Definition of a Basic Design for Conversion of an Offshore Fixed Platform on a Depleted Reservoir Into a Sustainable Plant

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ABSTRACT

In the framework of energy transition, a focus is given to the study of the conversion of offshore Oil&Gas platforms at the end of their life due to the depletion of the reservoirs on which they operate. Their modular and versatile structure allows the implementation of new processes and innovative sustainable technologies for reducing the environmental impact of a complete decommissioning, especially on the subsea ecosystem that has grown around the jacket, and for guaranteeing cost-saving solutions.

Among different conversion options, this paper focuses on the installation on the platform of a system for the production of photovoltaic (PV) energy to be used for seawater desalination and its delivery to other platforms operating in the same area. The project focuses on the definition of technical characteristics of the basic design, on the investigation of the technical feasibility of the conversion process, on qualitative safety and environmental impact studies.

Moreover, the old platform equipment to be decommissioned (i.e. the equipment necessary for hydrocarbons treatment) are identified and the installation of new equipment is optimized, e.g. the number of PV panels and, therefore, the installed power are maximized. At the same time, decommissioning costs and impacts can be minimized.

The basic design is completed with a preliminary structural verification to guarantee that critical situations do not rise, with an indication on the main maintenance activities for the preservation of plant good efficiency and with safety and environmental preliminary analyses for the identification of potential criticalities to be managed at different design levels.

INTRODUCTION

A large number of offshore platforms for Oil&Gas (O&G) production are approaching or have already reached the end of their productive life, mainly due to the depletion of the reservoirs they are installed over. The complete decommissioning of these structures is expensive: in fact, it is estimated that its cost worldwide will be around

40,6 billions of US dollars by the 2040 [1]. Moreover, decommissioning involves major hazards and can result not sustainable from an environmental point of view, because marine ecosystems often develop in the surroundings of the platforms steel lattice structures, the jackets. This is favored by several factors: jackets are usually built with corrosion resistant materials (e.g. galvanized metals); the infrastructure dimensions allow the growth of the marine life with many different species and the articulated structures represent the ideal environment for the reproduction [2]. In the US, complex marine habitats developed around the submerged sections of the offshore platforms, using the jacket as artificial reef. Many biotic reefs have been created from O&G installations in US Gulf of Mexico, Brunei, and Malaysia. In particular, the Rigs to Reefs (RtR) practice, i.e. the conversion of the platforms at the end of their life into artificial reefs with only a partial removal of the structures, has been applied in approximately 11% of decommissioned platforms in the US Gulf of Mexico [3]. As another example, an entire supply chain of wild mussels was born in the offshore area of Ravenna (Italy) resulting in a production of one million kilograms per year of mussels from Marina di Ravenna that is released for consumption after the biological and environmental controls of the competent authorities [2].

Another option besides the RtR, is the reuse of offshore facilities for scientific, environmental monitoring and/or for other purposes in the framework of the energy transition, e.g. renewable energy offshore plants. In this case, unprofitable or decommissioned assets can have a new life in a sustainable, low-carbon future, stimulating the search for innovative solutions, with the aim of reusing waste materials for other purposes and contemporarily minimizing the consumption of energy and other resources [4].

Decommissioning is a phase that requires a careful preparation according to the existing standards and codes of practice and the option of re-using the structure is often seen as the primary solution to be assessed. This is the position, for example, supported by the UK Government as reported in the “Guidance Notes” on “Decommissioning of Offshore Oil and Gas Installations and Pipelines under the Petroleum Act 1998”. This option, even in less recent times, has always been considered, for example by the United Nations Convention on the Law of the Sea (UNCLOS III) which included the possibility of only partially removing the offshore infrastructures. However, decommissioning activities, even in the case of adaptation of the infrastructure to a new task, involves hazardous operations that, according to the existing regulations, such as Directive 2013/30/EU, must be identified and assessed according to a well-defined risk analysis reporting scheme. As the number of ageing offshore infrastructures increases, the regulatory framework that defines the boundaries of a safe and fruitful conversion of platforms must be updated to include the variety of options investigated by operators and researchers throughout the world.

After transposing Directive 2013/30/EU in a national Decree, the Italian Ministry of Economic Development (MiSE) started to pave the path for ageing Italian infrastructures towards their final destination, being it either a completed removal or a re-use/conversion project (Ministerial Decree 15 February 2019 [5]). The Ministry initiative was pushed by the fact that the Italian offshore panorama is constituted by 138 platforms and, according to the data published, only 7 were built after 2010, suggesting that the number of structures at the end of their productive life will increase in the short/medium term [6].

To deepen knowledge about the possible options in sustainable decommissioning, MiSE further financially supported a series of research projects aimed at comparing some of the most suitable site-dependent alternatives. The preliminary list of alternatives to be investigated is the following:

- Option 1 - Conversion of the platform for the production of photovoltaic (PV) energy to be used for the desalination of sea water and fresh water delivery to other platforms operating in the same area;
- Option 2 - Conversion of the platform for the injection and extraction of a CH_4-H_2 mixture for underground storage in the depleted reservoir for temporary storage in the optics of a strategic energy supply;
- Option 3 - Conversion of the platform for the injection and extraction of CO_2 captured from the atmosphere for underground storage in the depleted reservoir for temporary storage to stabilize the atmospheric concentration of greenhouse gases from any anthropogenic emissions.

For each option, the research focuses on the definition of technical characteristics of the project, on the investigation of the technical feasibility of the conversion process, on data collection supporting the environmental impact study, on the validation of the basic design with reference to safety and reliability issues.

Such a detailed assessment allows the involved parties to check if the existing regulatory and technological framework is ready for the implementation of the new offshore paradigm. Besides, it forces to clarify since the early stages of the process which design philosophy and educated assumptions can be made to propose a sustainable alternative life to these infrastructures.

The present paper presents this philosophy, the technological choices and the safety and environmental considerations related to the project of converting a natural gas extraction platform into a desalinated water production plant supplied with solar energy (Option 1). The general choices and framework are strengthened by the application to a case study on a realistic infrastructure.

The second section of the paper is dedicated to the description of the design philosophy and of the applied methodology; the third section briefly describes the case study, including the platform description and site identification, the block diagram, the description of the converted system, the civil activities to be performed during decommissioning of old equipment and installation of new equipment, the major results of the Safety and environmental analysis. In the end, some conclusions are reported.

METHODOLOGY

Design philosophy

The aim of the project (of the three options, indeed) is to guarantee that the operational and environmental sustainability of the converted platforms are maintained throughout their new lifecycle. For Option 1, the pillars of the design philosophy were:

- The conversion prevents damages to the marine biota which would be expected in case of complete decommissioning;
- There is a utility in the new destination of the platform represented by potable water, otherwise supplied in less sustainable way, such as via fossil-based vessels;
- The complete operation is achievable by exploiting exclusively renewable energy sources, namely solar energy.

Further design choices were made to limit the impact on the structures:

- As far as possible, the conversion is conceived to reduce to a minimum any intervention on the jacket structure;
- Existing equipment will be removed in case their dimensions are limited, or in case their removal is essential for leaving space to new devices; otherwise, large equipment that are non-obstructive for the new operations are left in place after the necessary remediation;
- As a basis for design, it is assumed that the existing structures have been correctly maintained until the time of conversion. The design will take care only of the balanced positioning of the new loads and of their being within the limits so that no additional bending stresses are added on cantilever structures;
- To limit subsea impacts and costs, interventions on existing cables, umbilicals and pipelines are kept to a minimum.

As for the operation of the new platform, this is kept unmanned with periodic maintenance inspections and restoring guaranteed as in the previous period. Due to the new type of operation, restoring can be more limited in volumes and iterations.

Desalinated water is conveyed to the neighboring platforms via pipelines, but backup vessels can still be foreseen.

The general approach to safety and environmental protection during the project is dictated by the existing applicable laws; nevertheless, whenever practicable, more restrictive decisions are taken to guarantee the sustainability of the solution as this is the central theme and the reason for the development of the project.

Project flow

The project of adapting an O&G platform to the new use, namely the production of desalinated water, is made of a series of steps that are described hereafter.

1. *Selection of a real case study for the implementation of the methodology*: a "typical" platform, called GREEN1 for the purposes of the project, has to be chosen. The idea is to develop a project over a platform that is realistic and representative of the average of the Italian platforms under assessment for decommissioning. Besides, as the greater scope of the project of the Ministry is to investigate other two options, the choice of the platform is made so that it can be suitable also for the other two kinds of conversion solutions. Notably, Option 2 an Option 3 have very different requirements with respect to Option 1. As such, the case study has to be selected considering the following factors: the area of the weather deck (fundamental for the Option 1), the presence of wellheads and the typology of extracted hydrocarbon (for the realization of Option 2 and 3) and the number of decks (important for the layout definition of the three options). In the end, the geographical position of the platform is identified in order to be as representative as possible of future Italian offshore decommissioning panorama.

2. *Preliminary block diagram of the analyzed system*: the components necessary for the realization of the selected option are preliminarily identified as well as the connection among them; at the end of this step a block diagram is realized as a starting point for successive phases.

3. *Definition of the design criteria guiding the choice of the components composing the system*: the design criteria are the goals to be achieved for a project to be considered successful and aim at guiding the detailed definition of the components identified in the previous steps. At the beginning, the main purpose of the plant is identified (e.g. the flowrate to be produced by the desalination unit); then, other system objectives are defined, e.g. to maximize the plant availability and the component integrity, to minimize the environmental impact and the safety issues; at the end of this phase, the general criteria are specified into component specific criteria in order to define for each piece of equipment the target characteristics (e.g. the power absorbed by a pump), the redundancies (e.g. pumps and filters in the seawater intake line helpful to satisfy the required function without excessively challenging the system availability), the control logics (e.g. level transmitters on the atmospheric tanks), the safety/protection logics (e.g. in case of release of hazardous substances); the location on the platform (e.g. the platform deck on which each equipment is located). The outputs of this step are technical documents of the plant, in particular the process flow diagrams, a graphical representation of the main components and the process flows, including the connections

among the systems, the instrumentation, by-pass and recirculation lines, operational data (e.g. temperature, pressure, etc.); the platform layout, a representation of each platform deck with the components that are supposed to be installed on it, including the information of the dimensions of each component; the Cause & Effects matrix, which objective is to summarize the inputs/outputs of the safety/protection logics; the equipment list, a document summarizing all the new components to be installed on board including weights and dimensions; a technical report describing the detail of each component.

4. *Definition of the decommissioning strategy and preliminary structural verification*: to install the new equipment on-board, the previous ones have to be treated. For each component of the original platform layout, one out of three possibilities is selected: the component is re-used in the new platform configuration; the component is left on the platform since its removal is too economically and/or environmentally expensive; the component is dismantled and disposed. In the last case, the materials will be recovered/recycled, if feasible. Since one of the project objectives is to minimize the environmental effects of all the life cycle phases of the conversion activities, including the decommissioning of the previous equipment, it is worth to note that preliminary securing and cleaning activities are foreseeing in order to avoid any kind of pollution during the subsequent phases, e.g. the use of ROVs (Remote Operated Vehicles) for submerged structures; depressurization, emptying and inertization of equipment and piping; planned inspections to check the state of the superstructure and the eventual presence of

remaining hazardous substances before starting the decommissioning operations (e.g. cutting operations). After the dismantling of the unnecessary components, the new ones have to be installed: a comparative analysis of the mechanical solicitation of the structures is proposed at this level of the design. The weight of the components to be removed (full of fluids) is compared to the weight of the component to be installed (full of fluids) in order to have a preliminary indication about the project feasibility from a mechanical point of view. A detailed mechanical analysis has to be performed in the successive and more detailed design phase.

5. *Safety Assessment*: The safety analysis aims at identifying the risks associated to process deviations, the presence of workers in the workplace and external events during the operation of the installation considering the effect on people (on-board workers and final users), environment and asset (the damage of the components, the loss of economical incomes because of production interruption, etc.). After the definition of the analysis battery limits and the operational modes to be considered, the first step is the qualitative identification of the hazards, using the HAZID (HAZard IDentification) methodology [7] particularly suitable in the preliminary stages of the design. It is a structured brainstorming of the credible hazards using a comprehensive set of guidewords: for each hazard, specific cause(s) and the associated consequences are qualitatively described, as well as the existing safeguards (preventive and/or mitigating). The risk of each scenario associated to the hazardous event is evaluated using qualitative indices to estimate the severity and the probability of the accidental event and a properly

calibrated risk matrix (see Table 1, Table 2 and Table 3). The risk matrix allows for the risks categorization, and is useful for concentrating intervention actions on the riskiest activities or processes. It can be used as a criterion of risk acceptability, and therefore to identify acceptable or unacceptable events, or those that require more refined assessments. In general, 3 risk categories are defined:

- Risks considered *"acceptable"* (green area in Table 3) refer to events characterized by a low probability of occurrence and whose consequences are slight;
- The risks considered "*unacceptable*" (red area in Table 3) refer to events for which immediate attention must be paid and which require the cessation of the activity, until risk reduction measures have been implemented;
- Between acceptable and unacceptable risks, it is possible to identify an intermediate area (yellow area in Table 3) known as "*ALARP*" (As Low as Reasonably Practicable) [7], i.e. events for which the risk must be reduced, with appropriate time planning, up to the point when a further risk reduction intervention does not create a high disproportion between costs and benefits.

In the event that relevant safety aspects emerge from the qualitative analysis, a quantitative evaluation is required in order to obtain more accurate estimations of the expected occurrence frequencies and of the consequences of potential accident scenarios and to assess if the associated risk can be considered acceptable or have to be managed.

Table 1: Qualitative indices adopted for estimating the effects of the accidental event on the various targets considered (People, Assent and Environment)

Damage	
Index	**Description**
1	*Damage on people*: Minor injury, first aid is sufficient

	Damage on the asset: Negligible monetary loss *Damage on the environment*: Negligible amount of contaminant released into the environment
2	*Damage on people*: Light injury requiring up to 3 days of inability to work *Damage on the asset*: Monetary damage on components ≤5,000 € *Damage on the environment*: Amount of contaminant released into the environment, which requires <1 year to restore environmental conditions or with minor effect (<1 km^2)
3	*Damage on people*: Serious injury requiring a period of inability to work greater than 3 days *Damage on the asset*: Monetary damage on components € 5,000 <damage <€ 50,000 *Damage on the environment*: Amount of contaminant released into the environment, which requires 1-2 years to restore environmental conditions or with local effect (<10 km^2)
4	*Damage on people*: Injury causing permanent damage or a single death *Damage on the asset*: Monetary damage on components € 50,000 <damage <€ 500,000 *Damage on the environment*: Amount of contaminant released into the environment, which requires 2-5 years to restore environmental conditions or with extended effect (<100 km^2)
5	*Damage on people*: Multiple fatalities *Damage on the asset*: Monetary damage to components ≥ € 500,000 *Damage on the environment*: Amount of contaminant released into the environment with consequent long-term environmental damage (> 5 years)

Table 2: Qualitative indices adopted for estimating the probability of occurrence of the accidental event

Probability	
Index	**Description**
A	Unexpected event during the life of the system
B	Event expected at most once during the life of the system
C	Event expected more than once in the life of the system and less than once every 5 years
D	Event expected more than once every 5 years and less than once a year
E	Event expected more than once a year

Table 3: Risk matrix

Consequence				**Probability**				
	People	**Asset**	**Environment**	**A**	**B**	**C**	**D**	**E**

Level of severity				Rare occurrence	Improbable occurrence	Credible occurrence	Probable occurrence	Frequent occurrence
1	Minor injury	Negligible damage	Negligible impact					
2	Light injury	Minor damage	Minor impact					
3	Serious injury	Light damage	Light impact					
4	Single fatality	Local damage	Local impact					
5	Multiple fatalities	Serious damage	Serious impact					

6. *Environmental impact evaluation*: The environmental analysis [8] aims at identifying those activities that may cause a relevant impact on the surrounding environment during normal operation for the entire system lifecycle. The main idea is to drive the design, the technological choices and the management strategies for minimizing the anthropogenic effects. The considered impacts are: gaseous emissions in atmosphere, liquid releases into the sea, waste production, noise or vibrations generation, heat generation, light pollution, energy and resources consumption. For each impact, the contributing activities are qualitatively analyzed using a points system (1 point corresponds to a negligible effect, 2 points correspond to a medium effect, 3 points correspond to a relevant effect) according to the criteria reported in Table 4. The summation of the points associated to all the criteria gives the total score for the considered activity. This total score can vary from a minimum of 5 to a maximum of 15: the environmental impact is evaluated according to the criteria reported in Table 5:

- Environmental aspects with a *negligible impact* fall within the acceptability area and do not require a continuous monitoring or additional prevention/mitigation measures.

- For environmental aspects with a *medium impact*, monitoring procedures and prevention/mitigation measures must be considered; in some cases, improvement actions may also be necessary to lower the significance of the considered aspect.
- The environmental aspects with a *relevant impact* require the formulation of an environmental improvement plan aimed at bringing the analyzed effects back to an acceptable zone.

Table 4: Criteria and associated points for the activities with potential environmental impact

Criterion	3 points	2 points	1 point
1- Legal limits	Possibility of exceeding the legal limits repeatedly	Possibility of occasional exceeding of legal limits	Negligible possibility of exceeding of legal limits
2- Public image	Negative perception by many	Negative perception from a niche	Negligible negative perception
3- Economy	The considered aspect leads to a considerable cost on the budget (>= 10%)	The considered aspect leads to a non-negligible cost on the budget (1%).	The considered aspect leads to a negligible cost on the budget
4- Frequency	Each time the production activity takes place	Few times / only in abnormal conditions	Never negligible frequency
5- Severity of the effect	The considered aspect generates large-scale environmental effects	The considered aspect generates local-scale environmental effects	The considered aspect generates negligible environmental effects

Table 5: Significance of environmental aspects

	SIGNIFICANCE	DESCRIPTION
From 5 to 7	LOW	The environmental aspect has a negligible impact

From 8 to 11	MEDIUM	The environmental aspect has a medium impact
From 12 to 15	HIGH	The environmental aspect has a relevant impact

CASE STUDY

Platform description and site identification

Considering the previously mentioned criteria for the case study selection (presence of wellheads, treated hydrocarbon, area of the weather deck and number decks), GREEN1 is a four decks installation (plus the boat landing), characterized by a weather deck sized 20 x 22 meters, unmanned, without helideck and equipped with four wellheads for natural gas production. This kind of plant matches with the 11% of the platforms existing in Italy (excluding the small mono- or bi-tubular platforms) [6]. All decks are plated with the exception of the wellheads area, the muster areas and the boat landing. A lateral view of GREEN1 is reported in Figure 1.

The original purpose of the platform is the production of natural gas. The process foresees that the wellheads are connected to the production and test collectors through flow lines equipped with HIPPS (High Integrity Pressure Protection System) to protect downstream equipment. After chemical injections (corrosion inhibitor, pour point depressant and wax inhibitor and emulsion breaker), the natural gas production is sent onshore through a sealine. On-board there is a launching trap for periodical inspection and cleaning; a drain system to convey drainages from equipment/system physically separating hazardous and non-hazardous substances; a system to store, filter and transfer diesel fuel to feed two electrical generators that guarantee electrical power to the platform; a vent and blowdown system to safely collect and dispose all hydrocarbon relieves and depressurizing flows during upset conditions; glycol for hydrates inhibition system necessary during well start-up and shut-down to avoid possible hydrates formation because of severe temperature/pressure drops; hydraulic actuation system for the movement of the X-tree and HIPPS valves; firefighting system and fire&gas detection system.

GREEN1 platform is a six-legged platform, located at a distance of 18 km from the coast, where the seabed is 25 m deep, and is part of a cluster of platforms operating in the same area.

It is decided to locate the plant in the northern Adriatic Sea, where the 90% of Italian platforms are located and they are almost entirely dedicated to the Natural Gas (NG) extraction. The remaining 10% is installed along the Apulian or Sicilian coasts and is dedicated to the extraction of both NG and oil. Moreover, the Italian platforms well represented by the GREEN1 case study are all located in the central-northern Adriatic Sea, in particular in the marine area between Ancona and Rimini. In addition, referring to the guidelines for the decommissioning of offshore structures intended for hydrocarbon cultivation [5] and to the list of the first structures subject to future measures compiled by the operators ENI and Edison [9], the infrastructures to be decommissioned in the next years are mainly plants intended for the NG production in the Adriatic Sea (except for the subsea wellheads).

The selected area is characterized by a more or less uniform annual average wind speed, between 4 and 6 m/s measured at a height of 50 m above sea level [10]. Solar data, fundamental to evaluate PV field performance, are derived from the online software SoDa-pro, which returns the data of interest (e.g. solar radiation every 15 minutes at ambient temperature) according to the geographical position of the platform, considering also “offshore” coordinates. From a seismic point of view, the area is characterized by a maximum ground acceleration with a 10% probability of excess between 0.050g and 0.150g, referring to rigid soils [11]. It is worth to note that the seismic suitability of the site for process activities was verified for the previous installation purpose (NG extraction) and the conversion activities described in this paper do not change the result of the previous studies.

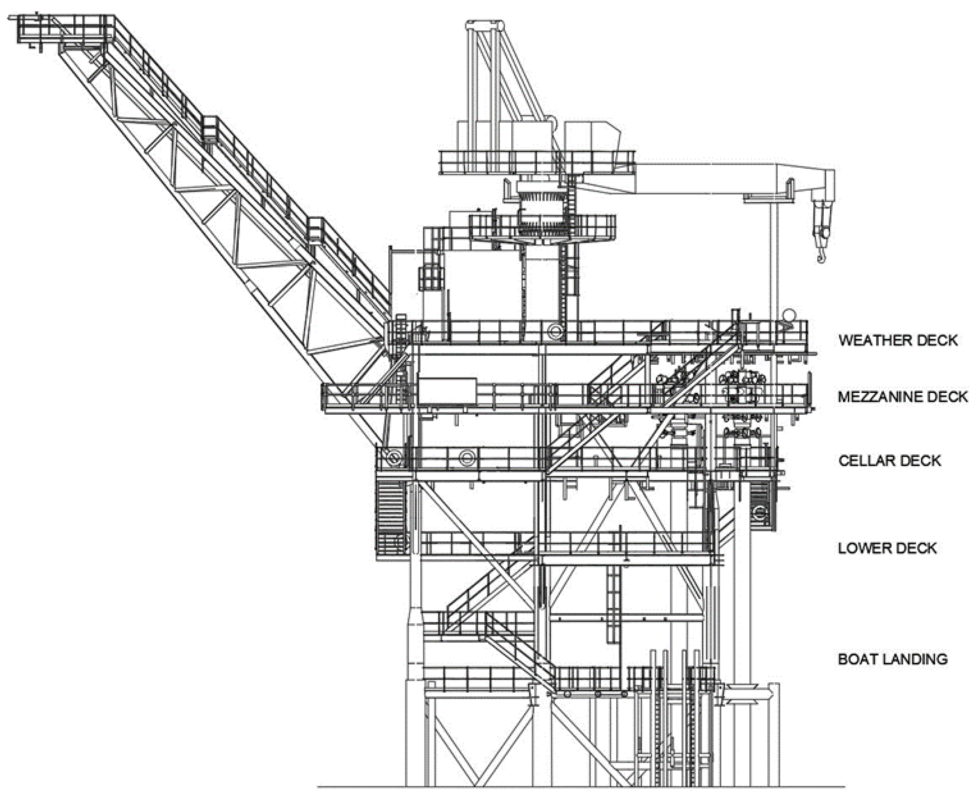

Figure 1: Lateral view of GREEN 1

Block Diagram

Figure 2 shows the block diagram of the process, i.e. the macro-components composing the system and the connections among them. The full description of the system is reported in the following paragraph "Design Criteria".

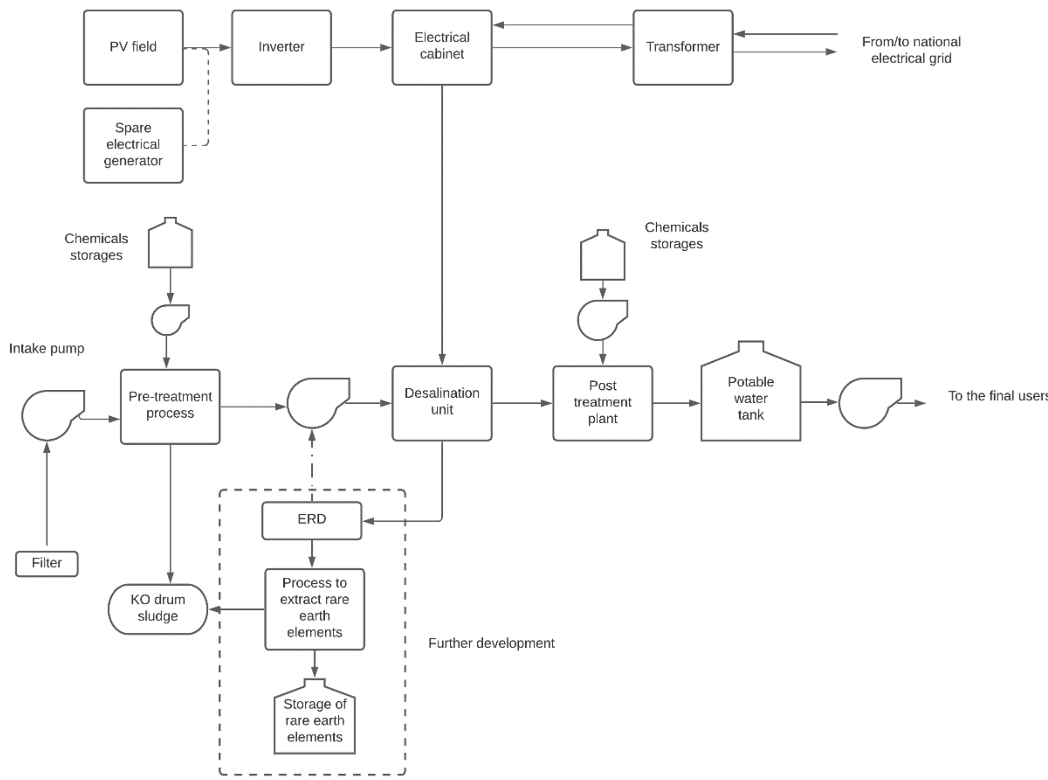

Figure 2: Block diagram of the process

Design criteria

Production system

The main criterion set for the design phase is that the fresh water produced by the platform shall be sufficient to feed a cluster of platforms operating in the area, where almost 50 operators are permanently hosted with an overall potable water requirement of 7.5 m^3/day (supposing an individual potable water need equal to 150 L [12]). To satisfy this objective the plant is supposed connected to the national electrical grid through a subsea connection: in this way, in the event that there is a PV power surplus with respect to the user absorption, this can be fed into the grid (mainly during the summer months). Conversely, if the PV power results insufficient with respect to the user absorption, the difference can be absorbed from the grid (mainly during the winter months).

A Matlab software, PlatApp, was developed at Politecnico di Torino ([13], [14]). It allows to size the PV plant for every Italian platform and, in particular, the number of the PV panels and their electrical connections, the power absorbed by a reverse osmosis desalination system and the number and the characteristics of all the electric/electronic needed components (inverters, string combiner, maximum power point tracker, etc.). Additionally, the software is able to simulate different operating conditions: plant connected to the national electrical grid or standalone plant, constant production of water or variable production following the daily solar radiation.

Using the previously mentioned PlatApp software, it is obtained that, to fulfil the production criterion and respect the platform geometrical constraints, the weather deck shall be covered by 80 PV panels corresponding to a power production of 25.2 kWp and the desalination unit chosen shall absorb a power of 9 kW using the system for about 8.5 h/day. In this way, over the year the energy balance is positive: 8-14 MWh/y depending on panels' degradation. A three-phase inverter alternates the direct current produced by the PV field in order to directly use it to feed the desalination package. In addition, considering the distance of the offshore platform from the coast, the installation of a transformer for voltage variation from low to medium (and vice versa) is necessary to allow efficient transport of energy along the submarine connection cable, minimizing losses.

The desalination unit, characterized by a recovery factor of 25%, is fed by an intake line, properly dimensioned to guarantee a seawater flowrate of 30 m^3/day with a speed of approximately 1 m/s to reduce the losses. The entry point is located at 15 m from the seabed to minimize the influence of atmospheric conditions, of the marine environment and of the surface currents on the feed water. Downstream the suction pumps, the pre-treatment unit removes all impurities (suspended solids, colloids, microorganisms, etc.) that can settle on the surface of the osmotic membrane causing a decrease in process performance or damaging the membranes themselves. Then, the pressure is increased up to 55 bar and the pre-treated water flows through the membranes of the reverse osmosis unit, which retains about 99.5% of the dissolved salts. The post-treatment unit make the water reaching the quality standards, in terms of salinity, alkalinity and pH, and performs a cover disinfection to ensure the water desired pureness. The potable water is finally stored in a storage tank with the function of an intermediate buffer and, in the end, it is sent to its destination, to the neighboring platforms, via the umbilical or, in some cases, by vessel.

The brine is released into the sea, in accordance with the environmental legislation currently in force. Nonetheless, the discharge line is designed so that the brine flowrate and turbulence favor a rapid diffusion.

It is worth noticing that the potable water may be useful not only for drinking purposes but also for feeding process and/or protection systems (e.g. the firefighting system with water mist as well as other parts of the process). Hence, the desalination package is oversized compared to the production of the PV field in order to meet any potential additional needs for potable water. In fact, even if the main power supply of the system is provided by PV field, if necessary, the package can exploit the national grid as an alternative power source and no longer just as a backup.

The plant is equipped with auxiliary systems to support the process such as the lifting crane for the installation and maintenance of components, process monitoring and control systems, UPS, containment basins in case of loss of dangerous fluids and fire extinguishing devices for electrical equipment.

In the end, the platform is equipped with all the necessary instrumentation and communication devices.

Platform layout

The platform layout is described in the following:

- The *weather deck*, the only deck directly exposed to solar radiation, is dedicated to the exclusive use of the PV field with the exception of the communication media and the crane that need to remain on the highest deck. During the operation of the PV panels, the crane orientation is such to minimize the possible shading of the PV field.
- The *mezzanine deck*, the deck immediately below the weather deck, hosts the technical room in which the inverters and electrical panels necessary for the

operation of the PV field are located, in order to optimize the distance between the PV field electronic control and instrumentation from PV field itself. In this way it is possible minimize both the cost of wiring the instrumentation and the loss of signal efficiency. Also the transformer is positioned on this level, inside a container to preserve its integrity by protecting it from the aggressive marine environment.

- The *cellar deck* hosts the desalination unit (desalination package + pre- and post-treatment unit), which is supplied in a containerized solution that has the double advantage of protecting the equipment from the highly aggressive marine environment and preventing accidental releases into the sea of any potential losses of the hazardous chemical substances necessary for the water treatment upstream and downstream the osmotic desalination. Moreover, there is the piping necessary to connect the package with the potable water storage tanks and with the intake line. The cellar deck is chosen as the process deck because its intermediate position allows to optimize, at the same time, wiring and coupling activities with the PV field and the power of the sea water suction pump.
- The *lower deck* is dedicated to the potable water storage tank, which is large enough to contain the weekly water requirements of the surrounding platforms. The distribution pumps, necessary to send the produced water to the other platforms of the cluster, and the discharge pump, necessary to release the brine into the sea, are also installed on this deck.
- The *boat landing* hosts the storage (KO drum sludge) of waste substances extracted during the pre and post-treatment process, which are performed using

chemical substances some of which may settle on the bottom part of the equipment (e.g. the flocculation phase, which is one of the activities performed during the water pre-treatment, produces sludge that has to be removed to keep the process efficiency).

It is worth to note that all the new components are resistant to the aggressiveness of the marine environment. In particular, all the metallic components are tropicalized, i.e. they have underwent a galvanizing treatment that made them suitable to work in a corrosive environment such as the offshore one.

Plant operational modes

All the systems and components of the plant are designed and sized to produce a daily flowrate of potable water (7.5 m^3/day) sufficient to meet the needs of operators hosted in the platforms of the cluster of GREEN1 and this represents the primary operational mode of the plant. It is assumed that the plant works continuously during the year 8.5 h/day in order to obtain a positive energy balance (energy fed into the grid during is higher than the energy absorbed from the grid).

Other operational modes are envisaged:

- *Start-up*: this operational phase includes the first start-up of the plant and the start-up of the system after a prolonged shutdown, e.g. more than one week for maintenance purposes or bad weather conditions. It is necessary that all the valves are in the correct position, the pumps are in good condition, and the chemicals storages necessary for water pre and post treatment are connected to the line. There must be no leaks either along the main line or on the auxiliary chemical injection lines. During the start-up phase, the potable water storage tank is disconnected from the line and the water produced is discharged into the sea until the analyzers guarantee that the composition of the water is within acceptable limits. The alignment of the manual valves and the connection of the chemicals must be carried out on site.

- *Shutdown*: this operational phase refers to a prolonged stop of the system. e.g. for maintenance activities. It is necessary to completely drain the system and refill the potable water storage tank, to ensure the quantity of drinking water required by the users for a week. In addition, after medium-long inactivity of the desalination plant, the impurities present in the system tend to deposit on the surface of the membranes, reducing their efficiency; it is therefore recommended a flushing operation to eliminate the deposited high salinity water.
- *Black-out*: it occurs in case of simultaneous loss of electricity from the PV panels and from the national grid. In this condition the electrical loads are no longer powered and the pumps block. An UPS allows the system to be safely switched off, reports the black-out signal to the technical control room, switches on the navigation lights and feeds the telecommunication systems in order to report the blackout onshore. If the black-out is not automatically solved, the on-board intervention of an operator is required; in the meanwhile the UPS role only consists in feeding the navigation lights.
- *Deficit and energy surplus*: in the event of an energy surplus produced by the PV panels, it is sent directly to the grid, vice versa, in the event of an energy deficit,

the energy is absorbed from the network. The annual goal is to obtain a positive energy balance (i.e. the energy sent to the grid is higher than the energy absorbed from the grid).

- *Daily start-up and shut-down*: the system is expected to be operational for 8.5 h/day: therefore, daily remotely controlled shutdown and start-up are performed without the operator intervention. The daily start-up is preceded by a transient during which the potable water storage tank is disconnected from the line and the produced water is discharged into the sea until the composition of the water is within the acceptability limits. The daily shutdown foresees the shutdown of the desalination package and the closure of the intake line. The use of the distribution line for dispatching potable water to neighboring platforms remains available.
- *Additional demand for potable water*: in the event of an additional need of potable water (e.g. due to an unusual presence of operators on board), the system can work for a time longer than the 8.5 h/day fully exploiting the PV or, if the photovoltaic energy is not available or sufficient, purchasing the energy from the national electricity grid.
- *Maintenance:* this operational phase includes the replacement of chemicals storages, periodic inspections of the system (scheduled every six months), monthly cleaning and washing of the exposed surfaces of the PV to reduce the possible performance deterioration, functional tests of all the electrical equipment (electrical panels of the PV field, inverter, electrical cables), substitution of damaged components.

Decommissioning and conversion civil activities

The criterion guiding the decommissioning phase of the old equipment (i.e. the ones aimed at the NG extraction) is to clear as much weather deck area as possible to maximize the number of PV panels and, therefore, the installed power. Hence, the removal involves most of the equipment and buildings located in the weather deck with exclusion of the main crane, which is north-oriented while the system is in operation, and the telecommunication antennas, which are moved on the north side of the installation, to avoid shading of the PV field. The crane is kept even if it could create interference with the PV field (reduction of the usable surface and possible shading of part of the strings) since it is indispensable both for the dismantling of disused components, for the installation of new components, and for future maintenance operations.

Also the technical room, which was located on the weather deck, has to be dismantled as it occupies a non-negligible percentage of the deck and would cause shading issues. Since it constitutes an indispensable structure for system operation, a new smaller technical room is installed on the mezzanine deck.

Referring to the methodology described in paragraph 2 and, in particular, to the decommissioning strategy, each component previously used for the NG extraction is analyzed to decide if it can be used in the new configuration, it has to be removed or it can be left on board.

It results that all old components (equipment and pipes connected to them) located on the mezzanine, cellar and lower deck must be removed to make room for new equipment. Few exception are made, e.g. the pig trap, the wellheads and the torch are left in their position but put out of service since it was assessed that the burden of their dismantling does not correspond to an equivalent benefit in terms of space useful for the installation of new equipment. On the other hand, other components as the drainage storage located in the boat landing and safety shower and eye-wash station are considered useful for the new plant and maintained in operation. In order not to damage the marine ecosystem, it is decided not to remove the sealine but only to inertize and isolate it. In the end, option 1 envisages the mining closure of the wells, i.e. a sequence of operations that precedes the final abandonment of a well; generally, the hole is closed with concrete.

At this point, a preliminary comparative structural analysis is performed: it consists in a deck-by-deck comparison between the components necessary for the new platform configuration and the ones used in the old platform configuration, with particular attention to their weight and size.

The conversion activities allow a reduction of the total weight installed on the platform equal to 107.5 t. Nevertheless, it should be underlined that the loads are differently positioned, hence can differently stress the supporting structure of the platform. In fact, in the old platform configuration the heaviest loads were positioned on the weather deck, while in the new configuration the heaviest loads are on the lower deck. Even if the new configuration heavy components are positioned to minimize the shear stresses along the horizontal bearing beams of the decks (e.g. the loads are positioned centrally with respect to the four vertical legs), a detailed mechanical analysis has to be performed in the successive design phases.

Safety analysis

The HAZID analysis has been performed considering the following operational phases: normal operation, start-up/shut-down, daily start-up/shutdown, maintenance and simultaneous operations (the only foreseen type of simultaneous operations is the superposition of maintenance activities on the PV field and operation of the desalination unit powered by the national grid).

The HAZID analysis did not highlight unacceptable scenarios, hence a quantitative analysis is not considered necessary at this stage of the project since input data are not sufficient to ensure that valid and robust results can be obtained [15]. In particular, for thirty-nine (39) scenarios the risk has been considered acceptable, while for eighteen (18) scenarios the risk has been considered ALARP (As Low As Reasonably Practicable). Different ALARP risks are referred to the different identified targets: people (both operators on board and final users), environment and asset. Few examples of ALARP risks are listed hereafter per each target:

- For on-board operators the ALARP scenarios are associated to the objects drop during the lifting activities of the decommissioning/installation/maintenance phases, while for final users they are associated to the dispatching of out of spec potable water.
- For the environment, the ALARP scenarios are associated to the accidental releases of substances dangerous for the environment.

- For the asset the ALARP scenarios are associated both to severe atmospheric conditions or abnormal process conditions.

Thirty-six (36) recommendations are identified in order to reduce the risk of the ALARP scenarios and to improve the process management and strengthen the existing safeguards of some acceptable scenarios. The recommendations are supposed to be implemented during different design phases (e.g. basic design, detailed design, decommissioning phase, etc.). The recommendations identified for the basic design are of particular interest for the purposes of the study since they have already been implemented in the project. Few examples are reported hereafter.

For the PV field, the HAZID analysis recommends to check that the conditions of the solar panels are compatible with the installation area also considering the possible extreme climate change and to provide buttons to disconnect the PV field that can be activated even in case the technical room is not accessible (i.e. below the Mezzanine Deck). For the crane the installation of an acoustic/optical alarm to be activated during the component operation is suggested. For the desalination unit, many recommendations are formulated; among the others, the installation of a redundant analyzer located on the intake line to optimize the chemicals injection on the basis of the actual seawater composition.

Environmental analyses

The environmental analysis focuses on those activities that may have an environmental impact during the plant normal operation/routine activities. It should be highlighted that the impact is not due to accidental events, as for the previous safety analysis, but it is intrinsic to the plant configuration and functioning.

Twenty-five (25) activities with a potential environmental impact have been identified, in particular, for twenty-three (23) activities the environmental impact is considered negligible; for two (2) activities the environmental impact is considered medium; activities with relevant environmental impact have not been identified.

The two activities with a medium environmental impact are: the discharge of the brine into the sea (liquid releases) and the disposal of the PV panels at the end of their life (waste production), reported in Table 6.

Table 6: Extract of the results of the environmental impact analysis with a focus on the activities with a medium impact

Description of the activity	**Environmental aspect**	**Legal limits**	**Public image**	**Economy**	**Frequency**	**Severity of the effect**	**TOTAL**	**CLASSIFICATION**
Discharge of the brine into the sea	Liquid release into the sea	C	B	C	A	B	9	MEDIUM
Disposal of the PV panels at the end of their life	Waste production	B	B	B	C	C	8	MEDIUM

Focusing on the discharge of the brine into the sea, since there are no legal limits that regulate it, a C index is considered adequate for this criterion; however a part of the population attentive to environmental aspects dislikes uncontrolled discharges, therefore an index B is assigned to the public image criterion. No costs are foreseen for this activity, hence a C index is assigned to the economy. Since the brine is produced whenever the desalination package is in operation, an A index is assigned to the frequency. Since the environmental impact is considered limited to the release zone, a B index is assigned to the severity of the effect. In the end, it should be highlighted that the design of the brine discharge system and the efflux speed ensure rapid and efficient mixing with seawater; in addition, the impact can be reduced if, in the future, a brine treatment system will be implemented in order to recover rare metals or energy from the saline gradient.

Focusing on the disposal of the PV panels at the end of their life, the overcoming of the legal limits is considered plausible considering the complexity of the current regulatory framework, hence a B index is considered adequate for this criterion. As for the previous one, a part of the population considers the life cycle of PV panels to be particularly impactful from an environmental point of view, therefore an index B is assigned to the criterion public image. At the end of their life the PV panels are sent to authorized plants for recovery/disposal with a consequent impact of the cost of managing the waste that has been estimated approximately equal to 1% of the budget, hence a B index is assigned to the economy. Since both the frequency and the severity of the impact are considered negligible, a C index is assigned to both the criteria. In the end, a proper disposal strategy has to be implemented knowing that all the new components have to be selected also considering their future dismantling phase.

LESSONS LEARNED AND CONCLUSIONS

This paper summarizes the key concepts of the design philosophy and the main steps of the methodology developed to guide the definition of the basic design of several options for the conversion of offshore Oil&Gas platforms at the end of their life. In particular, the analyzed case study refers to the installation on the platform of a system for the production PV energy to be used for seawater desalination and for its delivery to other platforms operating in the same area.

On one hand, few critical aspects emerge from the analysis. From a design point of view, the plant needs to be connected to the national electrical grid because of the difficulties related to the energy storage; a pack of battery sufficient to store all the produced energy would involve issues in terms of weight, costs, degradation of the batteries themselves due to the corrosive marine environment and production of waste. A grid connected solution results more sustainable, flexible and economic than a stand-alone plant, but it implies constraints in terms of platform localization (to minimize electrical losses) and may require the installation of an electrical cable, whenever it is not present. Other criticalities arisen from the project are linked to the cost of conversion activities that may result relevant if compared to analogous systems installed onshore; to the need of preliminary structural analyses to guarantee that the installation is suitable to host the new equipment; to the maintenance of the new systems impacted by potential difficulties to reach the platform (e.g. in case of bad weather conditions); to the novelty of the proposed project that requires the interface with a potentially immature regulatory framework: for example it results necessary to update the PV technical standards to consider also the offshore applications (e.g. corrosion, radiation, fauna issues). In addition, the proposed project requires that the weather deck of the platform is sufficiently large to host a PV field economically sustainable and the presence of other installations in operation in the surrounding of the platform in conversion for the optimization of the potable water distribution.

On the other hand, many positive aspects result from the analysis. The investment of the decommissioning phase is delayed and partially payed in installments (e.g. thanks to the decommissioning of the equipment removed for the installation of the new systems); the environmental impact of the decommissioning phase is sensibly reduced, especially for the marine ecosystem; no major safety and environmental criticalities arise from the conversion activities. Moreover the case study experiments a new industrial paradigm based on the use of infrastructures once dedicated to fossils and now hosting renewables and the analyzed plant represents the outpost for the implementation of more advanced technologies for example dedicated to the separation of rare earths from the brine. Furthermore, since the components for the Oil&Gas production and treatment are heavy and bulky, the platforms are suitable to host many kinds of new installations, which are largely lighter in the major part of cases; in addition, platforms are complex infrastructures equipped with advanced technology components that can be partially reused in the converted plant. In this optics, it is worth to note that this conversion option is the most distant from the original platform purpose, while the other options that will be analyzed in the MiSE projects (i.e. injection of CH_4-H_2 mixture and injection of CO_2 for temporary storage), more related to the platform original purpose, will guarantee the re-use of many of the already present equipment; among the others, the wellheads will play an essential role.

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Figure Captions List

Table Caption List