solea*), red seabream (*Pagellus erythrinus*) and red mullet (*Mullus barbatus*) in Emilia-Romagna coastal waters are important for the entire Mediterranean.

5.4 Marine mammals and sea turtles

Impact of reduced prey availability due to overfishing, habitat degradation and by catch are the main sources of concern for large marine vertebrates including cetaceans, marine turtles and cartilaginous fish.

The loggerhead turtle (*Caretta caretta*) is an endemic species of the northern Adriatic Sea that is the preferred hunting area during demersal phase of turtles. The loggerhead turtle express high level of philopatry for nesting places and for marine habitats. They are under heavy pressure of anthropogenic activities like bottom trawlers and estimated number of incidental captures by only bottom trawlers is over 11,000 specimens (Casale, 2011). A study carried out on 264 loggerhead turtles from northern Adriatic between 1995 and 2007 confirmed the northern and central Adriatic as a neritic habitat of loggerhead turtles. Of importance is gillnet mortality of 74% and bottom trawling by-catch with direct mortality of 7.5% and potential mortality of 26.9%.

The common bottlenose dolphin (*Tursiops truncates*) is the only species of cetaceans considered sedentary in the northern Adriatic Sea. Other species like the striped dolphin (*Stenella coeruleoalba*), the fin whale (*Balaenoptera physalus*), the sperm whale (*Physeter macrocephalus*), the Risso's dolphin (*Grampus griseus*) and the Cuvier's beaked whale (*Ziphius cavirostris*) are considered sporadic or wandering. The long-finned pilot whale (*Globicephala melas*), false killer whale (*Pseudorca crassidens*) and humpback whale (*Megaptera novaeangliae*) represent rare visitors to the Adriatic Sea. Finally, the short-beaked common dolphin, once present in the entire Adriatic Sea should be considered regionally extinct, as it is present only through either remnant or stray animals (UNEP-MAP-RAC/SPA, 2014).

5.5 Marine traffic

The northern Adriatic area is highly exposed to anthropogenic activity. The presence of several gas drilling platforms may pose some threats to its ecosystem, including an increased ship traffic as well as chemical and floating pollution. On the other side, the submerged parts of these constructions offer a valid substrate for the settlement of many marine organisms and provide shelters and nourishment for fishes. Triossi et al. (2013) analyzed the behavior of the common bottlenose dolphins around and within the offshore gas fields off Ravenna (Italy). Their analyses showed that dolphin density was approximately 80% higher within 750 m of gas platforms (compare to densities >750 m from platforms). A survey conducted through observations performed from June to October 2001 and 2002 and focused on bottlenose dolphin allowed to quantify their presence and distribution in the area and suggested that the ecosystems created around the gas drilling platforms is suitable for invertebrates and fish-biomass as well as for marine mammals. Bottlenose dolphins could be possibly attracted by the favorable environment in the proximity of the platforms, consisting of abundant and clumped living species as potential food resources for individuals (Triossi and Tizzi, 2002). In addition, the area nearby the platforms is relatively calm in terms of boat traffic and fishing activities, allowing dolphins to remain in a safer environment. In fact, both transit and fishing operations are forbidden within five hundred meters around each artificial construction.

Maritime traffic in the Adriatic includes transport routes for tankers with crude oil, liquefied gas transport, dry cargo and container ships, chemical tankers and passenger ships. Maritime traffic further constitutes of fishing vessels, yachts, recreational boats, military and other official boats and research vessels.

Such large shipping produces several negative effects on the marine environment. Of environmental concern are ballast waters, pollution and oil spill, collision, noise and habitat degradation. As species appearing in the Adriatic are smaller and more agile, collision with larger vessels is highly unlikely. Nevertheless, collision with fast moving vessels, is of concern for sea turtles.

5.6 Pollution (including marine litter)

Polychlorobiphenyls (PCBs) are among the most common and the most toxic chlorinated hydrocarbons. Their presence in marine environments, including in sea turtles and cetacean tissues of the Adriatic Sea, is well documented. Marine debris (i.e. marine litter) is proven to have a widespread negative impact on marine wildlife.

5.7 Seabed sediments

The western Adriatic continental shelf has a low gradient of 0.02°, the inner shelf is slightly higher in the range of 0.5°. During the last sea-level rise (transgressive phase or TST), which culminated ca. 5500 years ago in the present high stand (HST), a large portion of the alluvial plain of the last glaciation (ca. 20,000 years ago) was drowned and became an epicontinental shelf. Depositional sequences represent the sediment deposited during an entire glacial cycle and can be subdivided in units bounded by timelines which identify the different stages of the glacial cycle, these are called systems tracts (ST) and are sediments deposited in the same time interval, as chronostratigraphic units. The wedge of sediments deposited during the HST are comprised of silty mud sediments (sand < 10 %) and show a progradational geometry and is elongated parallel to the coast, in the last millennia sedimentation rate is 1.2-1.5 cm yr^{-1} (Correggiari et al., 2001).

The environmental impact study conducted 30 km SE from the AZALEA A platform in 2013, commissioned by Eni S.p.A. and carried out by GAS S.r.l., revealed seabed sediments characterized by pH 8.4-8.8 in the upper surface and descripts anoxic conditions. TOC (Total Organic Carbon) and organic matter were 1.2 and 1.4 %, Ntot = 0.12 %, Ptot = 505 mg/kg. No light hydrocarbons were present, heavy hydrocarbons were 27 mg/kg and PAHs 115-157 µg/kg; in these areas the Polycyclic Aromatic Hydrocarbons PAHs are adsorbed in the organic particles of the sediment and are transported by the numerous rivers of the Po Valley (Artegiani et al., 1997). No anomalous concentration of heavy metals was detected. Macrobenthos is mainly represented by polychaetas, bivalves and cidarids, with no significant biogenic outbuilding.

5.8 Geohazards: faults and seismogenic sources

No significant tectonic deformation or dislocation is visible at the seabed in the study area (Figure 20; Figure 21), thought a deep-buried Apennine thrust is present below the Quaternary sediments of the Adriatic Sea (Pieri and Groppi, 1981; Figure 22).

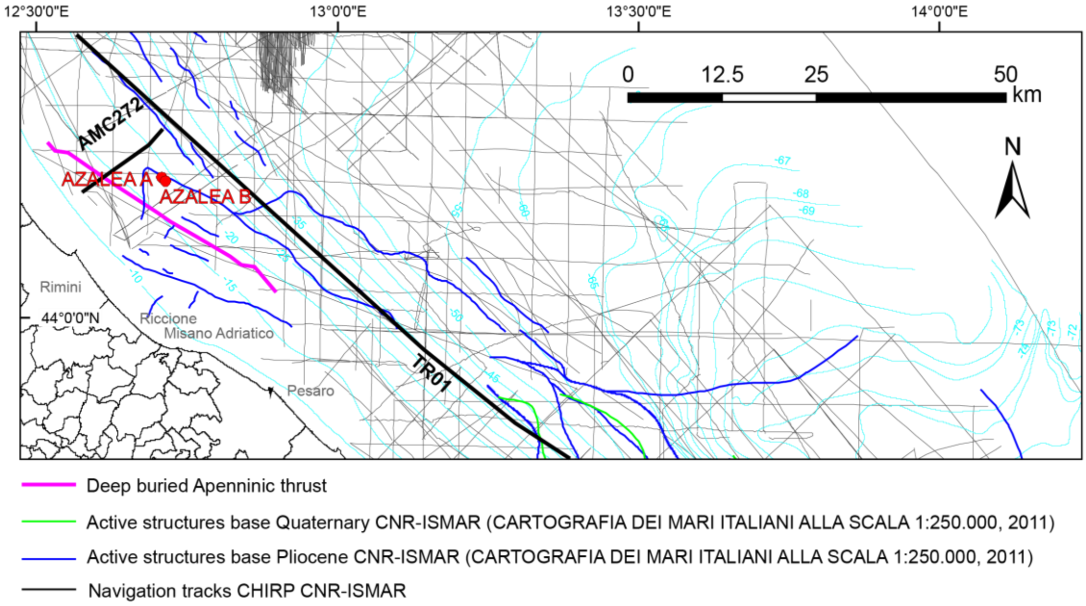


Figure 20. Bathymetric contour map showing the location of the AZALEA A platform in respect to the deep-buried Apennine thrust and 2 single channel seismic reflection profiles (CHIRP)

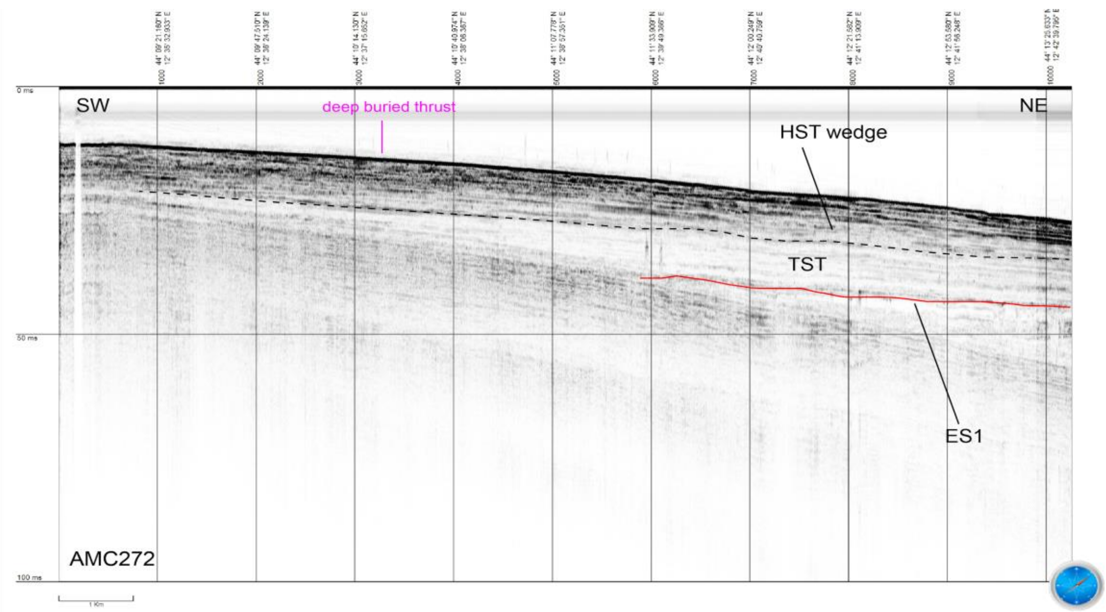


Figure 21. CHIRP seismic profile running along the western Adriatic coast in proximity of the AZALEA A platform. ES1 is the subaerial erosional surface related to the last sea level lowstand, occurred around 20,000 years ago

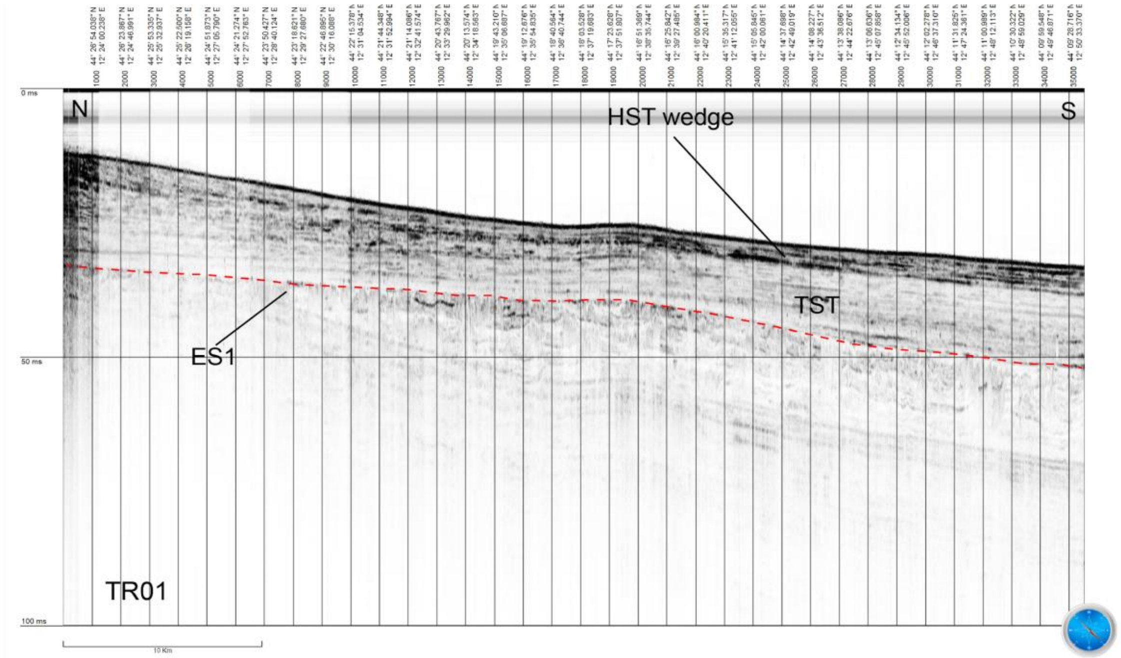


Figure 22. CHIRP seismic profile running perpendicular to the HST wedge in proximity of the AZALEA A platform

The Database of individual Seismogenic Source (DISS Version 3.2.1) shows one composite source 5 km south of the platform AZALEA A (Figure 23). This Composite Source straddles the Adriatic Sea just east of the city of Rimini and is the southernmost part of the Umbro-Marche Apennines outer offshore thrust. The minimum depth of this source is estimated at 3 km and the maximum depth is 7 km, detected by Bally et al. (1986) through geophysical prospecting. Therefore, no significant tectonic implications are present in the platform area.

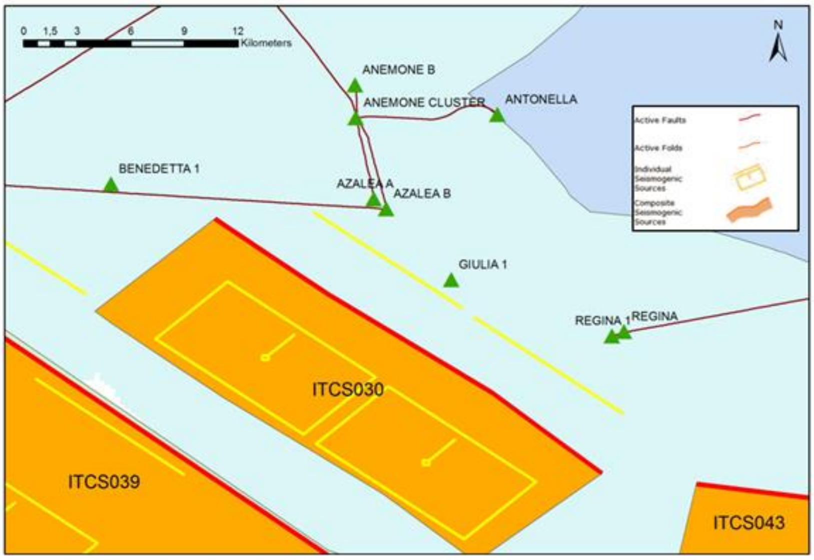


Figure 23. Database of Individual Seismogenic Sources in the AZALEA A study area (From: DISS 3.2.1 http://diss.rm.ingv.it/diss/)

5.9 Environmental protection strategy

In the offshore of Emilia-Romagna various measures are currently active to protect the marine environment, resources of high ecological importance and related ecosystem services. The purpose of the Biological Protected Area "Fuori Ravenna" is to safeguard and repopulate marine resources through the regulation of fishing effort.

The SIC "Relitto della piattaforma Paguro" is an artificial reef characterized by the colonization of the metal structures of this former gas platform. The highest part of the reef (from -9 to -12 meters) is entirely covered with mussels, oysters and other sessile organisms (Tunicates, Porifera, Briozoa, Polychaetes and colonial Cnidarians). The fishes are typical of rocky bottoms, rare to find in other parts of the northwestern Adriatic sea, such as brown meagre (*Sciaena umbra*), seabream (*Oblada melanura*), striped seabream (*Lithognathus mormyrus*), black scorpionfish (*Scorpaena porcus*), European bass (*Dicentrarchus labrax*) and conger (*Conger conger*). On the muddy bottom around the reef there is a luxuriant fauna: *Atrina pectinata*, cnidarides and echinoderms belonging to *Asteroidea*, *Ophiuroidea* and *Holothuroidea* classes.

5.10 Geohazard risk assessment strategy

The objectives of any site survey around AZALEA A platform are to define potential hazards or factors of operational significance in the area of the above development and the placement of a suitable drilling unit and top-hole drilling, at client supplied well coordinates, in order to achieve the following:

- to establish or confirm water depths and seabed condition;
- to identify any seabed obstructions;
- to investigate sub-seabed geological conditions at the locations for detailed soils classification and integration with other investigations for assessment of foundation conditions;
- to define any potential hazards or factors of operational significance for any vessel for operations;
- to identify geohazards and geological conditions relating to the emplacement of seabed structures.

5.11 Monitoring program for environment and infrastructures

Considering the area features as reported in previous paragraphs, monitoring of the marine environment near the offshore structures AZALEA A plays a very important role for the decommissioning or reuse phases. In fact, it is essential to study the impact of a structure in the environment that surrounds it, to assess possible environmental risks.

Monitoring existing structures is a prerequisite to evaluate their status and usability in order to plan eventual re-uses but also to monitor their impact on environment.

Monitoring program will concern:

- study of the environment surrounding the pipelines, so to assess their impact on the marine ecosystem, and to consider their maintenance or their dismantling;
- morphological reconstruction of the pipelines and seabed, in order to assess their residual life, any damage, and to detect areas where replacement is necessary;
- study of parameters that can influence the life of the platform.

Current monitoring systems are based on on-site sampling, transport of the sample to the laboratory and subsequent analysis. This chain has numerous disadvantages, among which the main ones are the low sampling frequency, the excessive duration which entails the impossibility of correlating any contamination with possible contaminants, high costs.

Here the test of innovative technologies is suggested to create a most efficient monitoring program and share new methodologies.

Autonomous underwater vehicles – AUV

Within the Network CLYPEA, the DGS UNMIG (General Directorate for Safety of Mining and Energy activities – Italian Ministry of Economic Development), in collaboration with the SEADOG of Polytechnic of Turin, is working on the development of a technology for environmental monitoring in the area adjacent to the offshore hydrocarbon production platforms - AUV in Figure 24 and Figure 25.

Figure 24. Autonomous Underwater Vehicle equipped with a miniaturized laboratory, developed by Polytechnic of Turin, for autonomous heavy metal detection in seawater near offshore hydrocarbon platforms

To repurpose no longer active structures, it is necessary to monitor the state of health of the structure. For pipelines, a morphological reconstruction of the pipes and the surrounding seabed represents a crucial step.

Hull-mounted or towed sonars can provide high-quality seabed maps in shallow waters, but they cannot show highly resolute details at high depths. Using AUV (Autonomous Underwater Vehicle) drones with high frequency sonar that can operate in deep water it is possible to map the high-resolution seabed. As previously seen, the resolution decreases however with the increase of the measurement range, it is therefore necessary to bring the instrument closer to the bottom, to maximize the resolution of the same. The platforms in the past used submarines, which are expensive, noisy and irregular, or towed systems, which in deep waters, particularly near the rough seabed, can be dangerous and slow and produce inaccurate and contaminated data from the movement of the ship. AUVs offer a faster and more agile platform to produce high quality datasets especially in the marine depths and can perform this activity efficiently and reliably, as well as autonomously.

It is desirable to choose a drone that better meets the need for high resolution bathymetry. This vehicle must allow to reach high depths (measuring in complete autonomy and safety thanks to the sensors mounted on board.

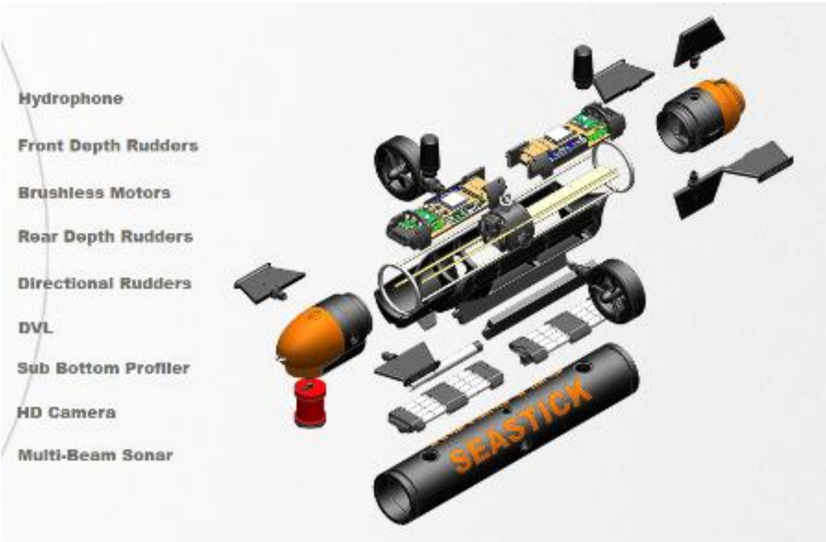


Figure 25. All the components that can be integrated on an AUV which allow a high-resolution bottom bathymetry, with a completely automatic drone control. In this picture SEASTICK 300 from Gabri S.r.l. is taken as an example

The assembled multibeam sonar allows a high-resolution bathymetry (analogous to the ground topography), while the sub-bottom profiler penetrates the sediments on the seabed, allowing the detection of layers within the sediments, defects and depth in the rock. The sub-bottom profiler is designed for AUV, which can reach a depth of about 2,000 meters. The high ping frequency and the possibility of transmitting sound pulses over a wide range of frequencies ensure echo-prints with excellent resolution and excellent rock penetration.

As part of this project, Polytechnic of Turin created an instrument capable of performing chemical analysis on small samples of water for detecting any anomalies in the concentration of heavy materials with respect to the current legislation.

The UPH2O sensor platform, in fact, provides the possibility of sampling at least daily (or more frequent depending on the risk analysis) marine water, activating an ON/OFF procedure on the presence or absence of contaminants and preparing the collection of samples for a more accurate and quantitative analysis on the ground. This platform uses Lab-On a-Chip microfluidic technologies for fluid and flow management in situ analysis of the samples. The requirements relating to sensors must include the collection and analysis of samples in situ of water and for this purpose it is housed in autonomous submarine vehicles (hereinafter Autonomous Underwater Vehicle - AUV). The expected advantages for this technological application not yet present in the state of the art consist of the possibility of:

- long-term monitoring, with multiple parameters detected simultaneously and characterized by the fact of being "where and when not otherwise possible";
- higher sampling / analysis frequency;
- wider spatial coverage around the platform;
- low cost and high cost/benefit ratio platform.

To verify the potential of this approach, a "Case study" was taken as first step, consisting of an implementation project for customizing the platform to detect heavy metal ions (Cr, Cu, Zn, Ni) in seawater. The UPH2O platform therefore provides for an autonomous submarine vehicle (AUV) and a module (PAYLOAD) interfaced with the vehicle in which the measurement systems are housed). They provide for the collection and analysis of sea water samples autonomously.

MATRAC-ACP

The general objective is to show a cost-effective and relocatable geophysical and geochemical monitoring system of offshore natural and human-induced hydrocarbon seepages that may combine the monitoring of the integrity of the infrastructure with the environmental assessment post-opera and during decommissioning and reconversion phases.

Traditional and routinely environmental monitoring and maintenance of sealines basically include sampling of sediment in the proximity of the sealine for: grain size, T, pH, Eh, heavy metals concentrations, TOC, N, P; heavy and light hydrocarbons, PHAs, pesticides, microbiology tests; analysis of abundance and biodiversity of the macrozoobenthos for the ecological health assessment.

Some industry sectors are more advanced, with proprietary remote-sensing leak detection systems in development. There is a study from Eni S.p.A which is based on vibroacoustic data processing, and where the monitoring stations are placed at the terminals of a sealine (Giunta et al., 2017). The monitoring stations are placed at the terminals of a 12 km, 3 inch inner diameter sealine, conveying a fluxing agent (diesel fuel) from the onshore Enimed's CROPP terminal (Gela) to the offshore platform PERLA. The stations record synchronizes (by GPS) and send to a central unit, continuously and in real time, the fluid pressure transients and pipe shell vibrations. Advanced multichannel processing permits to distinguish the vibroacoustic signature of normal operation from anomalous events generated by interferences with the pipeline and by fluid leaks.

DNV-GL, the world leading provider of risk management and quality assurance services to the maritime, oil and gas, and power and renewables industries, has released a Recommended Practice for Offshore leak detection, which provides recommendations for successful planning, design, integration and operation of leak detection technology in offshore fields for hydrocarbon production and it includes a variety of sensors (optical, laser, bio). On the contrary, the EU guidance document on best available Techniques in the upstream Oil&Gas sector issued in spring 2019 foresees practices that are more standard, such as monitoring discharges to the environment, e.g. sampling for PAH accumulation and quantification with high-performance liquid chromatography, monitor the seafloor and water column with sonar detection techniques and geochemical measurements.

The pilot project proposed by CNR addresses the sealine maintenance and monitoring with the employment of a ROV (Remotely Operated Vehicle), namely a robotic platform capable of performing autonomous operations (such as automatic guidance over operational areas, hovering on points of interest, multi-parametric data sampling to name a few) integrated with geophysical devices and geological sampling tools. In the proposed framework, the exploitation of a ROV will allow the close-range observation of sealines and complementary submerged structure, allowing the analysis and evaluation of the infrastructures. Sets of aggregated data will be collected by means of both high resolution cameras (imagery data), a multi-beam echo-sounder device (acoustic data of the water column and of the seafloor/sealine object), further environmental measurements (e.g. conductivity, temperature, biological indicators), and geophysical inspection of the sediment surrounding the sealine (seismic reflection data). Such data sets will allow the reconstruction of the underwater environment and sealines, in such a way to provide a comprehensive knowledge for the human operators and to evaluate possible maintenance actions to be performed on the structures. The ROV is connected to a remote station or mother-ship by means of a tether that allows a real-time data flow, allowing the operator to observe the environment and targets of interest and, at the same time, reacting to the operative conditions and re-planning the mission tasks.

Furthermore, CNR has designed an interdisciplinary source-diagnostic tool to monitor the sealine that involves sensor-based measurements, water and sediment sampling. The integration of gas gauge detectors (commercial off the shelf or custom designed) will provide key information about the presence of dissolved substances which are diagnostic for possible leakages from the sealine or, alternatively, derived from natural emissions in the proximity. Customized gas bubble sampling device will be used to characterize the composition of large-scale leakages. Chronic release of hydrocarbon gasses dissolved in the water column will be monitored by water sampling from the vessel paired with ROV sampling. Surface sediments will monitor the effect of hydrocarbon spill on the benthic environment. Specifically, sediments will be retrieved with a small box-corer in the vicinity of the sealine and/or possible leakages for a fit-to-purpose monitoring. Through the composition of sediments will evaluate to what extent the fossil material has been actively re-introduced into modern biogeochemical cycles and ecosystem. Analyses encompass pH, Eh, T, grain size, total hydrocarbons, hydrocarbon indices, polycyclic aromatic hydrocarbons (petrogenic vs anthropic origin), heavy metals, TOC, stable C isotopes of bulk OC and biomarkers, P and N total. As the Mediterranean has experienced large changes since the first industrial revolution, we will also constrain the background values (i.e. prior to human impact) by collecting cores to be dated with short-lived radionuclides. By comparing modern sediments with pre-industrial conditions, we will be in position of disentangling the large-scale chronic human effect over the Mediterranean from the local sealine impact.

5.12 Partial Conclusion

The employment of the ROV system will allow a repeatable execution of observation operations over space and time, providing in such a way a periodic characterization of the environment and infrastructure.

ROV technology application: will improve methodology and operational standards, quality of the gathered data, operation efficiency, increasing operator safety, sustainability, repeatability, eventually it will reduce costs and operating time; ROV will define new protocols for monitoring or re-use of sealines and maintenance operation, relying on the employment of new technological tools.

For the proposed project two innovative technology are explored: AUV from Polytechnic of Turin and a ROV platform created by CNR-INM.

This last one is equipped with cameras and basic environmental sensing devices; CNR ISMAR will provide the multi-beam acoustic device and other geophysical/sensors tools to be fully integrated onboard the ROV. CNR ISMAR will also analyze water and sediment samples collected with the ROV.

The main opportunity for a next scale-up of the project is to test this technology on a real case study to improve the technologies and defines some protocols or best practices for marine environment.

6. REGULATION

6.1 Existing international regulatory framework

Global legislation on decommissioning is minimal, to overcome the lack of specific and comprehensive regulation, regional protocol and international guidelines may provide requirements basis; in some instances, decommissioning matters are regulated by operating agreements between Operators and Concessionaires.

In terms of International Guidelines and Requirements for offshore decommissioning the most observed reference is the United Nations Convention on the Law of the Sea (UNCLOS III) 1982, jointly to the International Maritime Organization's (IMO) Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone (EEZ), adopted in 1989. IMO Guidelines state that abandoned offshore installations are to be removed, but they do allow some flexibility to leave parts of installations in place in case they do not interfere with other uses of the sea, exceptions are primarily based on water depth and structures size; decision for non-removal are although to be made case by case. Neither UNCLOS III nor the IMO provide guidance about sealines.

6.2 Mediterranean Area

The European Community and sixteen Mediterranean countries adopted in 1975 the Mediterranean Action Plan (MAP), the first regional seas program by United Nation. One year later the Barcelona Convention comprising seven protocols addressing specific issues on environmental conservations finalizing MAP legal framework. The Offshore Protocol (effective from 2011) covers Oil&Gas activities including decommissioning and removal, Article 5 states that any applications for authorization in exploitation must include plans for removal; operator are required in Article 20, to dispose any abandoned or disused structure to ensure safety of other users of the sea (mainly fishing linked activities), navigation, and to safeguard marine environment. Operators are also required to remove disused sealines or to provide cleaning and burying to "not interfere with other legitimate uses of the sea".

In relation to artificial reefs guidelines were also adopted in the Barcelona Convention of 2005, they however only focus on specific created artificial reefs with no mention of re-use of offshore platform as reefs.

For the purpose of this feasibility study a general description of the regulatory framework for each Mediterranean country has been taken into account (Table 5) and compared with the international benchmark for the best practice in the field of decommissioning and removal (e.g. United Kingdom, Norway etc. that already have a consolidated experience in the sector, see Appendix A). After a general overview about the existing regulation in the Mediterranean region, a focus has been reported about the legal framework in Italy where the case study AZALEA A is located.

The Sealines Start-Up Action workshops discussion on regulation highlighted International regulatory gaps.

Table 5. Regulatory framework for each Mediterranean country. Highlighted in blue, countries (also partners of Sealines project) with detailed paragraph about decommissioning and reuse in Appendix A

Mediterranean Country	E&P Activity	Regulatory References	Platforms	Sealines	Drill cuttings piles	Decommissioning plan needed	References note
Southern France	no	-	-	-	-	-	Infield, 2019
Southern Spain	yes	-	-	-	-	-	Infield, 2019
Morocco	no	-	-	-	-	-	Infield, 2019
Tunisia	yes	Barcelona Convention/ Article 20	x	x	x	National requirements submitted to the new Ministry of Energy Transition	Ministry of Energy Transition
Algeria	yes	Barcelona Convention/ Article 20	x	x	x	No national requirements. The Algerian Hydrocarbon Law, 2005 and amendments	IOGP, 2017 Vol1
Libya	yes	-	-	-	-	-	Infield, 2019
Egypt	yes	Barcelona Convention/ Article 20. IMO/UNCLOS III	x	x	x	No national requirements	IOGP, 2017 Vol1
Lebanon	yes	-	-	-	-	-	Infield, 2019
Israel	yes	-	-	-	-	-	Infield, 2020
Cyprus	yes	Barcelona Convention/ Article 20	x	x	x	x	Infield, 2019
Turkey	yes	-	-	-	-	-	Infield, 2019
Montenegro	yes	-	-	-	-	-	Infield, 2019
Albania	yes	-	-	-	-	-	Infield, 2019
Croatia	yes	Several National Acts	x	x	x	Yes to be submitted	Infield, 2019
Greece	yes	Several National Acts	x	x	x	Yes to be submitted	Infield, 2019
Slovenia	no	-	-	-	-	-	Infield, 2019
Syria	not found	-	-	-	-	-	-
Malta	not found	-	-	-	-	-	-
Italy	yes	Barcelona convention/art. 20. UNCLOS III and IMO. Ministerial Decree 2019 and Guidelines	x	x	x	Yes to be submitted to Department of Economic Development. No timescale available	IOGP, 2017 and Ministry of Economic Development, 2019

6.3 Italian regulatory framework

The regulatory body for the oil industry in Italy is the Ministry of Economic Development, which also issues concessions and authorizations for the exploration and development of oilfields. All applications for an exploration permit, or a production concession, must include a work program covering the expected requirements during decommissioning of any plant, and facility, used in the exploitation. Operators must provide a detailed work plan within a timeframe needed to carry out all decommissioning activities. In the absence of any national guidelines, decommissioning requirements will be governed by the Barcelona Convention to which Italy is a signatory.

National Guidelines for Decommissioning

By Ministerial Decree February 15th, 2019, by Ministry of Economic Development with Ministry of Environment, Ministry of Cultural Heritage and positive opinion by State Region Conference “National Guidelines for Mining Decommissioning for Offshore Platform and Connected Installations”, were approved. The guidelines establish decommissioning procedures regarding offshore platforms, and related installation, used for hydrocarbon production from depleted or no longer exploitable deposits and apply to: production structures, pressure structures, transit pipe, submarine wellheads and submarine pipes serving offshore infrastructures related to exploiting and cultivating activities located in national water.

Abandonment of offshore platform and connected facilities is forbidden. However, alternative re-use may be authorized by the regulatory body with or without a partial removal of some structures.

Art.5 of the National Guidelines confirms that companies holding a mining lease must communicate, by March 31st of every year, the listing of soon divested wells, noting a procedure timeframe and a detailed report on the well structural status.

The Ministry of Economic Development will evaluate the status of the structure for a re-use (where applicable) and with a positive statement from Ministry of Environment, and Ministry of Cultural Heritage, it will publish by June 30th of each year a list of inactive rigs available for re-use projects. Within one year interested institution could submit a complete reuse project to Ministry of Economic Development, Ministry of Environment, Ministry of Cultural Heritage and Port Authority. The evaluation will be based on the level of scientific or technical innovation, general socio-economic impact, economic feasibility, synergy between structure and technology proposed in the project, environmental sustainability of the project, a valid maintenance plan.

6.4 Partial Conclusion

Considering decommissioning legal framework, some gaps in International legislation are emerged because of the lack of common best practices. A specific focus has been giving to the Italian legislative framework, since

National Guidelines for Decommissioning, issued February 2019, represent the opportunity to submit a repurposing project on a no longer active platform, otherwise decommissioned. It would be highly advisable to involve in the future step of the project partners coming from countries that have experience in matters of decommissioning (see Appendix A).

7. COMMUNICATION PLAN AND SOCIAL ENGAGEMENT

The Sealines Start-up Action has been updating followers on a dedicate twitter page with an editorial plan core mainly based on news about meetings and BlueMed activities (https://twitter.com/SealinesA).

Communication activities carried out by the Start-up Action during its development have taken place during Ecomondo 2019, an exhibition about circular economy with a poster and a speech during a workshop "Circular Economy for a Sustainable and Integrated Blue Growth" and a poster in the CNR Exhibition stand (Figure 26).

The Start-up Action will issue a small "Citizen Guidebook" describing to a non-scientific audience the feasibility study (attached to this report).

Figure 26. Poster presented at Ecomondo 2019

7.1 Planning blue growth training

The Italian National Institute of Oceanography and Applied Geophysics (OGS), partner of the project, is involved in many international network of which the core activities aim to promote the creation of skills, knowledge and research in the field of Blue Economy, leading to "blue" careers and scientific research. By supporting the Euro-Mediterranean community of stakeholders of the Blue Economy through Higher Education and Research. The idea is to plan, develop and implement a series of trainings (mainly summer schools) in order to promote opportunities for "Blue" marine and maritime careers by developing skills, exchanging knowledge and valorizing research findings for a more sustainable Mediterranean Sea.

The aim of the trainings is to develop new curricula and increase the employability of youth in the marine and maritime sectors by supporting the Euro-Mediterranean communities through higher education, research and innovation. Sealines Network foresees an active participation, sharing knowledge and experience, expanding and intertwining within the existing networks.

8. CONCLUSION

The Mediterranean Sea is a peculiar marine region with a delicate environmental balance. A more sensitive approach to assess all maritime and marine activities, has become necessary, to embrace a more environmentally sustainable path.

Actions to increase safety, surveillance and awareness align with the growing need to readdress economic development towards blue economy principles.

The Sealines Start-up Action feasibility study is the outcome of the project which foresees the reuse of disused platform, otherwise decommissioned, as a scientific research hub to test an integrated energy system or renewable energies, embracing the growing need to move towards cleaner sources. AZALEA A platform, being in the list of inactive platforms available for reuse projects, issued by the Ministry of Economic Development, has been identified as an ideal set to carry out a pilot test that may later apply to other cases. Both its structural features and the energy potential from green energy resource in the area surrounding the platform have been analyzed.

In order to proceed it has been considered:

- photovoltaic power generation and integration with wind turbines;
- hydrogen generation;
- sealines as power line or hydrogen storage and transport.

Three ideal business cases have been evaluated along with their corresponding investment cost, of which only one is applicable to the case study of AZALEA A:

- Option 1: hybrid electric power generation integrated into the power system of the nearby platforms in operation;
- Option 2: direct H_2 injection into the existing gas sealine of the nearby platforms in operation and sold at the same price of the natural gas (same case of AZALEA A);
- Option 3: inland transportation through abandoned sealine and sold as H_2 technical gas.

Considering the second option, the power production from integration of solar panels and wind turbines estimated for AZALEA A, considering energy potential from literature data, is 270,000 kWh/a at a cost of €0.4 million. Supposing conversion of H_2 to power to the connected platform Anemone Cluster, the total cost of the investment for this case is €0.8 million. Otherwise, considering the third option of possible inland transportation by an abandoned sealine, power generation through the integration of the renewable resource pooled with storage and inland transport could be carried out through an existing abandoned sealines with a total estimated cost of €0.9 million (including power generation).

Although the potential for different kind of sources (as defined by literature) may be not enough currently for an economic investment, the use of existing offshore infrastructure for power generation, included the reuse of sealines for energy storage and transport of H_2, seems to be a good solution from an economic point of view, if considering underlying decommissioning costs. Furthermore, the results coming from the analysis of reuse of existing sealines for hydrogen storage and transport highlight the possibility to store hydrogen until 1,852 kg at maximum pressure of 330 bar (considering the safety threshold defined by API standard). The proposed technical study demonstrates how the integration of the existing offshore infrastructures with the new hybrid power generation systems is feasible and can be envisaged as a positive example of "Blue Economy"; however it is important at this stage to create a place to test the technological and scientific improvements. A further scale-up of the SEALINES Start-up Action may provide a good solution proposing a scientific research hub and an integrated green energy system on a disused platform.

The outlined monitoring program is a precondition to best define all activities foreseen by the feasibility study. It looks crucial to define the structural status of the platform and to monitor environmental components of the area. Whit this aim may be a good opportunity testing new technologies like those of AUV and MATRAC-ACP.

The opportunity that the Sealines Network is envisaging, requires to be implemented and enriched within new cooperation programs like Horizon Europe and BlueInvest Platform and with engagement of other expert countries.

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APPENDIX A

Regulation and best practices in other countries

United Kingdom as a benchmark example (from BEIS web site and IOGP, 2017 Vol. 1)

The decommissioning of offshore oil and gas platforms and pipelines in the United Kingdom is regulated by the Petroleum Act 1998, as amended by the Energy Act 2016. The Oil and Gas Authority (OGA) is responsible on ensuring a safe, environmentally sound and cost-effective decommissioning.

The Department for Business, Energy and Industrial Strategy (BEIS) is the competent authority for decommissioning. The OGA works with BEIS and is specifically required to assess decommissioning programs based on cost, future alternative use and collaboration. All oil and gas decommissioning operations must be described in a detailed program, which has undergone an appropriate amount of stakeholder scrutiny. Other government departments and agencies, non-governmental organizations, and relevant bodies are given the opportunity to comment on the proposals set out in a program. Once a program is sufficiently mature it is submitted it requires final approval from BEIS.

Part IV of the Petroleum Act 1998 provides a framework for the orderly decommissioning of disused installations and pipelines, it enables the Secretary of State to require the submission of a costed decommissioning program for each offshore installation and submarine pipeline. Those people given notices are accountable to submit a decommissioning program and once approved, by the Secretary of State, are to carry it out.

Petroleum Act sets out the requirements for a formal Decommissioning Program, which has to be approved by BEIS, operators are as well to consult the OGA. For most cases, the general rule under OSPAR Decision 98/3[10] is applied and the Decommissioning Plan will provide for full removal for reuse, or final disposal of the structure on land.

The BEIS Guidance Notes (DECC, 2011) require that the Decommissioning Program is supported by an Environmental Impact Assessment (EIA), which considers the potential environmental impacts. The EIA must draw from relatively recent development specific survey data, such as site surveys must not be more than 5 years old. Hence it is likely that an environmental baseline survey will be required before decommissioning activities commence if a relevant survey has not been undertaken in the last five years.

The Decommissioning Program must be made available for public comment and include a statement indicating how the principles of the waste hierarchy will be met. In more complex cases relating to concrete installations and to steel installations with a jacket weight greater than

[10] The Convention for the Protection of the Marine Environment of the North-East Atlantic. OSPAR Decision 98/3 on the disposal of disused offshore installations

10,000 tons, a full assessment of the options in accordance with Annex 2 to OSPAR Decision 98/3[11] must be undertaken by the operator to allow BEIS to decide whether there is a case for seeking a derogation from the general rule of the Decision.

Pipelines should be the subject of a separate Decommissioning Program unless they are located within the same field as other equipment or installations to be decommissioned at the same time. There are several options for the decommissioning of offshore pipelines, the process takes account of the technical, safety, environmental and societal impact and cost to determine the optimum decommissioning option for a specific pipeline and associated infrastructure. Where it is proposed that a pipeline should be decommissioned in place, either wholly or in part, then the decommissioning program should be supported by a suitable study which addresses the degree of past and likely future burial/exposure of the pipeline and any potential effect on the marine environment and other uses of the sea.

Energy Act 2008 and Energy Act 2016: Oil and Gas Decommissioning Chapter 3 of Part 3 of the Energy Act 2008 ("the 2008 Act") amends Part IV of the Petroleum Act 1998. Experience has shown that it has not always been possible to share liabilities equitably between parties responsible for any installation or pipeline. In summary, the 2008 Act amends the regime by:

- enabling the Secretary of State to make all the relevant parties liable for the decommissioning of an installation or pipeline and, where a license covers multiple sub-areas, clarifying which licensees will be liable;
- giving the Secretary of State power to require decommissioning security at any time during the life of an oil or gas field if the risks to the taxpayer are assessed as unacceptable;
- protecting the funds put aside for decommissioning, so in the event of insolvency of the relevant party, the funds remain available to pay for decommissioning and the taxpayers' exposure is minimized.

The Energy Act 2016 establishes the OGA as an independent government company and sets out the OGAs functions. Schedule 2 of the Energy Act amends the Petroleum Act 1998 to require relevant persons to consult the OGA before submitting an abandonment program to the Secretary of State, and to require the Secretary of State to consider representations from the OGA when deciding whether to approve a program. Alternatives to decommissioning, such as reuse or preservation, must be considered by the OGA.

There are other applicable legislation applying to Decommissioning activities:

[11] OSPAR Decision 98/3, Annex 2: Framework for the Assessment of Proposals for the Disposal at sea of Disused Offshore Installations

- the Environmental Permitting (England and Wales) Regulations 2010, Pollution Prevention and Control (Scotland) Act 2012 and Waste Management Licensing Regulations 1994 (apply in Scotland), which regulate industrial processes involved in the treatment of certain prescribed wastes.
- the Environmental Protection Act 1990, which places a duty of care on the waste producer to ensure that the waste is managed properly, recovered or disposed of safely, does not cause harm to human health or pollution of the environment and is only transferred to someone who is authorized to receive it;
- special Waste Regulations 1996 – Special Waste Amendment (Scotland) Regulations 2004/Hazardous Waste (England and Wales) Regulations 2005 which require all movements of special/hazardous wastes to be tracked by way of a consignment note system;
- transfrontier Shipment of Waste Regulations 2007 (Council Regulation No 1013/2006/EC on shipments of waste (see Sections 2.4.2), enforced by the EA (England and Wales), SEPA (Scotland) and NI Environment Agency (Northern Ireland) to control the international movement of waste;
- Health and Safety at Work etc. Act 1974, the Offshore Safety Act 1992 and The Offshore Installations (Offshore Safety Directive) (Safety Case etc.) Regulations 2015 (SCR 2015). The SCR 2015 include requirements for safeguarding the integrity of an installation throughout its life cycle, from design and construction, through operation and maintenance, to decommissioning and dismantling. The dismantling of a fixed installation requires a specific revision of the Safety Case to take account of the hazards and risks involved;
- the Pipelines Safety Regulations, 1996 which require that pipelines are decommissioned safely either by dismantlement and removal or by being left in a safe condition, and for notification of decommissioning works at least 3 months prior to commencement.

Norway (from IOGP, 2017 Vol.1)

Authorities from different government bodies are involved in regulating decommissioning activities which are part of the petroleum activities. The Petroleum Act 1996 covers the decommissioning of offshore installations and pipelines in the Norwegian sector of the North Sea in which chapter 5 of the Act deals with the termination of petroleum activities. The plan for development and operation of a field should include already at an early stage information about future disposal following OSPAR Decision 98/3. Petroleum Act is administered by the Norwegian Ministry of Petroleum and Energy, MPE, who decides if the disposal method stated in the plan is acceptable case by case. A Decommissioning Plan is to be submitted by the licensee two to five years prior to the shut-down of the facility, licensee is required to clarify the scope of the Impact Assessment with the Ministry. Cessation/Decommissioning plan covers infield pipelines and smaller pipelines; larger pipelines usually require a specific Cessation Plan. Decommissioning Plan consists of two parts, a Disposal Report and an Impact Assessment. MPE make final decision after a consultation with other bodies: the Norwegian Petroleum Directorate (NPD) and Petroleum Safety Authority (PSA). Any exceptions from removal of the facility must be assessed and grounds given for this option: these cases must also be presented to OSPAR before the Parliament decides. Decommissioning Plan must be supported by EIA which assesses the impact of the proposed decommissioning activities on the environment, it should also contain details of potential mitigation measures to be implemented to reduce impacts. EIA will be subject to a public hearing, while the Disposal Report will be evaluated by the MPE, the Ministry of Local Government and Regional Development and the NPD. The MPE will coordinate the evaluation of the Disposal Report and the EIA. All consultations are coordinated by the MPE and the operator is not required to conduct any consultations independently. The Norwegian Environment Agency (NEA) is one of the bodies consulted in these matters and can provide input on ways of reducing pollution. Activities that may result in pollution during dismantling offshore, and that are not covered by the general permit for the field, must be dealt with separately by the NEA. According to the Petroleum Act, the decommissioning plan shall include an assessment of the options for disposal for the installations/components to be removed with consideration of further use in petroleum activities; other uses; complete or partial removal; and abandonment.

If installations are not left in place or re-used directly, they must be removed to shore and delivered to approved waste treatment plants. If an installation is to be transported from the Norwegian sector of the continental shelf to another country, or imported, an export application must be sent to the competent authority in the dispatch state, and this process should be started between two and six months before the planned start of the operation. The Norwegian Oil and Gas Association (NOROG, joint operators) has put together a Guide for Impact Assessments of Offshore Decommissioning, which includes a list of appropriate disposal alternatives which can be considered for offshore installations.

The Norwegian Parliament has issued a White Paper which comprehensively addresses the decommissioning of pipelines and cables and which will form the basis for future decisions regarding the disposal of pipeline. Generally, pipelines and cables may be left in place so long as they do not cause an obstruction or present a safety risk for bottom fishing, considering the costs of burial, covering or removal of these items. Final decisions on the disposal of oil and gas installations, including pipelines, are made by the MPE. The following disposal solutions are normally considered: clean and leave in situ; burial/trenching; rock dumping; or removal.

Greece (from HHRM)

Provisions about decommissioning can be found in two legal texts in Greece; the Hydrocarbons Law (Law No. 2289/1995) and the Offshore Safety Law (Law No. 4409/2016), as well as in the Lease Agreements that the Hellenic Government has entered.

Currently there is no legal framework in Greece covering the potential re - use of a platform.

Offshore Safety Law 4409/2016

Law 4409/2016 (the Offshore Safety Law) makes Hellenic Hydrocarbon Resources Management S.A. the Competent Authority for the major hazard regulation of offshore oil and gas operations within licensed areas in Greece and gives effect to Directive 2013/30/EU of the European Parliament. HHRM is committed to ensuring that the offshore oil and gas industry meets the requirements of the Law and this will be achieved through assessment of submissions and inspection.

Under the Law, operators and owners are charged with ensuring the risk of all major accident hazards related to their offshore oil and gas operations is acceptable. Operators and owners have responsibility for, among other things, the control of risk from potential major accidents, including responsibility for continuously improving that control to ensure risk is reduced to a level that is ALARP. The Law requires operators and owners to have in place a Corporate Major Accident Prevention Plan (CMAPP), a Safety and Environmental Management System (SEMS), a Verification Scheme and a Report on Major Hazards (RoMH) and operate in accordance with these. How the risk is reduced to ALARP is communicated in the RoMH.

The Law requires operators/owners to submit RoMHs to HHRM, who then consider them for acceptance, which, if successful, allows the described offshore oil and gas operations to commence. The Law gives HHRM the right to inspect to check that operations are being undertaken in accordance with RoMHs, CMAPPs, SEMSs and Verification Schemes.

To enforce compliance with the Law, the broad powers of HHRM include (Article 18 of the Law):

- prohibiting the operation or commencement of operations on any installation or any connected infrastructure where the measures proposed in the RoMH are considered insufficient, or where a RoMH or other accepted notification is not in place;
- requiring the operator to take such proportionate measures as considered necessary to ensure all suitable measures are taken to prevent major accidents;
- informing the licensing authority of the inability of an operator to meet the relevant requirements of the Law and hence suggests the replacement of the operator;
- requiring improvements and, if necessary, prohibiting the continued operation of any installation if the requirements of Law are not being fulfilled or there are reasonable safety concerns. Non-compliance with the Law can lead to fines and, potentially, imprisonment.

Decommissioning

Prerequisite for the commence of the decommissioning operations is the submission and acceptance of the material change of the RoMH.

Hydrocarbons Law 2289/1995

Law 2289/1995 ("Hydrocarbons Law"), which has transposed Directive 94/22/EC on the conditions for granting and using authorizations for the prospection, exploration and production of hydrocarbons, constitutes the main applicable legislation governing the development of hydrocarbons in Greece. Hydrocarbons Law was substantially amended by Law 4001/2011 ("Energy Law"), through which new practices were incorporated, aiming to create a more appealing investment climate and to attract serious investments in the oil sector. The rights to prospecting, exploration and production of hydrocarbons that exist in onshore areas, sub-lake and submarine areas upon which the Greek State exercises sovereignty or sovereign rights in accordance with provisions of the United Nations Convention on the Law of the Sea are exclusively vested in the Greek State (Article 2, para. 1 of Hydrocarbons Law). Such rights are exercised by the Hellenic Hydrocarbon Resources Management S.A. ("HHRM"), whereas certain powers are also exercised by the Ministry of Environment, Energy and Climate Change (the "Minister").

Decommissioning

Based on Article 6, para. 7 of Hydrocarbons Law, any equipment and materials from any unusable facilities can be sold by the contractor, subject to a relevant notification to the Hellenic Hydrocarbon Resources Managements S.A. Further to the above, upon completion of the production phase, the contractor must return to the State any blocks used, free of any encumbrances, in clean and environmentally safe condition. Environmental provisions for the decommissioning procedure can be also found in the Environmental Impact Assessment that is granted to every installation prior to the commence of its operation.

Lease Agreements

In Greece, the Lease Agreements of every block are ratified by the Hellenic Parliament and consist *lex specialis* to the general provisions of the Hydrocarbons Law. The Lease Agreement's provisions may differ slightly from one bid round to another, following the negotiation of the contracting Parties, but generally the articles about decommissioning and the protection of the environment remain as set out bellow.

Decommissioning

Upon the expiration of the Exploitation Stage in any Exploitation Area, this Area shall revert, free and clear, to the State. Unless the Lessor states otherwise not later than six months prior to the expiration of the Exploitation Stage the Lessee shall be obliged to:

a) plug all producing wells and known water zones and/or aquifers:
b) remove all installations; and
c) restore the environment in accordance with the proposals set out in the Development and Production Program, the EIS and any further environmental impact study prepared pursuant to Article 12 of the Lease Agreement.

A committee shall be formed for the monitoring and coordination of work to ensure the fulfilment of the Lessee's obligations ("The Committee for the Removal and Disposal of the Installations"). This Committee shall comprise three (3) members. One member shall be appointed by the Lessor, one by the Lessee and the third member, who shall be the chairman of the Committee, shall be appointed by the two already appointed members, jointly. This third member shall be selected from persons who are independent of the Lessor and the Lessee and have experience on matters of Good Oilfield Practices. If the two members fail to appoint the third member of such Committee within thirty (30) calendar days of their appointment, the Lessor or the Lessee shall be entitled to request the selection and the appointment of the third member by the Sole Expert.

The Committee shall examine all technical, legal, environmental and fiscal matters related to the removal of the installations and may, at its discretion, request the assistance of specialists on such subjects. The Committee shall decide in accordance with the opinion of the majority of its members and its decisions shall be binding upon the Lessor and the Lessee. The Committee's decision is subject to the approval of the Minister. The Committee's expenses shall be paid by the Lessee and shall be debited to the Lessee's income and expenditure account.

In order to cover the decommissioning expenses, the Lessee shall, either from (i) the beginning of the sixth year from the Commercial Production Date where Crude Oil is produced; or, (ii) the beginning of the ninth year from the Commercial Production Date where Natural Gas, or Natural Gas and Condensates are produced, open a special dedicated account in a bank or banks legally operating in Greece. During the Exploitation Stage it shall periodically deposit annual amounts into such account and such funds, plus any interest thereon, shall be developed to be the Lessee's special reserve for the fulfilment of its obligations to remove the installations. The procedure and all relevant details for these periodic deposits shall be mutually agreed upon the Commercial Production Date. If no agreement is reached, the matters in issue shall be referred to the Sole Expert for determination as provided in Article 23.2 of the Lease Agreement. The time when the special reserve shall be used as well as the necessary amounts and the time when the Lessee shall deposit them, shall be determined by decision of the Committee for the Removal and Disposal of the Installations. Any funds accumulated in the special reserve, without the relevant interest, shall be debited to the Lessee's income and expenditure account.

The obligations to remove installations may be suspended following the consent of the Minister of Environment and Energy for whatever period of time the existence of such installations is considered necessary for the performance of the Lessee's operations in the Contract Area or in another contract area, in accordance with the provisions and the procedure laid down in paragraph 4 of Article 10 of the Hydrocarbons Law.

Croatia (from Croatian Hydrocarbon Agency)

Currently there are some works in progress on the Croatian legal framework. Then, in this paragraph, it is reported the legal framework active to date even if some updating will be possible later.

Act on the Exploration and Production of Hydrocarbons (OG 52/18 and 52/19) is the main piece of legislation regulating all activities regarding exploration and exploitation of hydrocarbons, including the decommissioning. In this Act the decommissioning is defined as „all works necessary for the relinquishment and rehabilitation of the exploration block or exploitation field, i.e. area no longer required for petroleum operations in accordance with this Act and regulations adopted pursuant to this Act, as well as the international good oilfield practice“. After the completion of petroleum operations, the investor must decommission the exploration block or exploitation field in accordance with this Act, special regulations concerning environmental and nature protection, safety of people and property, protection of human health as well as International good oilfield practice. The Act stipulates the obligation of preparing the Decommissioning Plan as part of various petroleum plans, which need to be done in order to perform petroleum operation and to construct petroleum facilities (i.e. development and production plan for the exploitation field, well drilling project). These decommissioning plans are indeed a part of the petroleum plans for the existing exploitation fields on the Adriatic, however they are focused on the decommissioning of the whole exploitation field, and not on the individual petroleum facilities. For the individual petroleum facilities, the Act stipulates the procedure of removal of petroleum facilities, defined as "*a part of Decommissioning, and means the performance of works to remove a petroleum facility, or a part thereof, from its location, including the management of the existing waste at the petroleum facility, building material and construction waste generated during the removal of the petroleum facility pursuant to the regulations governing waste management and restoring the property or land where the petroleum facility was located to the condition similar to the original, acceptable for nature, the environment, flora and fauna, safety of people and property and human health*". For this removal of petroleum facilities, the Petroleum Facilities Removal Plan has to be prepared, a document defines as "*a plan providing a technical elaboration of solutions, i.e. the procedure and the method of Removal of Petroleum Facilities or the parts therein, prior solution of issues related to disconnection of Petroleum Facilities from the energy grid or other infrastructure, safety measures, waste management, recovery or disposal measures regarding waste generated by the Removal of Petroleum Facilities, in accordance with regulations governing waste management, as well as transportation and disposal of building material generated as a consequence of the Removal of Petroleum Facilities*". This Petroleum Facilities Removal Plan has to be harmonized with the Decommissioning Plan.

To summarize the analysis of these provision, the decommissioning is focused mainly on the whole exploration block or exploitation field, and the part of this decommissioning is the removal of individual petroleum facilities. The Act does not differentiate between land and offshore petroleum facilities. The removal procedure as defined in the Act means that all the petroleum facilities must be removed from the site.

The Environmental Protection Act (OG 80/13, 153/13, 78/15, 12/18, 118/18) uses terms restoration and remediation for "*a set of prescribed measures and/or activities by which the environmental status prior to the occurrence of damage or environmental pollution is established or restored*". Although focused on damage or pollution in the environment, if used in the context of decommissioning, it could be interpreted as a need to restore the site to the original environmental status.

The Maritime Code (OG 181/04, 76/07, 146/08, 61/11, 56/13, 26/15, 17/19) terminology is somewhat different than the one in the Act on the Exploration and Production of Hydrocarbons. It recognizes "stationary offshore objects" and stipulates that they need to adhere to set of conditions regarding safety, pollution prevention and similar. The port authority can decide that these objects should be put in a temporary withdrawal from use, in a mechanism which could be translated as "lay off", which is subject to certain conditions that have to be fulfilled to obtain and maintain this status for the object.

Offshore safety act (OG 78/15) only briefly mentions decommissioning, stipulating that if the decommissioning is to be carried out, the investor must prepare and submit amended and updated report of major hazard, which needs to be accepted by the Competent Authority before any decommissioning activity can start.

The decommission of offshore oil and gas installations is regulated by several pieces of legislation from different competencies. There are some general overarching principles that are common for all of them, however there is no single coordinated process. This is because certain parts of decommissioning are governed by different regulations under different authorities with different competencies. Furthermore, there is no unique and harmonized terminology, which may cause some difficulties in the interpretation. What is clear is that under existing legislation, the only allowed method of decommissioning is total removal of the installation. To enable the re-use of existing exploitation installations, some changes would need to be done in the existing legislation, new legislation allowing such options should be adopted, or both.

Egypt (from IOGP, 2017 Vol.1)

Supported by EGPC, EGAS and Ganope, the Ministry of Petroleum is responsible in regulating all oil and gas activities through Fuel Materials Law No. 66/1953[12] and the Environment Law No.4/1994[13]. While the Egyptian Environmental Affair Authority supervise the compliance of the Environmental Law. Production Sharing Contract (PSC) between Egyptian

[12] Freshfields Bruckhaus Deringer, 2013

[13] http://www.misr.gov.eg/english/laws/

Petroleum Corporation (EGPC), the Egyptian Natural Gas Holding Company (EGAS) or Ganoub El Wadi Petroleum Holding Company (Ganope) and Contractor regulate all petroleum, said contract manages every aspect related to the concession. Egypt is signatory of the Barcelona Convention and decommissioning of facilities in the Mediterranean coast of the country will be governed by it, concerning the Gulf of Suez and the Red Sea coast UNCLOS III and IMO will be applied. To present day there is no specific Decommissioning related regulation, some PCSs set out agreements regarding decommissioning and abandonment issues most likely concerning decommissioning funds and ongoing liabilities. Production from oil fields in the Suarez Gulf is declining while today most gas is produced in the Mediterranean. Not many information if decommissioning has been or not undertaken are available to date.

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