ScienceDirect

Outline Download Share Export

Search ScienceDirect Advanced

Renewable Energy
Volume 135, May 2019, Pages 1121-1132

Reconversion of offshore oil and gas platforms into renewable energy sites production: Assessment of different scenarios

Mariella Leporini [a], Barbara Marchetti [b], Francesco Corvaro [c], Fabio Polonara [c, d]

Show more

https://doi.org/10.1016/j.renene.2018.12.073

Get rights and content

Highlights

- A model for the reuse of offshore oil rigs at end-of-life stage for the production of renewable energy has been developed.
- Various technical reuse scenarios have been investigated with the relative energy flows considering real data.
- A Discount Cash Flow Analysis and a Life Cycle Assessment of all the scenarios have been conducted.
- Cost competiveness and environmental impacts have been calculated.

Abstract

The contemporary energy transition will be characterized by many sub-transitions in the next three decades. Oil and gas will continue to play a very important role coupled with renewable energy sources in an energy mix scenario. In this context, the authors of the present work developed a project, named RELife (Renewable Energy for a new Life of offshore platforms), with the main goal of develop a model for the reuse of offshore Oil & Gas platforms at end-of-life stage for the production of renewable energy. In this paper, by considering two types of platforms (4-legged platform with 3 or 4 production wells), various technical scenarios are studied and investigated and for each scenario also the environmental and economic feasibility is evaluated. In addition, all the sub-models are compared with a standard decommissioning process. The evaluations are made for both the Adriatic Sea and the North Sea, two geographic areas with different availabilities of renewable resources. In order to assess also the economic and environmental feasibility, a Discount Cash Flow Analysis and a Life Cycle Assessment of all the scenarios have been conducted.

Previous Next

Keywords

Offshore platforms reconversion; Green decommissioning; Renewable energy; Life cycle assessment; Economic analysis

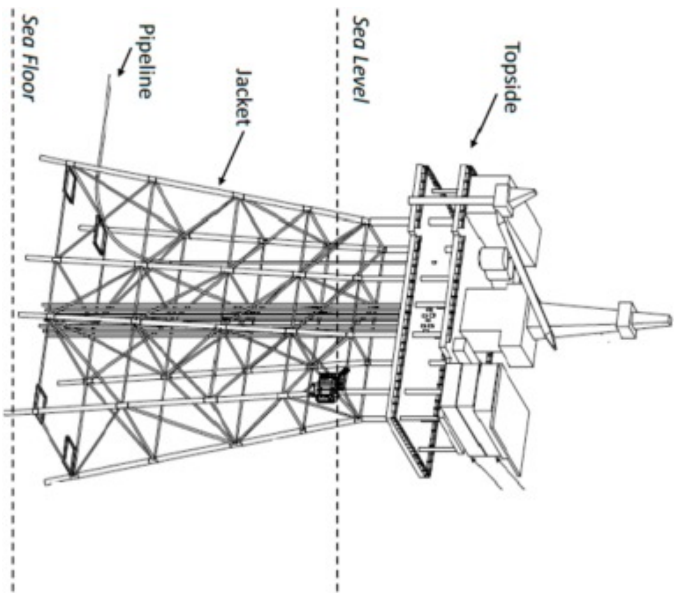
1. Introduction

Today, the energy sector is faced by two important challenges: the sustainable economic development and the global climate change [1]. Addressing them is often being linked to the decarborization of today's energy system obtained through a transition from fossil fuel to renewable energy. In fact, a fundamental structural change is occurring worldwide in the energy sector, an important energy transition related to energy sources, structures, scale, economics, and energy policy [2,3]. An example of this transition toward a sustainable energy, is the shift by Germany, to decentralized renewable energy, and energy efficiency but many examples and kinds can be reported. An important form of energy transition can be potentially represented by the re-use of offshore Oil & Gas platforms at the end-of-life stage.

Oil and Gas offshore platforms and installations have a limited life of operations. Currently, there are 6500 offshore Oil and Gas production installations worldwide, located on the continental shelves of some 53 countries. Over 4000 are situated in the Gulf of Mexico, some 950 in Asia, some 700 in the Middle East and 600 in Europe, North Sea and North East Atlantic [4,5]. Approximately 0.4% of world reserves of Oil and Gas are located in the Mediterranean basin with 127 offshore platforms which extract especially gas. These offshore structures are mainly distributed along the Northern and Central Adriatic coasts (about 90 platforms [6,7]), on depths between 10 and 120m, but also in the Ionian Sea and in the Strait of Sicily.

Worldwide, many Oil & Gas offshore structures are to be decommissioned in the coming years because exploration and production of fossils is ending [8]. Just in the North Sea, some 600 platforms will have to be dismantled. In 2014, the average age of, for instance, the Dutch North Sea structures was 24 years. Therefore, many of these structures are now reaching the end of their productive life or will do so in the coming 10 years. In the Mediterranean basin, more than 110 offshore gas platforms have been deployed since the 1960s in the northern and central parts of this basin (Maggi et al., 2007), representing the highest concentration of fossil fuel extraction platforms in the Mediterranean area. In the Adriatic Sea, once a lucrative gas prospect, the Italian Oil Company ENI has installed some 80 gas platforms over the last 50 years. With most of these structures approaching their end of life, the staged situation shows the Company in the middle of a critical decision: a plan to decommission the platforms at the lowest possible cost and risk. The same situation is characterizing other international Oil Companies.

The word decommissioning related to offshore installations has a recent origin. In fact, it became a concern to the international Oil & Gas industry following the 1995 Brent Spar controversy; before that incident many would refer to the concept of removing an abandoned offshore platform as abandonment [9]. Most nations will opt for a complete removal of the obsolete structures, which presents engineering challenges and is estimated to cost the Oil and Gas industry in excess of 40 billion USD [10]. In fact, different options of platforms exist and one of these is the complete removal of the structure [11]. In order to better explain and understand the various decommissioning options, a general scheme of a typical platform structure is reported in Fig. 1.



Download : Download high-res image (237KB) Download : Download full-size image

Fig. 1. Scheme of major offshore platform.

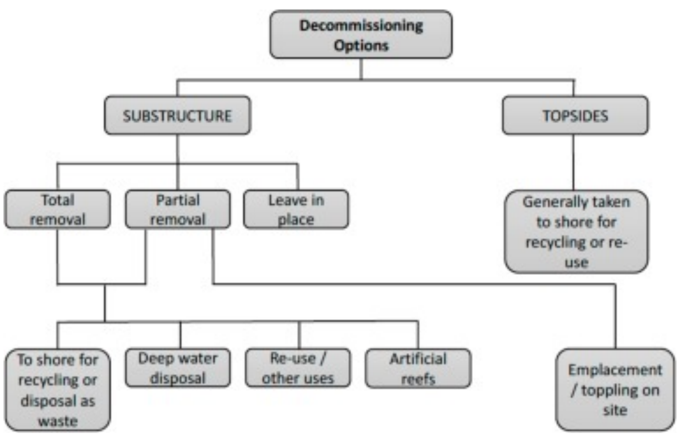
A typical offshore platform can be composed of:

- a topside, the above-water structure, including oil and gas processing equipment, where the offshore activities take place, including drilling rigs, helidecks, cranes;
- a jacket, which supports the topside and is composed of the parts of the structure that are anchored in the bottom;
- footings, the lowest and heaviest section of the jacket, which include pile clusters to aid piling of the structure into the seabed, and a drilling template, through which the wells are drilled;
- a pile of drill cuttings consisting of drilled rock particles and drilling fluids arising from drilling the wells;
- pipelines for the export of oil and gas.

Installations vary significantly in size and weight, depending on the sea depth and conditions and the extent of their processing, accommodation and other functions. Small installations can be only 200 tonnes while large topsides can be in excess of 50,000 tonnes and gravity based structures in the hundreds of thousands of tonnes (Techera & Chandler [12]).

Regardless of the structures' sizes, every offshore platform must be decommissioned at the end of the field life. The process to proceed with a platform decommissioning is usually undertaken by the operator of an Oil & Gas installation, in consultation with the regulatory agencies. The decision to decommission or not is usually the prerogative of the Government as in Europe and in the United States. In Europe, Oil & Gas companies must submit a legal decommissioning plan to the Government, a few years before the end of the platform operations. The regulations dealing with the offshore platforms decommissioning are different; for example, for the UK and Norway the main regulations are the Petroleum Act 1998, the Energy Act 2008 and the OSPAR (Oslo and Paris Convention for the Protection of the Marine Environment of the North East Atlantic) 98/3 decision on the disposal of disused offshore installations.

There are a number of different ways to remove and dispose an offshore installation. The main options open to offshore operators are summarized in Fig. 2.



Download : Download high-res image (141KB) Download : Download full-size image

Fig. 2. Standard decommissioning options.

Of course, operators are under legal obligation to decommission the infrastructure once at the end of the production and the cost of removing the installations is to high: some experts stated that only for the North Sea, the amount is somewhere between 28 and 39 billion euros. In order to avoid or delay some of these costs and the potential environmental impact of the decommissioning, research is dedicated to re-use of oil and gas infrastructures. Offshore conversion may lead to postponing of decommissioning. This in itself may create an economic value because of the discounted cash flow of the postponed decommissioning reservations made by the oil and gas companies. Given the cost data provided above, such cash flow can be substantial. In addition, the reuse of these structures for the production of renewable energy would lead to a “green decommissioning” and to a “green economy” which would play an important role in the energy transition scenario, in which a fundamental structural change is requested into the energy sector related to energy sources, structures, scale, economics, and energy policy.

The present paper aims to present a new model developed for the reuse of offshore platforms at the end of life stage. In particular, it involves different options for the reconversion of offshore Oil & Gas platforms into sites for renewable energy production and a techno-economic-environmental analysis of each option. To the author's knowledge there are no published works relating the study of the offshore platforms reconversion into energy production sites exist. The RELife project is born from the necessity of the platforms owners, the environment and the society to develop a new life for the obsolete structures to be decommissioned. Offshore structures conversion into energy production sites may benefit from the use of the existing oil and gas pipelines to transport the possibly fluids to onshore destinations. Insofar as such existing infrastructure can be used, the investment in new power transmission capacity may no longer be necessary. This may generate considerable positive externalities. In addition, such decommissioning can not only be costly, but also complex from a technical and environmental perspective. It can be interesting to see what options could be available in this regard that could create a win-win situation between business and environmental interests.

The main goals of the RELife project can be gathered into three groups:

a) technical objectives

b) environmental objectives

c) economic objectives

a) Beyond short-term technical goals of the re-use of offshore oil and gas platforms at the end-of-life stage such as to avoid the remove and dispose of the various structures (platforms, process plants, pipeline structures and piping, etc.), various technical objectives of RELife project can be identified. First of all, the identification of win-win potentials between fossil and renewable energy activities. In addition, renewable energy produced offshore can be stored in the form of green gases. In this way, it is possible to overcome one of the main drawbacks of renewable energy production, i.e. the balancing problem (uncontrollable electricity of renewable energy systems and the inelasticity of demand variability in electricity production). Another important aim is the combined use of existing infrastructure: it is challenging to investigate whether the renewables sector may be able to save on new infrastructure investment, by using existing infrastructure that is not yet technically written off as its use by oil and gas companies. Last but not least, the energy conversion investigation is an important technical objective of the RELife project; in fact, many energy conversion scenarios are investigated and studied from a technical point of view: the exploitation of energy from wind and sun and their conversion into green hydrogen and green NG are analyzed. According to the geographic area, the availability of renewable sources (solar and wind and marine energy) are individuated.

b) From the environmental point of view, of course, the first aim is to avoid the partial or total disposal and the in-situ abandonment of the platforms at the decommissioning life stage. In fact, all the standard decommissioning options (depending on national or international regulations) present important environmental impacts; in the long run, the permanent in-situ abandonment of the offshore structures requires maintenance and maritime traffic management with a consumption of fuels, can cause accidents and it can definitely change the aspect of the sea area with its ecosystem. Leaving the platforms' topsides in situ would ultimately lead to the depositing of hazardous materials into the marine environment. On the other hand, the partial or total disposal of the large-scale structures involve waste accumulation. In addition, deep-water removal or partial removal of offshore platforms can lead to significant adverse effects upon the marine as oil and gas structures are capable of developing abundant and diverse marine communities during their production lives, with some structures supporting communities of regional significance.

The RELife project evaluates the environmental impacts of all the technical reconversion scenarios by comparing these ones with the standard decommissioning options forecast for each particular platform (depending on the national or international rules) through a Life Cycle Assessment analysis. The implementation of the scenarios for the re-use of the platforms at the end-of-life stage can help to reach the EU 2050 mitigation target of having achieved by then a nearly carbon neutral economy.

c) From the economic point of view, the RELife project evaluates the financial feasibility of each technical scenario and compares the costs of all the scenarios with the ones of the standard decommissioning options forecast for each particular platform. In addition, significant financial benefits are expected by delaying decommissioning of oil and gas infrastructure like platforms and pipelines. Postponing decommissioning may itself create an economic value because of the discounted cash flow of the postponed decommissioning reservations made by the oil and gas companies and governments. In fact, part of the decommissioning cost can be avoided or delayed by re-use of oil and gas infrastructures, electricity cables and pipeline structures.

In conclusion, the RELife project allows to evaluate and compare alternative decommissioning options across key selection criteria, including environmental, financial and socioeconomic considerations. It could be used as a first approach to permit start a decision-making process, with the adequate region considerations. By developing the appropriate knowledge to answer questions like the decommissioning and the platforms' reuse, this project can have impact on short-term decisions about technology development and long-term decisions on investments and strategy.

The paper is organized as following: in Section 2, the materials and methods used for the study are presented; in particular, the RELife project and the investigated scenarios with the relating energy balances are presented, the utilities chosen and the methodologies followed for both the economic and environmental analysis are reported. Section 3 is devoted to the presentation and comments of the results obtained from the environmental analysis while Section 4 reports the results of the economic assessment; in Section 5, some conclusions are drawn.

2. Material and methods

In this section, there is presented the RELife project and the scenarios individuated from a technical point of view for the conversion of offshore platforms to be decommissioned into sites for the energy production from renewable sources; then, the energy balances for all the scenarios and the methods used to carry out the economic and environmental analysis are reported.

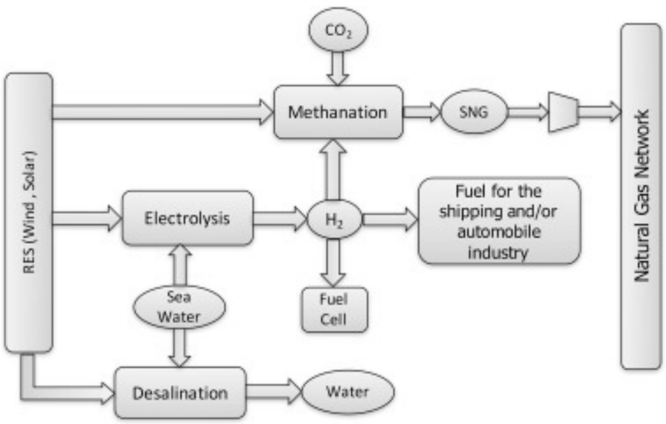
2.1. RELife project

The new global platforms' reuse model under the RELife project is shown in Fig. 3. As it can be seen, the renewable energy (RES) produced offshore can be used to:

- produce “green” hydrogen through the electrolysis process: the electrolysers and the necessary equipment can be located on the platform; the electricity needed for the electrolysis process could be brought from the near RES;

The produced hydrogen can be transported to the land by pipelines for different uses (fuel for vehicles, medical use, etc.) or introduced into a Sabatier reactor as a reagent to develop a methanation process, from which Synthesis Natural Gas (SNG) is obtained. Then, the SNG product can be stored or added to the natural gas grid. This is possible because the SNG has the same characteristics of the natural gas (methane); this also allows to use the pre-existing transport lines, therefore without additional costs or need of new structures;

- produce fresh water from sea water. This is possible through high-capacity industrial desalters and in this case too, the existing pipeline would be used for the transport of freshwater to land.



Download : Download high-res image (158KB) Download : Download full-size image

Fig. 3. Global model of the RELife project to reuse offshore Oil and Gas platforms.

In addition to SNG and fresh water, another direct product can be identified: direct electricity to be added to the national grid.

2.2. Offshore platforms

In order to assess the feasibility of the different options considered in the RELife project for the reuse of offshore platforms under decommissioning process to generate renewable energy, four real platforms have been individuated, two located in the Adriatic Sea and two located in the North Sea. In particular, they have been individuated two very similar 4-legged platforms with 3 production wells, one located in the Adriatic Sea and one in the North Sea. However, also two similar 4-legged platforms with 4 production wells have been individuated (respectively in the Adriatic Sea and in the North Sea). In this way, the same structures and materials amounts for each couple of similar platforms can be considered. In the following, the analysis will be simply referred to a 4-legged platform with 3 production wells and to a 4-legged platform with 4 production wells. In order to carry out the environmental analysis, the weights of the platform structure and of the equipment and instrumentation present on the platform are necessary. They have been collected by literature review and interviews to private companies and they summarized in Table 1 for the two types of platforms under investigation.

Table 1. Material and weights for the two types of platforms studied.

Component	Material	4-legged platform with 3 production wells	4-legged platform with 4 production wells
		Weight [tonn]	
Steel Jacket	Low-alloyed steel	1333,5	1515.2
Concrete Jacket	Concrete Block	78,1	37.2
Electrical Cables	Copper	30	28
	PVC	10	10
Piping	Low-alloyed steel	245	215
Deck	Low-alloyed steel	425	358.9
Mechanical equipment	Low-alloyed steel	110	50
	Chromium steel 18/8	10	10
Cabins and accessories	ABS	11	10
	Glass	5	4
	Ceramic	11	10
	Aluminium	13	12
	Woven Cotton	5	4
Safety	Low-alloyed steel	65	60
Old photovoltaic panels	Photovoltaic glass	1,2	1.2
Instrumentation	Aluminium	5	3
	Copper	3	2
	Low-alloyed steel	5	5
	PVC	3	2

2.3. New instrumentation

New machinery, instrumentation and equipment have been chosen by commercial datasheets in order to carry out the design of the different considered energy systems and to conduct the LCA and DCFA analysis. They are described here below.

For the wind energy production, the turbine model chosen develops a nominal power of 3.6MW and presents a rotor with a diameter of 107m. The rotor is sited on an 80m-high tower.

As hydrogen generator, it has been chosen a 3-bladed, horizontal axis model characterized by a hydrogen production of 170.6m^3/h and an oxygen production of 85.3m^3/h. It weights 15,200kg and it produces hydrogen with a purity of 99.5% and oxygen with a purity of 99%. It consumes 912kW/h and 144L of water at the maximum power operating condition.

The monocrystalline photovoltaic panel model chosen to form an offshore solar park is made by Solar World AG and it is lightweight, has a good quality and it is resistant to the marine environment. The main characteristics of the panel are: length of 1675mm, width of 1001mm, height of 33mm and weight of 18kg.

For the methanation process, a Sabatier Reactor has been chosen. The Sabatier Reactor is an innovative instrumentation [13]. For the present study, confidential data have been provided by Audi. The main characteristics of the reactor tower are the following: weight of 81t, height of 16m and length of 7.8m.

To produce fresh water, an industrial reverse osmosis desalter has been chosen. It is composed by 48 membranes contained in horizontal pressure vessels of various lengths to achieve maximum yield. The weight of the desalter is 1600kg. In addition, high voltage cables are considered to transport the electricity produced offshore to land.

2.4. Technical scenarios

The investigated scenario of the RELife project are summarized in Table 2. Each scenario has been studied both for Adriatic and North Sea.

Table 2. RELife project. Technical scenarios.

Scenario	Description
S1	Offshore wind farm for offshore hydrogen and electricity production
S2	Offshore wind farm for offshore hydrogen and electricity production and onshore methanation process
S3	Offshore floating panels park for offshore hydrogen and electricity production
S4	Offshore floating panels park for offshore hydrogen and electricity production and onshore methanation process
S5	Mixed plant (wind and solar) for offshore hydrogen and electricity production
S6	Mixed plant (wind and solar) for offshore hydrogen and electricity production and onshore methanation process
S7	Offshore wind farm for offshore desalination and electricity production
S8	Offshore floating panels park for offshore desalination and electricity production
S9	Mixed plant (wind and solar) for offshore desalination and electricity production

The different scenarios have been technically designed on the basis of the characteristic of the instrumentation chosen (and described in the previous section).

Scenarios S1 and S2 involve an offshore wind farm as RES coupled with hydrogen generators located on the offshore platform. Of course, also an electric hub is considered. For what concerns the case related to the Adriatic Sea, due to unavailability of existing offshore wind farms, it has been considered a hypothetic wind farm composed by 30 turbines and designed on the basis of the sun availability in the Adriatic Sea. In addition, by considering that the capacity factor of the wind farm represents the energy produced over a period with respect to the energy produced if the plant works at its nominal power, it has been calculated that the capacity factor of the wind farm situated in the Adriatic Sea is 25% [14], corresponding to approximately 2200 operating hours per year at nominal power condition. Instead, for the North Sea, it has been chosen an existing wind farm as RES in order to optimize costs and environmental impacts related to the construction of new RES. In addition, the wind farm considered is located near the platform individuated for this study and this allow also a real technical feasibility. The main characteristic of the wind farm located in the North Sea are summarized in Table 3.

Table 3. Characteristics of an existing offshore wind farm in the North Sea.

Project capacity	165MW
Numbers of turbines	55
Capacity factor	38%
Hub height	72m
Rotor Diameter	90m
Foundation	Grounded: Monopile
Distance from shore	46km
Depth range	15–24m

The alternative to the offshore wind farm is represented in the scenarios S3 and S4 by an offshore solar park. It is considered to be composed of thousands of photovoltaic panels positioned on a floating structure and specifically designed to withstand the adverse marine environment, waves and tides movements.

The commercial solution to this kind of problems has not yet been realized, but there are many studies about it. One of the most promising seems to be the research carried out by a team of scientists at the Vienna Technical University. They are designing a commercial floating structure called “Heliofloat”. It is based on a patented pressure based skirt system which is connected through a light weight structure. The flexible membrane and the air cushion reduce the wave excitation to a minimum. These two features minimize the material input and maximize the stability against waves and bad weather conditions. It has been calculated that 195,000 photovoltaic panels are required for the scenario S2, each one with a power of 300W, reaching a total nominal power of 58.5MW. The layout of the numerous photovoltaic panels has been optimized, and they have been arranged to form rectangular substructures containing 1500 panels, which are assembled together to form what is called “island”. The island consists of 10 rectangular substructures arranged on two rows, for a total of 15,000 photovoltaic panels, and they occupy an area of approximately 48,600m^2. Overall, the project requires the construction of 13 photovoltaic islands. Regarding the production of energy from the PV panels, it has been considered that each megawatt installed produces 1300MWh per year [15]. This value is relative to central Italy only.

The scenarios S3, S4 and S8 have not been studied for the North Sea due to the low incident solar radiation, which could lead to a production of 900–1000MWh annually for each megawatt installed. This discourages the scenario with the only floating solar plant (S2), but it could still represent a good solution to support the wind power production, so only the case of the mixed plant has been studied (S5 and S6). For the North Sea, the scenarios S5 and S6 involve the combined production of energy by wind farm (165MW) and solar plant (36MW), for a nominal total power of 201MW. The initial investment to be carried out would be related to the only solar plant, since the wind farm already exists. Instead, for the Adriatic Sea, the 15 wind turbines and 97,500 photovoltaic panels have been chosen, with a total nominal power of 83.25MW.

The case of desalination of marine water has been also taken into account for the purpose of water supply in periods of necessity, for the Italian scenario. It may be useful for industrial processes, farming uses, etc. This scenario can be achieved through the chosen industrial desalter, which produces 29,000m^3/h of fresh water with an electrical consumption of 180kW. 40 machines have been considered installed on the platform, 18 on the first and second floor, 4 on the third floor, for a total water flow of 1,160,000l/h. The three scenarios, S7, S8, and S9, consider as RES the wind farm, the offshore floating solar park and the mixed plant described above. For the mixed plant in the North Sea (S9), all the necessary instrumentation is the same as for the Adriatic Sea; the substantial difference is the different solar incident radiation [16] with an average solar production in this area of about 1000kWh/year per kW installed.

It is important to point out that the technical scenarios have been chosen specifically for the geographic sites investigated and, therefore, they are specific for this particular case. In addition, they have been developed also according suggestions by some Oil Companies interested in this project. When the project proposed is applied to other countries, an integrated energy planning is requested on the basis of the RES availability of each platform.

2.5. Discounted Cash Flow Analysis

As suggested by Giacchetta et al. [17,18]; beyond its technical performance, no engineering projects can be considered desirable, if it is not accompanied by a solid financial sustainability. In this work, the economic analysis of all the technical scenarios of the RELife project has been performed on the basis of the Discounted Cash Flow Analysis (DCFA).

The main Equations used for the DCFA are the following:

$$C_t = C_{tf} + C_{OM} \tag{1}$$

where C_t is the Total Annual Cost ($/year), C_{tf} is the Total Fuel Cost ($/year) and C_{OM} represents the Total O&M Cost ($/year);

$$OI = R_t - C_t \tag{2}$$

where OI is the Operative Income and R_t is the Total Annual Revenue ($/year): it is assumed to be equal to the Total Revenue by the sale of produced oil;

$$A_k = {}^{C_c}/_{P_{amm}} \tag{3}$$

where is k the considered year, A_k the amortization, C_c the Capital Cost and P_{amm} is amortization period;

$$TO = \mathrm{OI} - A_k \tag{4}$$

where TO is the Total Operating;

$$Tax = TO * t \tag{5}$$

$$NI = OI - Tax \tag{6}$$

$$DCF_k = \frac{NI_k}{(1+i)^k} \tag{7}$$

where *I* represents the Discount Rate;

$$NPV = -C_c + \sum_{k=1}^{n} \frac{NI_k}{(1+i)^n} \tag{8}$$

In addition to NPV (Net Present Value), the internal rate of return (IRR) and payback period (PBP) have been also considered to evaluate the financial performance of the various scenarios [19,20].

Results in terms of PBP and NPV have been drawn and discussions have been conducted considering also the cost of a standard decommissioning scenario.

All the economic information considered for the economic analysis of the various reconversion scenarios are reported here below. They have been collected by literature [[21], [22], [23], [24]] or through interviews with industrial suppliers and engineers. A life period of 20 years has been considered for all the reconversion systems analyzed because this is medium life time of both solar panels and wind farms [17,18,25,26].

Table 4 shows the initial investment and the maintenance costs (for 20 years) relating to the new machinery installed on the platform investigated in both Adriatic Sea and North Sea.

Table 4. Initial investment and the maintenance costs of new instrumentation.

Instrumentation	Initial Investment (€)	Maintenance Costs (€)	Initial Investment (€)	Maintenance Costs (€)
	Adriatic Sea		**North Sea**	
Desalter	€ 20,000	€ 80,000	€ 20,000	€ 80,000
High voltage cables	€ 110,000,000	€ 11,000,000	€ 75,000,000	€ 7,500,000
Hydrogen Generators	€ 13,200,000	€ 14,208,000	€ 17,600,000	€ 18,944,000

Sabatier Reactor	€ 10,000,000	€ 7,000,000	€ 10,000,000	€ 7,000,000
Industrial Desalter	€ 16,000,000	€ 2,400,000	€ 16,000,000	€ 3,200,000
Wind farm	€ 360,000,000	€ 38,880,000	€ 0.0	€ 59,400,000
Solar Plant	€ 163,800,000	€ 24,570,000	–	–
Mixed Plant	€ 261,900,000	€ 31,725,000	€ 100,800,000	€ 74,520,000

The sales prices of the different products investigated have been found in literature and they are related to the Italian market for the Adriatic Sea and to the Belgian market for the North Sea. They are summarized in Table 5.

Table 5. Sales prices of various products.

Product	Adriatic Sea	North Sea
SNG (€/Nm^3)	0.80	0.80
Hydrogen (€/kg)	8	8
Electricity (€/kWh)	0.065	0.085
Fresh water (€/m^3)	1.30	1.60

Table 6, Table 7 show the CAPEX and OPEX calculated for both the Adriatic Sea and the North Sea, with also the total revenues due to the sale of electricity, SNG and hydrogen over the 20 years of expected production. The discount rate value has been fixed equal to 5.4 (it has been assumed taking into account the actual inflation and a tax rate value of 30% has been used [27]).

Table 6. CAPEX and OPEX of the different Scenarios. Adriatic Sea.

Scenario	CAPEX (€)	Maintenance Costs (€)	Total revenues (€)	Transport Costs (€)	OPEX (€)
S1	483,220,000	64,168,000	4,094,274,730	40,527,545	104,695,545
S2	493,220,000	71,168,000	1,880,973,130	81,725,825	152,893,825
S3	287,020,000	49,858,000	3,906,524,830	39,949,853	89,807,853
S4	297,020,000	56,858,000	1,693,223,230	81,148,133	138,006,133
S5	275,120,000	57,013,000	4,000,399,780	40,238,699	97,251,699
S6	395,120,000	64,013,000	1,787,098,180	81,436,979	145,449,979

S7	486,000,000	52,280,000	371,932,080	31,617,742	83,897,742
S8	289,800,000	37,970,000	184,182,180	31,040,050	69,010,050
S9	387,900,000	45,125,000	278,057,130	31,328,896	76,453,896

Table 7. Table 6 CAPEX and OPEX of the different Scenarios. North Sea.

Scenario	CAPEX (€)	Maintenance Costs (€)	Total revenues (€)	Transport Costs (€)	OPEX (€)
S1	17,620,000	78,424,000	5,907,408,667	54,747,072	133,171,072
S2	27,620,000	85,424,000	3,662,465,947	95,945,352	181,369,352
S5	193,420,000	101,044,000	5,956,980,667	54,863,712	155,907,712
S6	203,420,000	108,044,000	3,712,037,947	96,061,992	204,105,992
S7	16,000,000	62,600,000	954,691,080	32,743,577	95,343,578
S9	191,800,000	85,220,000	1,004,263,080	32,860,217	118,080,218

3. Results

3.1. Energy flows

On the basis of the instrumentation chosen and described in Section 2.3, the energy flow balance for each scenario presented in Section 2.4 has been calculated. The input and output of the energy flow balances are necessary to perform both the economic and environmental analyses. In the present paper, the energy flow balances and the results related to only the 4-legged platform with 4 production wells are reported. The same conclusions can be drawn for the 4-legged platform with 3 production wells. Table 8, Table 9, Table 10, Table 11, Table 12, Table 13, Table 14 report the energy flows calculated for all the scenarios investigated, in both Adriatic Sea and North Sea.

Table 8. S1 and S2 energy flows. Adriatic Sea.

	INPUT	OUTPUT
Wind farm nominal power	108MW	
Hydrogen generator electricity consumption	10.94MW	
Sea water consumption	1728m^3/h	

Sabatier reactor electricity consumption	6MW	
SNG hourly production (S2)		$422m^3/h$
Hydrogen production (S2)		$747.2m^3/h$
Hydrogen production (S1)		$2047.2m^3/h$
CO_2 consumption (S2)	325 Nm^3/h	
Additional annual current production (S2)		146,075MWh
Additional annual current production (S1)		169,727MWh

Table 9. S1 and S2 energy flows. North Sea.

	INPUT	OUTPUT
Wind farm nominal power	165MW	
Hydrogen generator electricity consumption	14.60MW	
Sea water consumption	$2304m^3/h$	
Sabatier reactor electricity consumption	6MW	
SNG hourly production (S2)		$422m^3/h$
Hydrogen production (S2)		$1429.6m^3/h$
Hydrogen production (S1)		$2729.6m^3/h$
CO_2 consumption (S2)	325 Nm^3/h	
Additional annual current production (S2)		8,262,432MWh
Additional annual current production (S1)		8,735,472MWh

Table 10. S3 and S4 energy flows. Adriatic Sea.

	INPUT	OUTPUT
Solar plant nominal power	58.5MW	
Hydrogen generator electricity consumption	10.94MW	
Sea water consumption	$1728m^3/h$	

Sabatier reactor electricity consumption	6MW	
SNG hourly production (S4)		422m^3/h
Hydrogen production (S4)		1300m^3/h
Hydrogen production (S3)		2047.2m^3/h
CO_2 consumption (S4)	325m^3/h	
Additional annual current production (S4)		1652MWh
Additional annual current production (S3)		25,304MWh

Table 11. S5 and S6 energy flows. Adriatic Sea.

	INPUT	OUTPUT
Mixed plant nominal power	83.25MW	
Hydrogen generator electricity consumption	10.94MW	
Sea water consumption	1728m^3/h	
Sabatier reactor electricity consumption	6MW	
SNG hourly production (S6)		422m^3/h
Hydrogen production (S6)		1300m^3/h
Hydrogen production (S5)		2047.2m^3/h
CO_2 consumption (S6)	325m^3/h	
Additional annual current production (S6)		73,863MWh
Additional annual current production (S5)		97,515MWh

Table 12. S5 and S6 energy flows. North Sea.

	INPUT	OUTPUT
Mixed plant nominal power	201MW	
Hydrogen generator electricity consumption	14.60MW	
Sea water consumption	2304m^3/h	

Sabatier reactor electricity consumption	6MW	
SNG hourly production (S6)		$422 m^3/h$
Hydrogen production (S6)		$1429.6 m^3/h$
Hydrogen production (S5)		$2729.6 m^3/h$
CO_2 consumption (S6)	$325 m^3/h$	
Additional annual current production (S6)		8,845,632MWh
Additional annual current production (S5)		9,318,672MWh

Table 13. S7, S8, S9 energy flows. Adriatic Sea.

	INPUT	OUTPUT
Wind farm nominal power	108MW	
Solar plant nominal power	58.5MW	
Mixed plant nominal power	83.25MW	
Freshwater production (S7, S8, S9)		$1.016\times10^8 m^3$
Additional annual current production (S7)		236,520MWh
Additional annual current production (S8)		76,050MWh
Additional annual current production (S9)		156,285MWh

Table 14. S7, S9 energy flows. North Sea.

	INPUT	OUTPUT
Wind farm nominal power	165MW	
Mixed plant nominal power	201MW	
Freshwater production (S7, S9)		$1.016\times10^8 m^3$
Additional annual current production (S7)		9,318,888MWh
Additional annual current production (S9)		9,902,088MWh

3.2. Environmental analysis

The weights of all components and instrumentation present on the platform investigated have been collected by literature [28] and interviews to an International Oil Company in order to carry out the LCA analysis. Table 1 presents the material and weights of the components constituting the platform investigated at its end of life time, while Table 15 summarizes all the materials and the relative weights of the new instrumentation chosen on commercial datasheets. They have been implemented in the SimaPro software. As described by Herrmann and Moltesen [29]; SimaPro is an assessment software and product system modeling. It includes an user interface for modeling the product system, a life cycle unit process database, an impact assessment database (with data supporting several life cycle impact assessment methodologies), and a calculator that combines numbers from the databases.

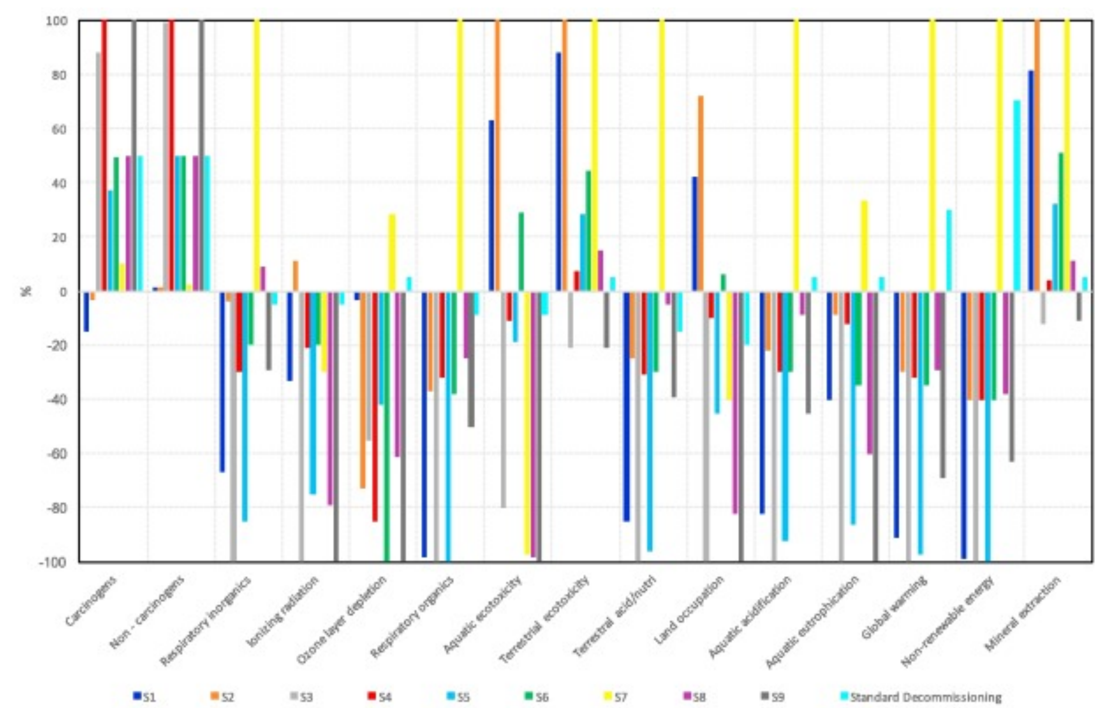
Table 15. Materials and the weights of the new instrumentation.

Element	Material	Weight [tonn]	
		Adriatic Sea	North Sea
Wind Turbine	Alloyed steel	30×200	–
	Alloyed steel	30×95	–
	Glass fiber	30×125	–
	Copper and PVC		–
	Alloyed steel		–
Floating System	PVC	12,460.5	–7670
Photovoltaic Panels	Photovoltaic glass	3510	2160
Solar cables	Copper, PVC,	33.15	20.40
	Aluminium		
Hydrogen Generator	Alloyed steel	12×15.2	16×15.2
	Aluminium		
	PVC		
Sabatier Reactor	Alloyed steel, Copper, PVC	81	81
Desalter	/	0.3	0.3
Industrial Desalter	Alloyed steel, PVC	40×1.6	40×1.6
Turbine Jacket	Low-alloyed steel	30×1000	–
Electrical cables	Copper, PVC	237,3	–

The application of the LCA methodology was carried out using the Ecoinvent database and the "Electricity, medium voltage, production UCTE, at grid/UCTE S" dataset [30]. This dataset is suggested by the standards for the majority of industrial processes such as those of steel, automotive, chemical industries, etc [31].

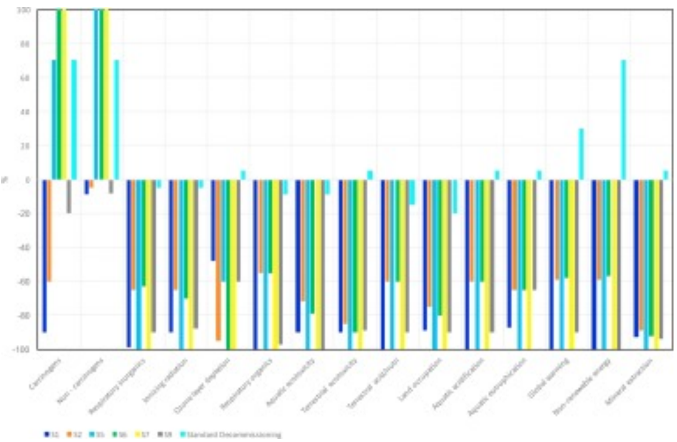
The environmental impact, it has been assessed by IMPACT 2002 + method and the contribution of each phase of the analyzed process has been calculated. Four damage categories have been evaluated (Human health, Ecosystem quality, Climate change and Resources) through the estimation of fifteen midpoint categories: carcinogens, non-carcinogens, respiratory inorganics, ionizing radiation, ozone layer depletion, respiratory organics for the evaluation of the category Human health; aquatic eco-toxicity, terrestrial ecotoxicity, terrestrial acid/nutria, aquatic acidification, aquatic eutrophication and land occupation for the Ecosystem quality; global warming in order to evaluate the Climate change and non-renewable energy and mineral extraction for the last damage class (Resources). The results related to the various developed scenarios have been compared with the ones related to standard decommissioning scenario in order to assess the positive environmental impact of the reuse of offshore oil and gas platforms. The standard decommissioning scenario consists in the total disposal of all the materials on the platform: those materials are moved to the land and then they could be both recycled (with appropriate percentages) or disposed in landfill.

Fig. 4, Fig. 5 show the damage assessment for each of the fifteen different categories of impact related to all the scenarios for the Adriatic Sea and the North Sea, respectively. The histograms Fig. 4, Fig. 5 show that the platforms reuse has a positive effect in many impact categories, especially for the North Sea case where an existing wind farm can be used, avoiding the environmental impact of its construction. In fact, while for the Adriatic Sea, the most promising solution from the environmental point of view is Scenario 3, i.e. the hydrogen production from an offshore floating solar farm, for the North Sea the best solution is the exploitation of offshore wind energy for the hydrogen production (Scenario 1).



Download : Download high-res image (487KB) Download : Download full-size image

Fig. 4. Damage assessment for categories of impact. S1–S9 Scenarios vs Standard decommissioning process. Adriatic Sea.



Download : Download high-res image (234KB) Download : Download full-size image

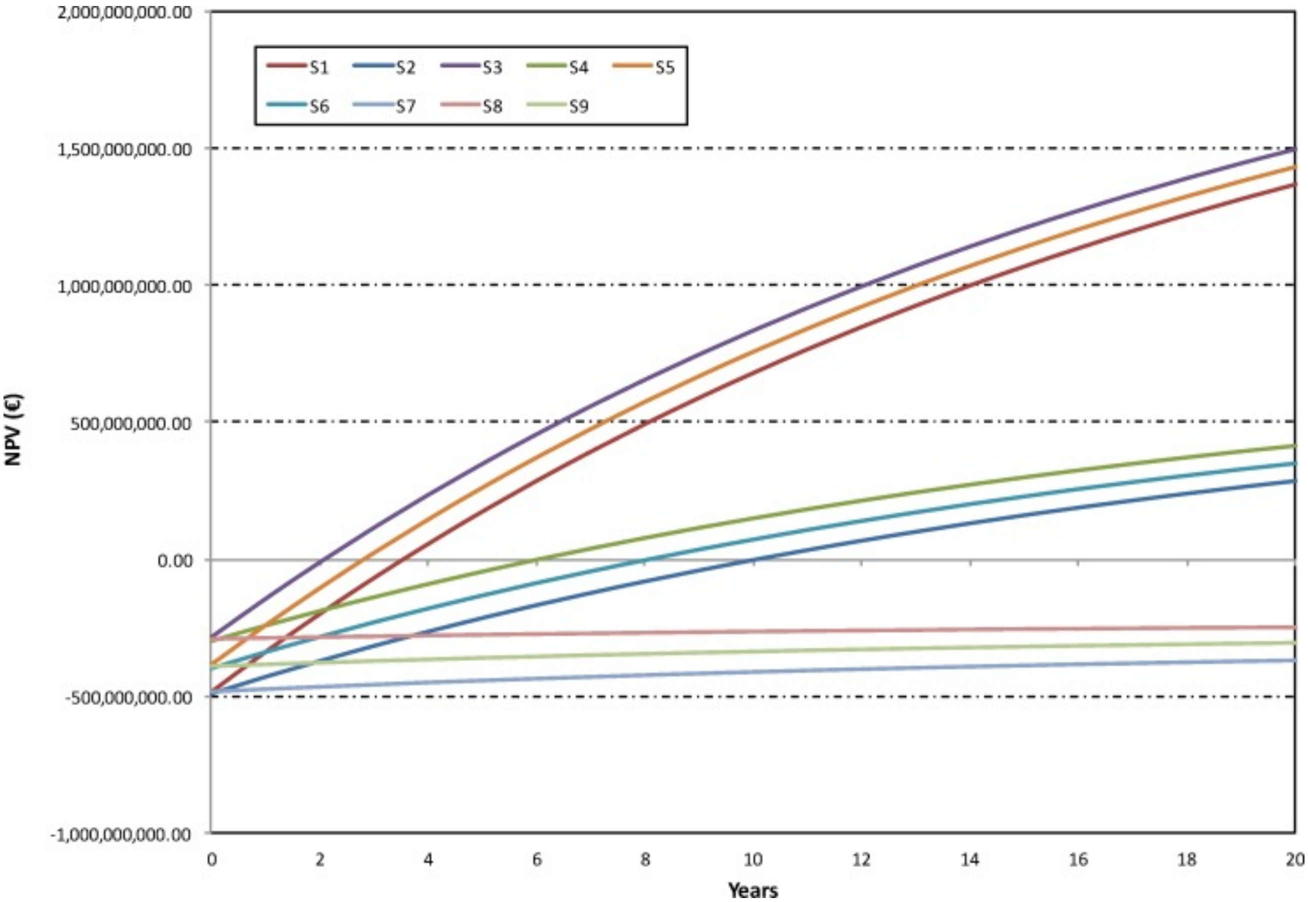
Fig. 5. Damage assessment for categories of impact. S1–S9 Scenarios vs Standard decommissioning process. North Sea.

3.3. Economic analysis

A Discounted Cash Flow Analysis (DCFA) for the RELife project's scenarios (S1–S9) has been performed as described in Section 2.5 for both the Adriatic and North Sea.

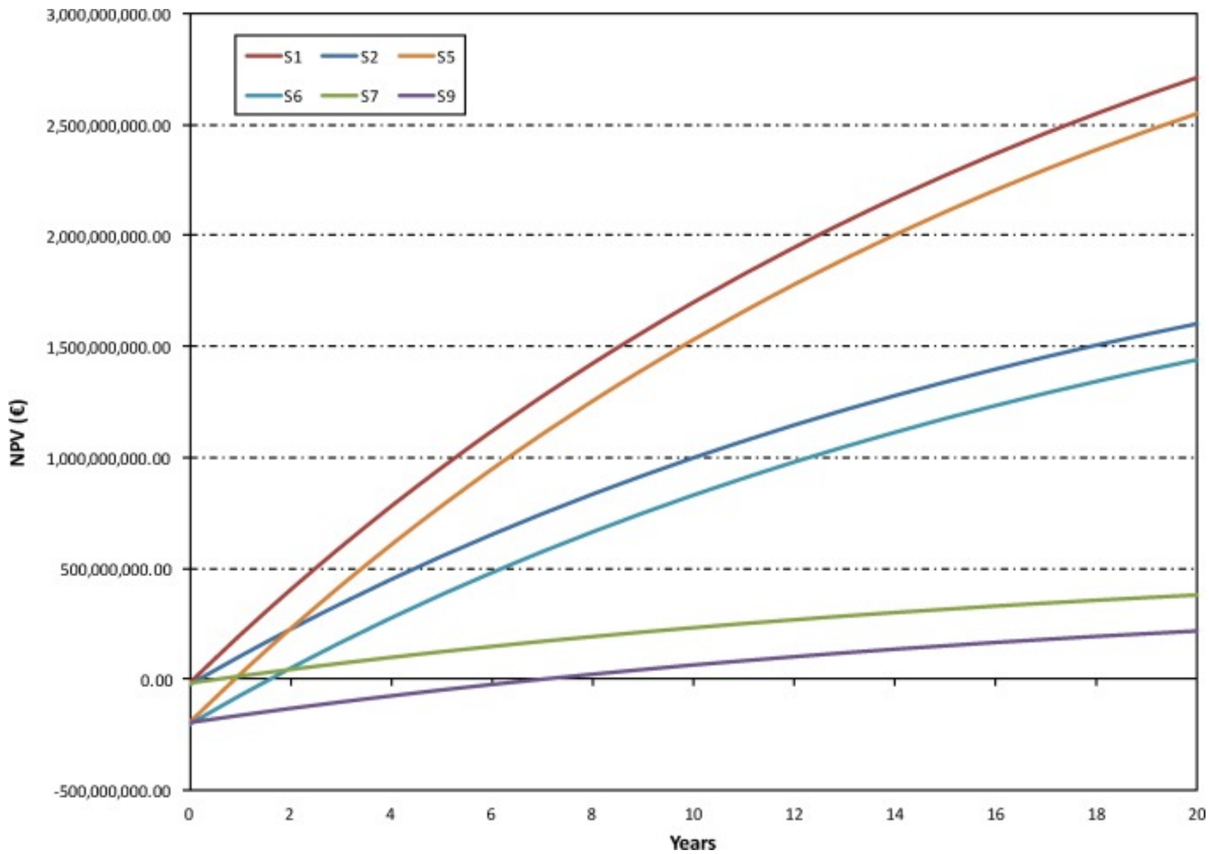
In a DCFA, after tax cash flows are “discounted” in order to reflect the preference for current consumption over future consumption, a discount rate is used to convey this preference and discount future cash flows to present value. A real (net of inflation) discount rate of 5.4% has been used in this study.

In Fig. 6, Fig. 7, Table 16, Table 17 the main results of the relative Discounted Cash Flow Analysis expressed on the basis of the parameters defined in Section 2.5 are reported.



Download : Download high-res image (495KB) Download : Download full-size image

Fig. 6. NPV trends for Scenarios S1–S9. Adriatic Sea.



Download : Download high-res image (428KB) Download : Download full-size image

Fig. 7. NPV trends for Scenarios S1–S9. North Sea.

Table 16. DCFA results for Scenarios S1–S9. Adriatic Sea.

Scenario	NPV (€)	PBP (years)	IRR (%)
S1	1.37E+09	3	7
S2	2.89E+08	10	2
S3	1.49E+09	1	10
S4	4.12E+08	4	4
S5	1.43E+09	1	8
S6	3.50E+08	6	3
S7	–3.70E+08	/	–7

S8	–2.47E+08	/	–9
S9	–3.08E+08	/	–8

Table 17. DCFA results for Scenarios S1–S9. North Sea.

Scenario	NPV (€)	PBP (years)	IRR (%)
S1	2.71E+09	0	22
S2	1.61E+09	0	18
S5	2.24E+09	0	12
S6	1.49E+09	1	10
S7	3.81E+08	0	17
S9	2.66E+08	6	5

For what concerns the Adriatic Sea (Fig. 6 and Table 7), the following conclusions can be drawn:

- all the proposed scenarios, except for the ones involving the desalination process (S7, S8, S9), provide a positive return of the investment and a positive IRR;
- the most profitable product is the hydrogen, followed by electricity and finally by the synthetic natural gas (SNG); the direct sale of hydrogen as an energy carrier is more profitable than SNG sale, essentially for two reasons:
  1. hydrogen production is three times higher than that of SNG;
  2. the unit cost (€/kg) of the hydrogen is considerably higher than that of SNG.
- the best scenario from the economic point of view is the one that uses solar power rather than wind power (S3). This depends on the considerable difference between initial investments between the two scenarios. The mixed scenario is a compromise between the two situations, as foreseeable;
- the payback period (PBP) is higher in the case of the wind farm (S1 and S2), because of its higher initial investment;
- the option for producing fresh water from Adriatic Sea water is economically unfavorable in all scenarios considered. This is due to low fresh water selling price and its high transport costs. This scenario must be considered for the geographic areas where the fresh water shortage is a real problem.

The most convenient scenario in the Adriatic Sea is therefore S3, with the hydrogen production (and selling as energetic vector) for renewable photovoltaic energy.

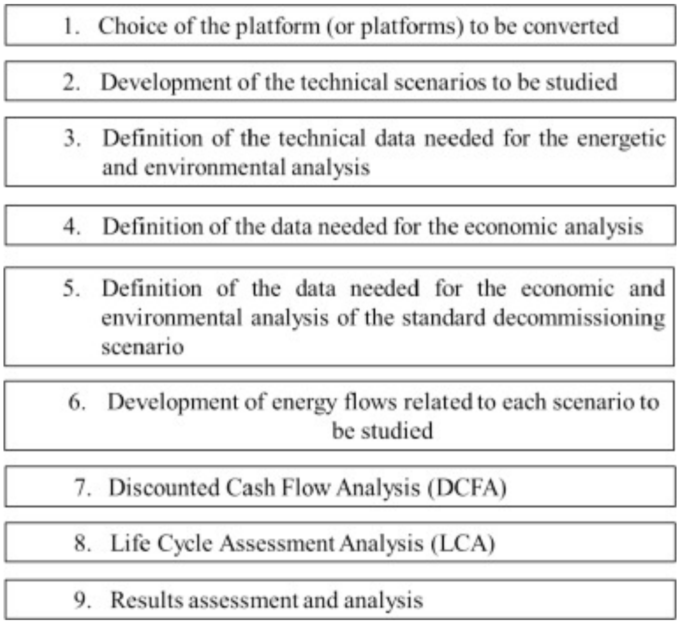
Instead, in the North Sea, different conclusions can be summarized (from Fig. 7 and Table 17):

- all of the scenarios show a positive return on investment, a very short PBP and a very positive IRR;
- the scenarios involving the wind farm are the most advantageous from an economic point of view, both in the case of methanation (S2) and the hydrogen production alone (S1). This is due to the fact that the initial investment is not present, so all the revenues immediately generate profit;
- the scenario with fresh water production is favorable in the case of wind farm (S7), whereas it is less favorable in the case of the mixed plant (S9). This is due to the greater initial investment and to the lower selling price of the fresh water.

In the context of the economic feasibility analysis, it must be pointed out that it has been considered that Oil & Gas companies are interested in making new investments; of course, when the RELife project must be applied to other platforms and other countries, first of all companies interested in new investments must be individuated.

3.4. Generalization of the proposed methodology

The particular case here investigated and presented under the RELife project is referred to two specific geographic sites and to reconversion scenarios based on specific RES systems chosen by the authors (on the basis of suggestions by Oil and Gas companies and literature data). However, the RELife project can be applied to different geographic areas worldwide and to various technical reconversion scenarios. The methodology here applied can be therefore generalized and it can be summarized as shown in Fig. 8. In particular, when the RELife project must be applied to a new case, the platforms to be converted into sites for renewable energy production must be chosen (Step 1) and all the technical scenarios to be studied must be developed (Step 2) according to the RES potential in the selected geographic area. Then, all the technical data needed for the energetic and environmental analysis and the data requested for the economic analysis must be collected (Step 3 and Step 4); these data are summarized in Table 18. In addition, the data needed for the economic and environmental analysis of the standard decommissioning scenario must be collected (Step 5) in order to compare the results of the new scenarios with those obtained studying a standard decommissioning scenario. After that, the energy flows related to each scenario to be studied must be developed (Step 6) and both the economic (DCFA) and the environmental analyses (LCA) (Step 7 and Step 8) can be carried out. As last step (Step 9), one of the most important and hard steps, conclusions must be drawn. In particular, they can be drawn from the environmental impact of each scenario and its economic feasibility. It is not easy to decide how the environmental impacts affect the final decision and how to compare it to the economic feasibility analysis. In fact, as suggested by Giacchetta et al. [32]; beyond its technical performance, no engineering project can be considered desirable, if it is not accompanied by a solid financial sustainability. On the other hand, the environmental impact is of vital importance in a period of energy transition which goes towards a global decarburization. In the light of this, a good compromise must be selected by the engineer or the researcher who apply the RELife project's methodology. Luckily, most likely, a high potential of RES in a specific site corresponds to a low environmental impact due to the possibility to exploit a green energy source and, when and where there is the possibility to easily exploit a renewable energy source, the economic feasibility of the project is high. However, a complete analysis of the results must be carried out and all the additional considerations (for example, the presence of companies interested in making any new investment) must be taken into account.



Download : Download high-res image (181KB) Download : Download full-size image

Fig. 8. General methodology of the RELife project.

Table 18. Required input for the RELife project.

Technical	Economic
Materials and weights of the platforms studied	Life period of the reconversion systems
RES availability	Investment costs
	Maintenance costs
New instrumentation requested for the reconversion: weights, materials and electricity consumptions	Costs of the standard decommissioning scenario
	Costs and recycling gains
Data related to the standard decommissioning scenario (disposal percentages, recycled percentages, transport emissions)	Transport and infrastructures costs
	Costs of the standard decommissioning scenario
Additional	Real discount rate

4. Conclusions

The decommissioning of aging offshore oil and gas platforms will increase dramatically in the next coming years. In order to help a decision-making process, the RELife project has been developed. It consists of the study of various technical scenarios for the reconversion of offshore platforms at the end-of-life stage into sites for the production of renewable energy.

In this context, this paper presented 9 scenarios of reconversion of one 4-legged platform with 4 production wells situated in the Adriatic Sea and one 4-legged platform with 4 production wells situated in the North Sea, in order to assess the impact also of the different availabilities of renewable sources. The scenarios studied involve the energy production from a wind farm and an offshore photovoltaic floating park. The renewable energy produced is considered exploited to produce hydrogen, to permit the methanation process or to produce fresh water from the desalination process. After the calculation of the energy flows for all the scenarios, a Life Cycle Assessment (LCA) analysis has been performed for all the options. The LCA demonstrated that all the alternative platform reconversion scenarios present positive environmental effects in most of the impact categories evaluated with respect to the standard decommissioning scenario.

The RELife project for the reuse of offshore oil and gas platforms for the renewable energy production represents not only a way to lower the environmental impact of their decommissioning phase but also an important business possibility. Therefore, a DCFA (Discounted Cash Flow Analysis) has been performed to assess the financial sustainability of the investigated scenarios: it has been calculated that, in the Adriatic Sea, where there is not large wind energy availability, the offshore photovoltaic floating park is the more convenient RES (Renewable Energy System) and if it is coupled with the hydrogen production on the offshore platform, it represents a very profitable scenario. Instead, in the North Sea, where existing wind farms can be used to produce renewable energy which can be exploited for different processes on the offshore platform, the scenarios involving the energy produced by the wind is the most economically convenient.

Recommended articles Citing articles (5)

References

[1] E. Foster, M. Contestabile, J. Blazquez, B. Manzano, M. Workman, N. Shah
The unstudied barriers to widespread renewable energy deployment: fossil fuel price responses
Energy Policy, 103 (2017), pp. 258-264
Article Download PDF View Record in Scopus Google Scholar

[2] C. Brandoni, B. Marchetti, G. Ciriachi, F. Polonara, M. Leporini
The impact of renewable energy systems on local sustainability
Int. J. Prod. Qual. Manag., 18 (2–3) (2016), pp. 385-402
CrossRef View Record in Scopus Google Scholar

[3] D. Dall'Acqua, A. Terenzi, M. Leporini, V. D'Alessandro, G. Giacchetta, B. Marchetti
A new tool for modelling the decompression behaviour of CO2 with impurities using the Peng-Robinson equation of state

Appl. Energy, 206 (2017), pp. 1432-1445
Article Download PDF View Record in Scopus Google Scholar

[4] D.F. Ferreira, S.B. Suslick
Identifying potential impacts of bonding instruments on offshore oil projects
Resour. Policy, 27 (1) (2001), pp. 43-52
Article Download PDF View Record in Scopus Google Scholar

[5] S.P. Truchon, L.P. Brzuzy, D. Fawcett, M. Fonseca
Innovative assessments for selecting offshore-platform-decommissioning alternatives
Oil Gas Facil., 4 (05) (2015), pp. 47-55
CrossRef View Record in Scopus Google Scholar

[6] A.M. De Biasi, G. Fabi, L. Pacciardi, F. Gai, S. Ferrari, M. Puletti, S. De Ranieri
Monitoraggio di una piattaforma di estrazione nel Mar Adriatico settentrionale: metalli pesanti
Atti Società Toscana Scienze naturali, Memorie, Serie B, 113 (2006), pp. 83-89
View Record in Scopus Google Scholar

[7] B. Trabucco, C. Maggi, L. Manfra, O. Nonnis, R. Di Mento, M. Mannozzi, M. Gabellini
Monitoring of impacts of offshore platforms in the Adriatic Sea (Italy)
Advances in Natural Gas Technology, InTech (2012)
Google Scholar

[8] V. Parente, D. Ferreira, E. Moutinho dos Santos, E. Luczynski
Offshore decommissioning issues: deductibility and transferability
Energy Policy, 34 (2006), pp. 1992-2001
Article Download PDF View Record in Scopus Google Scholar

[9] B.A. Hamzah
International rules on decommissioning of offshore installations: some observations
Mar. Policy, 27 (4) (2003), pp. 339-348
Article Download PDF View Record in Scopus Google Scholar

[10] A.M. Fowler, P.I. Macreadie, D.O.B. Jones, D.J. Booth
A multi-criteria decision approach to decommissioning of offshore oil and gas infrastructure
Ocean Coast Manag., 87 (2014), pp. 20-29
Article Download PDF View Record in Scopus Google Scholar

[11] M.D. Day, A. Gusmitta
Decommissioning of offshore oil and gas installations
S. Orszulik (Ed.), Environmental Technology in the Oil Industry, Springer, Cham (2016)
Google Scholar

[12] E.J. Techera, J. Chandler
Offshore installations, decommissioning and artificial reefs: do current legal frameworks best serve the marine environment?

Mar. Policy, 59 (2015), pp. 53-60
Article Download PDF View Record in Scopus Google Scholar

[13] B. Castellani, S. Rinaldi, E. Bonamente, A. Nicolini, F. Rossi, F. Cotana
Carbon and energy footprint of the hydrate-based biogas upgrading process integrated with CO 2 valorization
Sci. Total Environ., 615 (2018), pp. 404-411
Article Download PDF View Record in Scopus Google Scholar

[14] T. Soukissian, F. Karathanasi, P. Axaopoulos, E. Voukouvalas, V. Kotroni
Offshore wind climate analysis and variability in the Mediterranean Sea
Int. J. Climatol., 38 (1) (2018), pp. 384-402
CrossRef View Record in Scopus Google Scholar

[15] M. Rosa-Clot, G.M. Tina, S. Nizetic
Floating photovoltaic plants and wastewater basins: an Australian project
Energy Procedia, 134 (2017), pp. 664-674
Article Download PDF View Record in Scopus Google Scholar

[16] M. Šúri, J. Hofierka
A new GIS-based solar radiation model and its application to photovoltaic assessments
Trans. GIS, 8 (2) (2004), pp. 175-190
View Record in Scopus Google Scholar

[17] G. Giacchetta, M. Leporini, B. Marchetti
Evaluation of the economic impact of a new high value process for the management of the end of life of thin film photovoltaic modules
Int. J. Prod. Qual. Manag., 15 (4) (2015), pp. 528-541
CrossRef View Record in Scopus Google Scholar

[18] G. Giacchetta, M. Leporini, B. Marchetti
Economic and environmental analysis of a Steam Assisted Gravity Drainage (SAGD) facility for oil recovery from Canadian oil sands
Appl. Energy, 142 (2015), pp. 1-9
Article Download PDF View Record in Scopus Google Scholar

[19] I.K. Bhat, R. Prakash
LCA of renewable energy for electricity generation systems- a review
Renew. Sustain. Energy Rev., 13 (5) (2009), pp. 1067-1073
Google Scholar

[20] R. Briller
Discounted cash flow analysis to select equipment
J. Environ. Eng., 102 (EE3) (1976)
Google Scholar

[21] D.D. Ahiaga-Dagbui, P.E. Love, A. Whyte, P. Boateng
Costing and technological challenges of offshore oil and gas decommissioning in the UK North Sea
J. Construct. Eng. Manag., 143 (7) (2017), Article 05017008
CrossRef Google Scholar

[22] L. Castro-Santos, A. Filgueira-Vizoso, I. Lamas-Galdo, L. Carral-Couce
Methodology to calculate the installation costs of offshore wind farms located in deep waters
J. Clean. Prod., 170 (2018), pp. 1124-1135
Article Download PDF View Record in Scopus Google Scholar

[23] M. Lehner, R. Tichler, H. Steinmüller, M. Koppe
Power-to-gas: Technology and Business Models
Springer (2014)
Google Scholar

[24] B.M. McCann, M. Henrion, B. Bernstein, R.I. Haddad
May). Integrating decision support models with market and non-market value attributes for platform decommissioning: an effective approach for resolving the challenges inherent at the nexus of science and policy
Offshore Technology Conference. Offshore Technology Conference (2017)
Google Scholar

[25] G. Fiorenza, V.K. Sharma, G. Braccio
Techno-economic evaluation of a solar powered water desalination plant
Energy Convers. Manag., 44 (14) (2003), pp. 2217-2240
Article Download PDF View Record in Scopus Google Scholar

[26] L. Ziegler, E. Gonzalez, T. Rubert, U. Smolka, J.J. Melero
Lifetime extension of onshore wind turbines: a review covering Germany, Spain, Denmark, and the UK
Renew. Sustain. Energy Rev., 82 (2018), pp. 1261-1271
Article Download PDF View Record in Scopus Google Scholar

[27] L. Serri, E. Lembo, D. Airoldi, C. Gelli, M. Beccarello
Wind energy plants repowering potential in Italy: technical-economic assessment
Renew. Energy, 115 (2018), pp. 382-390
Article Download PDF View Record in Scopus Google Scholar

[28] S. Chakrabarti
Handbook of Offshore Engineering (2-volume Set)
Elsevier (2005)
Google Scholar

[29] I.T. Herrmann, A. Moltesen
Does it matter which Life Cycle Assessment (LCA) tool you choose?–a comparative assessment of SimaPro and GaBi

J. Clean. Prod., 86 (2015), pp. 163-169
Article Download PDF View Record in Scopus Google Scholar

[30] Pre Consultants
SimaPro 6 LCA Software: the Powerful Life Cycle Solution
(2006)
Available from:
http://www.pre.nl/
Google Scholar

[31] G. Giacchetta, M. Leporini, B. Marchetti
Evaluation of the environmental benefits of new high value process for the management of the end of life of thin film photovoltaic modules
J. Clean. Prod., 51 (2013), pp. 214-224
Article Download PDF View Record in Scopus Google Scholar

[32] G. Giacchetta, M. Leporini, B. Marchetti
Technical and economic analysis of different cogeneration systems for energy production from biomass
Int. J. Prod. Qual. Manag., 7 (2) (2014), pp. 209-228
View Record in Scopus Google Scholar

View Abstract

© 2018 Elsevier Ltd. All rights reserved.

ELSEVIER

About ScienceDirect

Remote access

Shopping cart

Advertise

Contact and support

Terms and conditions

Privacy policy

RELX™

We use cookies to help provide and enhance our service and tailor content and ads. By continuing you agree to the **use of cookies**.
Copyright © 2020 Elsevier B.V. or its licensors or contributors. ScienceDirect ® is a registered trademark of Elsevier B.V.
ScienceDirect ® is a registered trademark of Elsevier B.V.