RESEARCH HUB FOR AN INTEGRATED GREEN ENERGY SYSTEM
REUSING SEALINES FOR H₂ STORAGE AND TRANSPORT

Ilaria Antoncecchi¹,²*, Giada Rossi¹, Marzia Bevilacqua¹, Roberto Cianella¹, Giuseppe Vico¹,³, Sergio Ferrero³, Felice Catania³, Marco Pacini⁴, Nicola Mondelli⁴, Marzia Rovere⁵, Marco Bibuli⁵, Diego Vittorini⁶, Davide Di Battista⁶

¹Italian Ministry of Economic Development, Via Molise, 2, 00187, Rome - Italy
³Polytechnic of Turin, Corso Duca degli Abruzzi, 24, 10129 Turin - Italy
⁴Rosetti Marino Group of Companies Via Trieste, 230, 48122 Ravenna - Italy
⁵National Research Council of Italy, ISMAR and INM, Via Piero Gobetti, 101, 40129 Bologna & Via De Marini, 6, 16149 Genoa - Italy
⁶Department of Industrial and Information Engineering and Economics, University of L’Aquila, Via G. Gronchi, 18, 67100 L’Aquila – Italy

Abstract

In this paper, we propose innovative solutions for reusing an inactive offshore gas platform and its associated infrastructures as a scientific research hub, where an integrated energy system and innovative environmental monitoring methods are envisaged. To this end, the Azalea A platform, located in the northern Adriatic Sea, is considered a good pilot site. This study analyzes the engineering solutions on Azalea A for the combined production of solar and wind energy coupled with hydrogen production from seawater electrolysis. It analyzes the potential for storage and transport on land of the produced hydrogen using the sealines connected to the platform. However, this study does not deal with the current structural conditions of the platform (corrosion, stability etc.), which should be evaluated before these solutions are put into practice.

The main outcomes of this work consist in a feasibility study for the reuse of existing infrastructures as a self-sufficient research hub using green energy systems, which include considerations about the measures needed to ensure the protection of the marine environment. Data show a positive feedback about the technical feasibility of the proposal in safety conditions. Furthermore, encouraging outcomes derive also by the economic evaluation that estimates sustainable costs comparing to those implicated with the decommissioning of the infrastructures in the order of tens millions euro. In addition, the proposed reuse seems to be a good opportunity to promote both energy transition toward renewable energy systems and environmental protection, avoiding decommissioning impacts and promoting an innovative monitoring program for the Adriatic Sea.

Key words: blue growth, offshore monitoring, renewable energy, reuse, technology

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1. Introduction

In the framework of the BlueMed Initiative, the SEALINES Start-up Action created a network of Mediterranean partners with the aim of contributing to identify best solutions such as standards, technologies, practices to reduce anthropogenic impacts on the marine environment supporting a healthy, productivity and resilient Mediterranean Sea. The main outcome of the Start-up Action is a proposal for a feasibility study on the conversion of a disused gas platform and its infrastructures into a research hub where a renewable integrated energy system would be tested.

* Author to whom all correspondence should be addressed: e-mail: ilaria.antoncecchi.ext@MiSE.gov.it; Phone: +39 3453232152
In detail the proposal consists in installing and testing offshore plants for the production of renewable energy (solar and wind) in an integrated system that foresees also storage and inland transportation of energy and hydrogen, reusing a hydrocarbon platform that would be decommissioned if not converted.

To this end, the Azalea A platform, located in the northern Adriatic Sea, has been selected because it may be subject to reuse or decommissioned (art. 5 of 15 February 2019 Ministerial Decree, D.M., 2019), as identified in the National Bulletin for hydrocarbon and geothermal resource published by the Italian Ministry of Economic Development (hereinafter MiSE) (Coppi et al., 2019).

This study analyzes the engineering solutions for the combined production of solar and wind energy coupled with a hydrogen production system by seawater electrolysis; it also analyzes the storage and transport on land of the produced hydrogen in the sealines connected to the platform. Since sealines were used for the transport of natural gas they can be reused for the transport of hydrogen (liquid or gaseous) under similar conditions of pressure and temperature. However, before they can be reused in practice, it would be necessary to check the current technical and structural conditions of the infrastructure.

At present, wind and photovoltaic (PV) power are among the most cost-effective renewable technologies, particularly in developed Countries. 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 increasing 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 the 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 offshore infrastructures would simplify the installation process and facilitate the implementation procedures and management operations.

The combined production of solar and wind power, as well as energy storage and transportation, is here suggested to be coupled with hydrogen generation systems from seawater. This addition can enhance the proposal for reuse, since it can mitigate the limits related to volatility and randomness of renewable energies. Hydrogen can be easily produced with high response time exploiting the electrical energy produced on board the platform (Hernández-Gómez et al., 2020) and it can be stored in bottles or in the sealines that will act as energy buffers. Hydrogen transportation to inland would be provided by the same sealines and sold as technical gas for special applications such as food technology, electronics industry or utilized for CO₂ abatement through methanation processes. A layout of the possible integrated energy system is provided in Fig. 1.

A further advantage of the offshore installation is represented by the larger storage capacity augmented by the sealines with respect to onshore plants, whose size, operating conditions and location are expected to meet stringent requirements in terms of safety. The larger storage capacity allows to reach the optimum trade-off, between the direct sale of Hydrogen to customers and its use as a storage medium to re-generate electricity at a time when it is more valuable.

Fig. 1. Layout of the hypothesized integrated energy system.
The idea of converting a no longer productive platform, rather than decommissioning it, is certainly virtuous in terms of benefits from the economic, environmental and social point of view, as a preliminary study revealed (Grandi et al., 2017).

The decommissioning of offshore infrastructures is very sensible and several opportunities have been proposed to reuse them as artificial reef, which is the most explored one (Djokic, 2017), or for loading and unloading Liquefied Natural Gas (LNG) (Camporeale et al., 2017). However, other integrated ways of reusing the offshore infrastructures can be more effective (Rabindran et al., 2011). The possibility to reuse not only the main installation, but also the ancillary facilities (i.e. sealines) is not widely considered in this panorama. In particular, reuse of pipelines is widely studied for CO2 transportation to Carbon Capture and Sequestration sites and Enhanced Oil and Gas Recovery options (Onyebuchi et al., 2018) and it can have good reliability, if regular maintenance and pigging operations are performed (Kaiser, 2020). Thus, the novelty introduced by this paper is the integrated reuse of a platform structure and sealines for energy production, transformation, electricity grid connection and hydrogen transportation or storage, avoiding the high cost of hydrogen pipelines (Gondal, 2019). In this regard, a further degree of innovation is represented by the use of the abandoned sealines not only for gas transportation, but also storage; this solution would enhance the yearly production, by decoupling the energy demand from the renewable energy availability, which is affected by seasonal and daily constraints.

Furthermore, this feasibility study proposes to use the platform as a research hub from which deploying marine environmental monitoring programs in the surroundings of the platform to verify the environmental impact of the activities using innovative technological systems.

2. Description of the pilot case in the northern Adriatic Sea

The general characteristics of the Azalea A platform are briefly described hereafter. Azalea A is a bitubular platform for gas extraction located 16 km off the coastline of the town of Rimini within the 12 nautical mile limit of the territorial waters in 19 meters water depth. Azalea A is 17 meters high above sea level (a.s.l.) and has a rectangular shape 19 x 4 meters; it was installed in 1984 as part of the mining concession A.C8.ME in the Adriatic Sea linked to the Rubicone central on land. Azalea A is connected to the nearby Anemone Cluster platform by two sealines that are no longer in operation. The end points of the sealines are available from the WebGis of MiSE (IMED, 2019) with some preliminary information about the name of the sealines, their geometry and their past use (Error! Reference source not found.-2).

More in detail, the project idea plans to reuse the platform for:

a) renewable power generation from wind and photovoltaic;

b) hydrogen generation from water electrolysis;

c) sealine reuse for hydrogen transport and storage.

2.1. Renewable power energy generation from wind and photovoltaic

To assess the potential renewable resources in the area of the Azalea A platform, mainly literature and public data (RSE, 2017) were used (Table 3).

<table>
<thead>
<tr>
<th>Center</th>
<th>Line name</th>
<th>Start point coord-1</th>
<th>Start point coord-2</th>
<th>End point coord-1</th>
<th>End point coord-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubicone</td>
<td>Azalea 1-2 - Anemone Cluster</td>
<td>44°10'16.229&quot;</td>
<td>12°42’52.329“</td>
<td>44°12’43.694“</td>
<td>12°42'19.862&quot;</td>
</tr>
<tr>
<td>Rubicone</td>
<td>Azalea 1-2 - Anemone Cluster</td>
<td>44°10'16.229&quot;</td>
<td>12°42’52.329“</td>
<td>44°12’43.694“</td>
<td>12°42'19.862&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line name</th>
<th>Type</th>
<th>Fluid</th>
<th>Laying date</th>
<th>Offshore length (m)</th>
<th>Nominal diameter (”)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azalea 1-2 - Anemone Cluster</td>
<td>Rigid</td>
<td>Glycol</td>
<td>1978</td>
<td>4580</td>
<td>3</td>
<td>4.78</td>
</tr>
<tr>
<td>Azalea 1-2 - Anemone Cluster</td>
<td>Rigid</td>
<td>Gas</td>
<td>1978</td>
<td>4580</td>
<td>6</td>
<td>10.97</td>
</tr>
</tbody>
</table>
Table 3. Summary table about the potential renewable resources around Azalea A platform (RSE, 2017)

<table>
<thead>
<tr>
<th>PLATFORM NAME</th>
<th>AZALEA A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emerged part dimensions [m]</td>
<td>19*4</td>
</tr>
<tr>
<td>Height m a.s.l.</td>
<td>17</td>
</tr>
<tr>
<td>Distance from the shoreline [km]</td>
<td>16</td>
</tr>
<tr>
<td>Seabed depth [m]</td>
<td>19</td>
</tr>
</tbody>
</table>

**WIND RESOURCE**

<table>
<thead>
<tr>
<th>Wind Resource Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual mean wind speed at 25 m a.s.l. [m/s]</td>
<td>3.8</td>
</tr>
<tr>
<td>Specific annual energy production at 25 m a.s.l. [MWh/MW]</td>
<td>632</td>
</tr>
<tr>
<td>Annual mean wind speed at 50 m a.s.l. [m/s]</td>
<td>4.1</td>
</tr>
<tr>
<td>Specific annual energy production at 50 m a.s.l. [MWh/MW]</td>
<td>891</td>
</tr>
<tr>
<td>Annual mean wind speed at 75 m a.s.l. [m/s]</td>
<td>4.3</td>
</tr>
<tr>
<td>Specific annual energy production at 75 m a.s.l. [MWh/MW]</td>
<td>992</td>
</tr>
<tr>
<td>Annual mean wind speed at 100 m a.s.l. [m/s]</td>
<td>4.4</td>
</tr>
<tr>
<td>Specific annual energy production at 100 m a.s.l. [MWh/MW]</td>
<td>1083</td>
</tr>
</tbody>
</table>

**SOLAR RESOURCE**

<table>
<thead>
<tr>
<th>Solar Resource Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal tilt angle of PV plant [°]</td>
<td>34</td>
</tr>
<tr>
<td>Incident solar radiation on the horizontal plane [kWh/m²]</td>
<td>1463</td>
</tr>
<tr>
<td>Incident solar radiation on the plane with optimal tilt angle [kWh/m²]</td>
<td>1681</td>
</tr>
</tbody>
</table>

**MARINE RESOURCE**

<table>
<thead>
<tr>
<th>Resource Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual mean power available from waves[kW/m/year]</td>
<td>2.8</td>
</tr>
<tr>
<td>Marine current power flow [W/m²]</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Summarizing the data of Table 3, marine renewable energy is not considered in this study, since it has very low potential in the northern Adriatic Sea. On the other hand, more interesting are solar and wind energy availability.

Considering the Wind Atlas (RSE, 2020), the average wind speed at altitudes of 75 meters above sea level is about 4.3 m/s with a specific production approximatively equal to 992 MWh/MW (Table 3). For the purpose of this study, an available loading capacity of the deck of the platform of 300 kg/m² (about 60% of the design condition) and 10-ton maximum load are assumed. According to this design and considering the technical data of the infrastructure, one wind turbine of 100 kW nominal power could be installed, with a turbine nacelle height of 75 meters above the sea level. Estimated electric energy production from this system is about 99,200 kWh/year. No turbulence and wake effects, resulting from possible interactions between contiguous turbines in case of a wind turbine field, need to be considered.

On the other hand, as previously observed, the PV technology is a mature renewable energy source, whose economic feasibility strongly depends on scale benefits and, ultimately, on space constraints. Moving solar cells to the space-abundant marine environment 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 for the low energy density of the PV technology.

Assuming an available space on the Azalea A platform to allocate solar panels of about 100 m² and an incident solar radiation on the plane with optimal tilt angle of about 1680 kWh/year/m² (at the northern Adriatic latitudes), it would be possible to install 60 modules of 330 Wp and 1.6 m² each.

Considering these data, the total electrical energy production estimated for PV modules on the Azalea A platform is about 33,600 kWh/year, having considered a conversion efficiency equal to 0.2 for monocrystalline silicon modules (RSE, 2017). Hence, the final energy producible is equal to 132,800 kWh/y.

One issue related to the reuse of the platform for power production is the energy transport. The submarine power transmission technology already represents an effective and mature solution for bulk electric power transmission across large distances encompassing wide and deep-water bodies and exhibits characteristic values of operating reliability in the range of decades. The sector extensively relies on the experience for laying cables on the seafloor for telecommunication purposes. Reusing existing facilities permits to locate the power lines along the sealines, avoiding the operations of shoring approach. The electrical connection can be made to medium-high voltage grids, reducing the electric cable section and making easier its transportation.

### 2.2. Hydrogen generation

The solution for future energy production is often cited to be a hydrogen economy (Romm, 2004), and according to Sangster (2014) in the post fossil fuel age a clean hydrogen would have to be separated from water by electrolysis. For this reason, the hydrogen generation is considered in this feasibility study as the prime solution to transport energy by reusing sealines. Hydrogen could be generated in a volume compatible...
Research hub for an integrated green energy system reusing sealines for H₂ storage and transport

with the energy that is supposed to be produced using the above-mentioned values for wind and photovoltaic sources. An innovative energy conversion and storage solution using electrolysis that integrates renewable sources of generation, converts electricity to produce hydrogen and leverages the attributes of the existing natural gas infrastructure. Proton Exchange Membranes (PEM) may couple wide range of load, fast response to transient conditions and H₂ production.

Membranes (PEM) may couple wide range of load, natural gas infrastructure. Proton Exchange membranes (PEM) may couple wide range of load, fast response to transient conditions and H₂ production. The whole amount of electric power produced by photovoltaic and/or wind turbine systems is planned to be used to feed the PEM electrolyzer in order to produce H₂. The electrolyzer energy consumption can be estimated in 4.8 kWh/Nm³H₂ (considering 200 bar as operating pressure, (Scheepers et al., 2020) and about 1 liter of demineralized water is required. Assuming the available electric power as produced by the above systems approximately equal to 132,800 kWh/year, it is possible to generate about 27,700 Nm³/year of H₂.

2.3. Sealines as lines for hydrogen transport and storage

The Azalea A platform is connected to the adjoining one (Anemone) through two sealines. The first one (Sealine 1) was used to transport natural gas extracted in the platform and has an inner diameter of 150 mm. The second one is smaller (75 mm diameter) and was used to carry glycol for technical utilities (Sealine 2). Both sealines are 4580 m long and are made of steel. The geometry of the existing sealines (diameter and length) allow to evaluate the flow rate of the gas that can flow in the duct, which depends on the thermodynamic condition of the gas (i.e. density, pressure and temperature). Since the current sealine was used to transport natural gas (methane), it can be used to transport hydrogen in the same ranges of pressure and temperature.

The preliminary assessment of the maximum gas pressure inside the pipe is key to evaluate the potential of the existing sealine for transport and storage. In line with the common practice in pipeline design, the maximum shear stress criterion is selected for calculating the mechanical stress to which the pipe undergoes. Indeed, the boundary conditions for the system are: (i) the storage pressure of the gas inside the pipe, (ii) the seawater hydrostatic pressure and (iii) the seawater temperature. The seawater pressure and temperature range around 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 achieved in the pipeline.

The current thicknesses of the sealines assure a maximum allowable pressure of about 33 MPa for Sealine 1 and 29 MPa for Sealine 2, according to ASME Boiler & Pressure Vessel Code, section B31.1 (Meyer et al., 2020). These pressure limits 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, fatigue and corrosion conditions.

In the following figures, the calculation of possible flow rates of hydrogen has been performed, and associated pressure drop. Pressure drops (Δp, Pa) have been evaluated varying the inner gas velocity (v_gas, m/s) up to 4 m/s and the gas transport pressure up to the maximum allowable one. In this way, it is possible to calculate the density of the gas and, thus the pressure drop according to Eq. (1), knowing the tube diameter (D, m) and length (l, m), and fluid density (ρ, kg/m³):

$$\Delta p = f \cdot \frac{l}{D} \cdot \frac{\rho \cdot v_{\text{gas}}^2}{2}$$

(1)

The friction factor (f, -) is calculated considering the laminar-turbulent flow transition. In particular, for laminar flow it depends only on non-dimensional Reynold Number (Re, Eq. 2):

$$f = \frac{64}{\text{Re}}$$

(2)

While for turbulent flow, the relative roughness (ε, m) is introduced (D is the inner diameter) (Eq. 3):

$$f = \frac{1}{\left[-1.8 \cdot \log \left( \frac{6.9 \cdot \left( \frac{\epsilon}{D} \right)^{0.11} \text{Re}^{-0.12}}{3.7} \right) \right]^2}$$

(3)

Sealine 1 can easily allow a flow rate of about 250 m³/h with a maximum pressure loss along the line of approximately 0.9 bar. Negotiable pressure drops are accounted for the case where the transport pressure is 50 bar, equal to the hydrogen production pressure. Higher pressure drops and lower flow rate are obviously experienced for the smaller inner diameter Sealine 2. Thanks to the evaluation of the pressure drops, the hydraulic power needed to move the fluid can be calculated and it is shown in Fig. 2. It is demonstrated that a compressor of about 6 kW and 3 kW (Sealine 1 and Sealine 2, respectively) can be used if the maximum allowable pressure is used for H₂ 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 obtained with common commercial machines. In case the transport would be 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 LNG sectors and the thermal field across the layers calculated by a mathematical model of the duct (Cipollone et al., 2013), aimed to verify the inner temperature of the gas in worst external conditions of the sea (low temperature and high convective heat transfer conditions). 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 natural gas; the density of hydrogen is nine times smaller than that of natural gas. Hence, a flow rate of hydrogen three times larger than that of natural gas results in approximately the same pressure drop. Besides energetic considerations, also several material issues require some attention: e.g., the use of the existing compression and pressure-reduction devices, 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 natural gas to hydrogen, calling for a proper preliminary analysis of actual volumetric losses under normal operation, at different flow rates. The incidence of leakage and diffusion through the material of the pipeline is a further element that drives assessment of actual feasibility of the re-conversion of existing pipelines: cast iron and fibrous cement pipelines are particularly inclined to leakage phenomena, whilst polyethylene present large risk of diffusion of hydrogen.

As far as the compression devices 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 natural gas and in order to obtain the same pressure ratio, the rotational speed must be increased with respect to the natural gas case. A very interesting opportunity is represented by the use of the existing sealline as a storage volume of hydrogen. In fact, the sealline can be closed at one end, in order to create a bounded volume that can be used as 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. For a pipe compliant with the API SPEC 5L standard, with a 150 mm inner diameter and length of 4580 m (Sealline 1), the volume of the sealline is about 80 m$^3$.

The common practice suggests lowering the yield strength through a proper coefficient of safety, resulting in a 240 MPa admissible tension of the used steel. In order to meet such a specification, the maximum storage pressure of the hydrogen turns out to be 330 bar. Table 4 reports some scenarios in terms of storage pressures, densities and mass of hydrogen. It suggests that:

- at 3 bar pressure, the hydrogen density is 0.25 kg/m$^3$ (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 13 bar pressure, the hydrogen is beyond its critical state. The density tops 1.1 kg/m$^3$ and 88 kg hydrogen can be stored, before the pipeline capacity is saturated;
- the upper limit pressure (330 bar) corresponds to a 23 kg/m$^3$ density and 1852 kg hydrogen stored.
The same analysis can be performed, accounting for the Sealine 2: in this case the volume is reduced and the storable hydrogen too. At maximum allowable pressure considered (290 bar) the mass storable is 416 kg.

3. Environmental challenge and monitoring solutions

The northern Adriatic is an area of intense maritime activities and overlapping uses of the sea (Barbanti et al., 2015), such as productive hydrocarbons platforms, borrowing areas for beach replenishment, military zones, aquaculture farms, fishing grounds. More recently, the installation of an offshore wind farm in the same area of Azalea A was under the scope of a feasibility study (Schweizer et al., 2016). The northern Adriatic represents a hot spot of Mediterranean biodiversity and is particularly important for the endemism of Mediterranean fish species of high commercial value, which have here their breeding and nursery areas (Giannoulaki et al., 2013).

Among marine mammals and endangered species, the loggerhead turtle (*Caretta caretta*) is an endemic species of the northern Adriatic Sea as well as the common bottlenose dolphin (*Tursiops truncates*). 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, on top of fishing vessels, yachts, recreational boats and military vessels. Such large maritime shipping produces a number of negative effects on the marine environment (ballast waters, pollution and oil spill, collision, noise and habitat degradation) that require to be monitored.

Furthermore, the area is interested by historical seismicity; in 1916, a long seismic sequence (moment magnitude Mw = 6.0) caused intensity VIII damage in Rimini and neighboring towns with epicenter location offshore, which falls in the area of Azalea A (Rovida et al., 2011; Fig. 3). Some studies suggest that blind deep-buried Apenninic thrusts drive the growth of coastal anticlines, that may prove seismogenic (Vannoli et al., 2004; DISS Working Group, 2018). Notwithstanding, no significant tectonic deformation or dislocation is visible at the seabed around the study area (e.g. Fig. 4) and no significant tectonic implications have to be considered. In 1672, a tsunami hit the city of Rimini (Tinti et al., 2004), which is also frequently impacted by surges and floods, due to high waves with a lot of energy that are generated when strong winds blow over a long fetch, as in the case of the south-easterly Scirocco wind in the Adriatic Sea.

Considering the environmental characteristics and overlapping maritime uses of the study area, monitoring the marine environment and geo-hazard near the platform Azalea A plays an important role during both the decommissioning and reuse phases. Traditional monitoring systems are based on on-site sampling, transport of the samples onshore and laboratory analysis.

<table>
<thead>
<tr>
<th>$H_2$ pressure (bar)</th>
<th>3</th>
<th>7</th>
<th>13</th>
<th>20</th>
<th>100</th>
<th>200</th>
<th>290</th>
<th>330</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_2$ density (kg/m³)</td>
<td>0.3</td>
<td>0.6</td>
<td>1.1</td>
<td>1.7</td>
<td>7.9</td>
<td>14.9</td>
<td>20.6</td>
<td>22.9</td>
</tr>
<tr>
<td>$H_2$ mass storage (kg)</td>
<td>Sealines1</td>
<td>20</td>
<td>47</td>
<td>88</td>
<td>135</td>
<td>642</td>
<td>1209</td>
<td>1664</td>
</tr>
<tr>
<td></td>
<td>Sealines2</td>
<td>5</td>
<td>12</td>
<td>22</td>
<td>34</td>
<td>160</td>
<td>302</td>
<td>416</td>
</tr>
</tbody>
</table>

**Table 4.** Hydrogen storable in sealines.

![Fig. 3. Bathymetric contour map showing the location of the Azalea A platform in respect to the city of Rimini, the deep-buried Apenninic thrusts and 2 single channel seismic reflection profiles (CHIRP) and displayed as an example in Fig. 4](image-url)
This chain has numerous disadvantages, among which the low frequency of sampling campaigns, the implicated high costs related to mobilization and demobilization of the equipment, the slow response in case of polluting accidents or other environmental hazards, such as storms and earthquakes.

The reconversion of the platform Azalea A into a research hub, which will be reaching the self-sufficiency in terms of renewable energy production, would enable the rapid deployment of innovative technologies for efficient monitoring programs by applying methodologies shared between industry and academia. One technology, which is envisaged by this study, consists of the UPH2O chemical sensor installed on board an autonomous underwater vehicle (AUV), capable of performing in-situ chemical analysis on small samples of water for the detection of anomalies in the concentration of heavy metals and integrated by a real-time warning system. The UPH2O sensor provides the opportunity of water sampling with daily or sub-daily frequency, by activating a remotely controlled procedure based on the detected concentration of contaminants. The UPH2O integrated system offers also the opportunity to prepare samples that are ready for the quantitative analysis to be carried in the laboratories hosted by the research hub. This sensor uses Lab-On a-Chip microfluidic technologies for fluid and flow management in situ analysis of the water samples. Another monitoring technology, assess by this study, consists of the remotely operated vehicle (ROV) e-URoPe (e-Underwater Robotic Pet) equipped with geophysical and geochemical sensors, which would enable high resolution and space and time repeatability of the underwater measurements, including the fast detection of dissolved substances that are diagnostic of leakage from the decommissioned infrastructure or hydrocarbon reservoir depletion. The integration on board the vehicle of the calculation and visualization software and the use of adaptive procedures during the monitoring campaign will allow high speed of acquisition and real-time planning of the sampling stations. The monitoring program implemented by the ROV would allow the acoustic reconstruction of both the underwater environment and maintenance status of the decommissioned infrastructure, including the sealines, using multibeam sonar technology. The expected advantages for these technological applications consist in multifold benefits. They include the long-term monitoring; the scalable solution with multiple additional chemical and geophysical parameters that could be simultaneously detected; the higher sampling/analysis frequency; the possibility to operate in harsh weather conditions without human intervention; the wider spatial range of monitoring around the platform and the low operational costs and overall favorable benefit/cost ratio.

4. Result and discussions

The preliminary results of the study pointed out an alternative to decommissioning operations, supporting an energy transition phase and promoting the use of new fuels like hydrogen. The study provided a technical evaluation of the feasibility to reuse an offshore hydrocarbon platform and its sealines for renewable power generation and transport in safety conditions. The technical study highlighted that for an estimated energy generation of 132,800 kWh/year by solar and wind, it is possible to convert 27,700 Nm³/year of H2 of hydrogen in safe conditions.
Furthermore, the economic analysis conducted on the real case study of the Azalea A platform in the northern Adriatic Sea shows positive feedback on the costs implicated to convert the platform into a research hub self-sufficient in terms of energy production with a green energy system. The investment costs of the equipment for solar and wind energy production are 0.4 million of euro; the cost of hydrogen conversion comprises the electrolyzed for about 0.3 million euro and auxiliaries’ costs for about 0.1 million of euro. Therefore, the total investment cost amounts to about 0.8 million euro. On the other hand, if H₂ is stored in bottles for a total capacity/pressure of 19.2 m³/200 bar, and considering storage and auxiliary’s investment costs for about 0.9 million euro, the total investment cost rises to 1.3 million euro. In case of the H₂ is stored in the existing sealines, as in the case of Azalea A, the total cost is estimated about 0.9 million of euro. Therefore, the latter option seems to be a better choice both from the technical and economical point of view.

Other relevant results regard the benefits that would derive from the implementation of innovative, effective and low-cost environmental and infrastructures monitoring programs. The costs benefit attached to this innovation are invaluable because they likely avoid the cost implicated with the development and employment of expensive early warning and real-time systems controlled from remote locations, such as leak detection based on monitoring stations and advanced processing. Overall, the overarching benefit derives from the enhanced monitoring and protection of the marine environment based on knowledge transfer and technology sharing between the academia and the oil and gas industry.

5. Conclusions

This study proposes an innovative approach to test a possible reuse of an oil and gas platform as a self-sufficient scientific research hub to integrate and test a renewable energies offshore system. The innovative idea is to reuse not only the main structure, but also the ancillary facilities (i.e. the sealines), an option that is not frequently considered in this panorama. In this regard, a further degree of novelty is represented by the use of the abandoned sealines not only for gas transportation, but also as storage volume for the gas produced on the platform: this enhances the yearly productivity, decoupling the energy demand from the renewable energy availability, which is affected by unpredictability during day and year.

For this study, the Azalea A gas platform, which is located at shallow water depths in the northern Adriatic Sea and has come to the end of its lifecycle, represents an optimal pilot site. The potential for marine renewable energy production in the Adriatic Sea is not sufficient for an industrial-scale economic investment, however the reuse of the existing offshore infrastructure for testing new technological solutions for power generation that support monitoring of the marine environment proved to be a good opportunity for knowledge and technological transfer. This study shows that the proposal to convert an offshore hydrocarbon platform into a marine research hub, with additional storage and transport of H₂, is technically feasible in safety conditions (considering the safety threshold defined by API standard) and supports both energy transition from fossil sources to renewable energies and marine protection. Furthermore, the results of the study indicate that proposal is workable also from the point of view of the cost analysis that estimates a total investment of about 0.9 Million euro, if the existing sealines are reused for energy transportation and storage. Therefore, despite a low investment with the engineering solutions provided by this study, the proposal supports both energy transition and environmental protection; first, avoiding the impacts of decommissioning operations and secondly, promoting an innovative approach in the monitoring of the marine environment around the offshore platforms.

The proposed study demonstrates the technical and economic feasibility of the integration of the existing offshore infrastructures with the new hybrid power generation systems, highlighting a positive and concrete example of “Blue Economy”.

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