APPLICATION OF A LIFE CYCLE COST ASSESSMENT MODEL TO WIND OFF SHORE GENERATORS

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Abstract

In this paper a new methodological approach, Life Cycle Cost Assessment, is applied to evaluate the investment concerning a wind offshore plant location in Sicily East Coast, with the aim of highlighting the opportunity for distinguishing the single amounts of costs and of monetary and non-monetary benefits throughout the whole life cycle of the investment.

In particular, we analyze economic quantification of the damage deriving from the construction of the system, divided into environmental impacts due to the construction of a single turbine and environmental impacts as a consequence of the construction of the foundations. The preliminary economic information for the LCCA analysis of the examined wind park offshore regards the management of the monetary capital initially invested, evaluation of the interest rate and other useful parameters, used to compute the present value of the cash-flows accrue during the project lifetime. In particular, the costs for the construction of the plant, disposal of material, operation and maintenance are evaluated. Moreover, the positive cash-flows are quantified as a consequence of the sell of wind energy and Renewable Energy Certificates. In this way, a more precise implementation of the LCCA in whatever type of structural investment is made possible, allowing the examination of all information useful for supporting the decision process.

Riassunto

In questo lavoro la nuova metodologia dell'LCCA è stata applicata alla valutazione di un impianto eolico *off shore* di produzione di energia elettrica, da

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collocare a largo delle coste orientali della Sicilia, allo scopo di analizzare le singole categorie di costi e i differenti benefici monetari e non monetari derivanti dall'intero ciclo di vita di questa tipologia di investimento.

Le informazioni economiche preliminari all'analisi di LCCA relativa al parco eolico *offshore* in esame riguardano la gestione del capitale monetario inizialmente investito, la stima dei tassi di interesse e di altri parametri utili per l'attualizzazione dei costi (e degli eventuali ricavi) complessivi durante tutto il ciclo di vita dell'impianto. In particolare sono stati valutati e quantificati i costi per la realizzazione dell'impianto eolico offshore, i costi dismissione ed i costi operativi. Inoltre sono stati quantificati i ricavi derivanti dalla produzione dell'energia elettrica, sia tramite la sua cessione alla rete sia dalla vendita dei certificati verdi, in modo da analizzare tutte le informazioni chiave per una più esatta scelta di investimenti da parte del decisore.

Key words: Life Cycle Cost Assessment, wind offshore plant, environmental impacts, economic benefits.

Introduction

In a context of eco sustainable development the evaluations and the business decisions have to take into account some technical, economic and environmental aspects. The analysts, in fact, during the environmental study of the productive systems, have pointed out the necessity of setting out an inventory of the costs which, acting in the same way of the inventory weights on the environment obtained analyzing the life cycle (LCA), will allow to individuate the economic opportunity of an innovation related to the choice of more eco compatibility materials for the design of a product.

For this reason the SETAC (1), which has drawn up and published the series rules of the ISO 14040 about the LCA, has undertaken to point out a methodology, called *Life Cycle Cost Assessment* (LCCA) or evaluation of the life cycle cost, as a support instrument to make coherent choices in terms of energetic efficiency and environmental costs. The companies, in fact, often have to decide an investment considering different levels of complexity, regarding a single product, a productive plant or a real estate immovable so that, investing on products and on processes with a lower environmental impact, will give them the opportunity not only to respect the strict law requisites, but also to economize through high operative efficiencies. So the LCCA allows to evaluate in advance which are the economic efficiencies coming from the investments which will increase the environmental performances of products/processes steering the management towards an eco-sustainable development (2-3). The *Life Cycle Cost Assessment* methodology can be defined as an assessment of the global costs including the designing, the acquisition, the support costs and each other cost directly imputable to the property and the use of a determined good (4).

Considering the single costs for the entire period into consideration (it means the entire life cycle), it results that this instrument of analysis and of environmental evaluation allows to compare on a common base, the economic terms, all the possible alternatives.

Therefore the decisional process can be based on the evaluation of the global costs which a product implies: it means to consider the monetary costs and the social and environmental costs which are not often included in the decisional parameters. The analysis of the costs during the entire life cycle of the possible alternative allows to optimize, it means to minimize, the intervention times, because the preventive identification of the single costs allows to decide in the light of the *trade-off* among costs, the expected *performance* and the induced benefits during each step of the analyzed life cycle. Considering the time life of a good, the relationship between the possibility of reducing the costs and the size of the costs for a single intervention is an inverse proportion: that is the possibilities of an intervention during the entire cycle of life of a product/service become more expensive if they are not planned during the designing step and if they are near at the end of the life cycle of the same good.

The LCCA analysis, which has been already applied to different fields, has been confirmed as a valid instrument for the economic evaluation of an investment and of the environmental impacts connected with the product working and with the operation connected with its life cycle; this approach improves the main aspects of the sustainable development that is the environment and health protection, the social supportability and the economic feasibility (5).

According to the wind atlas produced by the Italian Experimental Center for Electrical Engineering (CESI), the coasts of southern Sicily are among the windiest regions in Italy, and for this reason they appear eligible for the installation of an offshore wind farm.

This paper is the third part of a work commissioned by the National Research Agency ENEA and it is a preliminary study of technical-economic feasibility concerning with a wind offshore plant location outside Sicilian coasts; part of the results here presented have been the subject, copies of a paper presented during the international conference OWENES 2009 which took place in Brindisi on May 2009 (6). A new LCCA metho-dological approach is applied in order to evaluate this investment with the aim of highlighting the opportunity to distinguish the single amounts of costs and of monetary and non-monetary benefits throughout the whole life cycle of the investment. In particularly, we analyze the economic evaluation of the damage deriving from the construction of the system divided into environmental impacts, deriving from the building of a single turbine, and the environmental impacts as a consequence of the foundations building. Wind turbines and foundations in the LCA Analysis is divided in four different steps, thus like previewed from the international norms reference, which are: the reference unit, Life Cycle Inventory, Appraisal of the result, Analysis of the improvements.

The LCA Analysis has been carried out just during the phases of building, use and discharge of the wind turbine and during the gravity foundations building for off-shore plants, while it has been left out the LCA study during the phase of the electric cables earth connection, because it depends on the exact site of the plant as regards to the coasts and to the distances of the cables from the earth transforming substation. Moreover it has been left out the analysis of the environmental impacts that the plant has on the local faunal and floristic bio diversity because, to conduct this study, it is necessary to know previously the exact placement of the off shore wind turbines in order to study the peculiarities which insist on that site plant area.

The preliminary economic information for the LCCA analysis of the examined offshore wind park regards the management of the monetary capital initially invested, the evaluation of the interest rate and other necessary parameters used to compute the present value of the cash-flows accrue during the project lifetime. Moreover, the positive cash-flows are quantified as a consequence of the wind energy selling and of Renewable Energy Certificates.

LCCA methodological approach

The life cycle of an investment as it is defined by the rule UNI EN ISO 14040 represents the " consecutive and interconnected phases of a system of products beginning from the acquisition of the raw materials or from the natural resources birth just the final discharge" (7) and, in particular it is divided into the following phases:

- **raw materials acquisition**: it holds both the operations and the processes necessary for the raw materials extraction from their place of origin (i.e. wood collection, oil extraction) and all the transport phases just to the processing place;
- **manufacturing**: the realization of the finished product up to the consumer direct delivery ;
- **work and maintenance**: it has to consider all the energy and materials requests associated to the utilization and the eventual maintenance operations;
- **recycling and waste management**: it regards both the energy and materials consumption and the emissions on the environment associated to the waste agricultural food chain enclosed therein the operations of collection, transport, treatment, recycle and final discharge.

According to the just introduced LCA methodological concepts, the LCCA allows to realize a more exhaustive economic feasibility analysis of an investment, compared with the instruments of the classical financial analysis, because it is based on the study of the entire cycle of life of an investment included the induced effects (i.e. direct and/or indirect employment, environmental effects, etc.) More in detail, the Life Cycle Cost Assessment (LCCA) allows to compare the starting investment with the future savings considering:

• idea development;
• design and product engineering;
• manufacturing and distribution;
• support and maintenance;
• updatings;
• decommissioning and discharge (Figure 1).

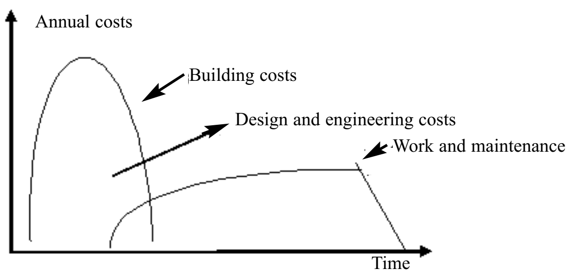

Fig. 1 – Distribution of the annual costs during the product life cycle.
(*Source*: VESTAS, Life cycle assessment of offshore and onshore sited wind power plants based on Vestas V90-3.0 MW turbines, 2006.)

From a strictly operative point of view the LCCA analysis can be divided into six different steps, linked together, and which can briefly explained in the following points (figure 2). The first four phases concern the planning of the analysis process which is finally realized in the last two steps (Figure 2).

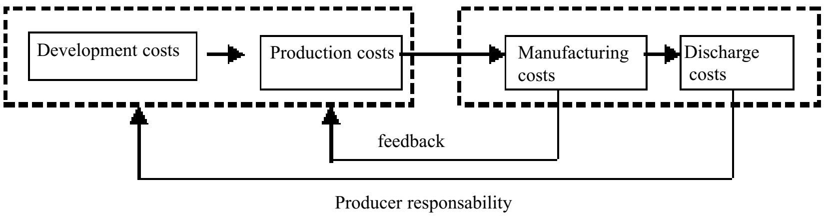

Fig. 2 – Costs Analysis in a perspective of a cycle of life.
(*Source*: VESTAS, Life cycle assessment of electricity delivered from an onshore power plant based on Vestas V82-1.65 MW turbines, 2005.)

I phase: it consists in the development of a plan which considers the extension, the aims and the goals of the analysis. In particularly the plan has to: a) define the aims and the goals of the evaluation analysis of the life cycle costs in terms of outputs necessary for the decisional process; b) define the analysis aim, the reference period in terms of cycle of life which has to be estimated, the different acceptable sceneries (for all possible options) in terms of ordinary and extraordinary e and in terms of the necessary maintenance during the supposed period of the life cycle; c) identify and point out all the acceptances and the hypothesis done, the limits and the bonds which can limit the number of the possible alternatives; d) indentify all the possible alternatives (8-9).

II phase: it foresees the development of a model which satisfies the aims of the analysis. In detail the model has to: a) define the disgregation of all the relevant cost categories during each phase of the life cycle; b) identify the cost headings (categories) which do not have significative impact on the global costs; c) screen a method for the costs estimate (categories) which cannot be directly quantified, defining the necessary data for these estimations and identifying the sources; d) integrate the so identified single cost headings into an overall scheme (representing the product/service) which answers to the aims of analysis and re-examine the model considering the prefixed aims and the acceptances advanced at the beginning of the analysis.

III phase: it is related in pursuance of the model previously developed and it can be organized complying with the following managing conditions: a) to validate the analysis model and the costs estimation of the life cycle using hystorical data; b) to associate a value to the identified heading costs in order to consider possible options and weighting the different results associated to the supposed sceneries; c) to quantify the differences and collect the LCCA analysis results in specific homogeneous groups; d) to review the results considering the targets and the starting aims in order to verify the coherence among them.

IV phase: the analysis results have to be supported by documents in order to allow a check/ control and a possible reproduction/validation by third bodies.

V phase: it allows the control and the management of the heading costs identified on the base of the model and of the results obtained and to which the nominal costs are associated with.

VI phase: the methodology implementation foresees frequent investment ratings monitoring during the life cycle (management, maintenance etc) in order to identify the areas of interest which are not in harmony with the evaluation analysis previously done and developed during the preceding phases.

The analysis of the costs which happen by turns during the natural cycle of life of an investment needs a previous and detailed report of the heading costs and of the proceeds which have to be considered in the reckoning and which can be divided as it follows:

- *starting investment costs*: it considers all the costs associated with the investment realization, for example: both the costs for the development of the idea and those related with the manufacturing of the same product;
- *support and maintenance costs*: it represents the costs which have to be periodically tackled in order to setting a plant considering also the costs necessary for the ordinary maintenance (replacement of the mechanical components due to the physical wear-out) and for the extraordinary one;
- *environmental costs*: they are the costs which are not considered by the price market and for this reason they do not fall on the producers and on the consumers but they are imposed to the entire society; they include the damages caused to the environment and those caused to human health during the entire product life cycle.

- *discharge costs*: they cover both the expenses which interest the plant removal from the area in which it has been built and the contingent expenses to restore the original conditions of the same area;
- *proceeds*: they are based both on those direct and indirect incomes related to the product-service selling and on the company gets exposure.

Considering that the cash flows are referred to different period of times (10), it is necessary to make data uniform according to periods of time different from an evaluation time which usually corresponds to the beginning of the investment.

According to this it is necessary to bring up-to-date the monetary flows which take place during the years and which are different compared with the period of time the work is realized ("year zero"). In order to determine the actual value of the cash flows generated by an investment it is necessary to individuate at the beginning an appropriate rate of actualization through which the monetary fluxes can be discounted.

At the end, considering the time during which the cash flows are realized, it is possible to determine the degree of the economic sustainability of an investment calculating the net present value (NPV) defined by the following equation (eq. 1):

$$NPV = \sum_{n=0}^{t} \frac{(R_n - C_n)}{(1+i)^n} \tag{1}$$

where R_n represents the active monetary flow obtained through the investment during a generic year n, C_n the passive monetary flow during a generic year n, i the real interest rate (or actualization rate) to make up-to-date the cash flows and t the investment time life.

The income determination of an investment can be also completed through the evaluation of two other financial indexes which are the *internal rate of returne (IRR)* and the *refund period* of an investment (11). The IRR indicates the discounting back rate which equalizes the present value of the in and out flows of a plant. The calculation of the yield internal rate comes from the solution, with respect to the variable i, of the equation NPV = 0; the IRR is so the rate for which the NPV is zero. Following this criteria, a project for an investment is convenient if the resulting IRR is higher than the cost opportunity of the capital or than another rate taken into account to discount back the cash flows. Formally, the IRR is expressed by the root of the following equation (eq. 2):

$$\sum_{n=0}^{t} \frac{(R_n - C_n)}{(1+i)^n} = 0 \tag{2}$$

In order to determine the *payback period*, it is necessary to solve the equation NPV with respect to the time for a predefined value of the rate i (i is fixed following some considerations about the specific investment and/or according to WACC), fixing the condition that the VAN is greater or equal to zero. According to this criteria an investment would be better if the payback period is lower.

The feasibility of LCCA studies and the quality of the results obtained using the financial rules is linked to the availability of the “right” information and, as a consequence, it is greatly influenced by the presence of acquisition instruments correctly implemented.

Identification and Quantification of the Environmental Impacts

Here below it will be weighed the potential environmental impacts produced by the analysed wind farm on the country both where it would be built and during the building construction- installation of the eight turbines provided by the project and on the foundations building. It won’t be considered the impacts coming from the installation of the connecting cables useful to transport on earth the produced electricity because it would have to do before some careful campaigns on the place which are not foreseen by the actual research study.

The environmental impacts coming from the construction of the wind plant can be divided into two macro categories depending on the more significative interections with the natural environment:

1) Environmental impacts coming from the building of a single turbine;
2) Environmental impacts coming from the building of the foundations.
These impacts are now examined in detail

1) Environmental impacts coming from the building-use-decommission of a single turbine

Here below it is presented the LCA analysis concerning the single environmental impacts coming from the building, the transport and the laying of the V90-3.0 MW turbine, a technological model chosen by most modern wind farm projects. The reported scientific data have been provided by Vestas Italia, producing company of the chosen turbine model, or by its companies suppliers. The selected functional unit is equal to 1 kWh of electric power generated by an wind offshore plant which uses the turbines V90-3.0 MW and which is situated in a sea location with the seabeds deep quite 13 meters so, as an analysed case, it is close to the studied case in object.

Building, laying and decommission of a turbine

The more significant impact which the wind turbines have on the environment is, in general, the one related to their building. The reason is based on the different environmental consequences generated both by the iron mineral extraction necessary for the production of the steel components and also by the fusion of all these components. Also the materials used for the production of the blades and which are extracted by the oil have their own environmental impact. From an environmental point of view the use of iron mineral and of the oil means using limited resources and the challenge consists in minimizing the use optimizing at the same time the output which these resources generate.

The analysis of the single turbine is carried out during the different phases of the life cycle so the building of the single turbine, the road and the sea transport , the elevation in the sea, other building actions in the sea, the laying and the functioning phases, the ordinary maintenance, the disposal and the spoil of the steal parts at the end of the cycle (11). The environmental impact during the transport and the installation phases is minimum because the only impact comes from the combustibles consumption used during these operations.

Operative phase

The negative impact related to the functioning and to the electric power production of a wind turbine is limited and it basically derives from the use of vehicles, helicopters and different boats used by the technicians for the various maintenance actions.

Moreover, considering an evaluation life cycle set, if the turbines efficiency and its consequent produced energy is higher it will be better evaluated the *life cycle* cost associated to it (12).

This is confirmed by the fact that the wind turbines generate substainable electric power and, using as a comparison parameter the selected functional unit that is the environmental impact for produced kWh electricity, it is clear that a higher electricity production induces to better evaluation results.

Discharge phase

The environmental impact during the offshore plant discharge phase is low because it is possible to reuse more than the 80% of the material of which the wind aerogenerator is made.
As provided in the Rule ISO 14040, the second phase concerning the LCA is the *Life Cycle Inventory (LCI)*.

TABLE 1

RESOURCES CONSUMPTION FOR 1 kWh OF THE ENERGY PRODUCED BY AN OFFSHORE WIND PLANT

Resources	Quantity (g/kWh)
Water	49.346
Hard Coal	0.74
Crude Oil	0.63
Iron	0.419
Natural Gas	0.375
Quartz	0.335
Lignite	0.324
Limescale	0.126
Sodium chloride	0.051
Stones	0.055
Zinc	0.041
Clay	0.031
Aluminium	0.011
Manganese	0.01
Copper	0.009
Lead	0.003

Source: VESTAS, Life cycle assessment of offshore and onshore sited wind power plants based on Vestas V90-3.0 MW turbines, 2006 (13).

TABLE 2

RESOURCES CONSUMPTION AND THE MORE SIGNIFICANT EMISSIONS INTO THE WATER FOR 1 kWh OF THE ENERGY PRODUCED BY AN OFFSHORE WIND PLANT

Emissions in the air	**Quantity (g/kWh)**
Carbon Dioxide (CO_2)	5.23E+00
Sulphur Dioxide (SO_2)	2.15E-02
Nitrogen Oxides (NO_x)	2.06E-02
Carbon Monoxide (CO)	1.99E-02
Volatile Organic Compound (VOC)	1.25E-02
Hydrochloric Acid	1.21E-04
Nitrogen	1.03E-04
Hydrogen	9.48E-05
Sulfureted Hydrogen	7.45E-05
Manganese	7.02E-05
Emissions into the water	
Total for Nitrogen	2.58E-06
Total for Potassium	3.20E-08
COD	2.41E-03

Source: VESTAS, Life cycle assessment of offshore and onshore sited wind power plants based on Vestas V90-3.0 MW turbines, 2006 (13).

The Tables 1 and 2 show the inventory results for each single offshore wind turbine, concerning the functional unit, 1 kWh of produced energy. In particular, the first table analyses the not renewable resources consumption necessary for the production of one turbine, while the second table shows the outputs into the water and in the air of the emissions linked to the same production. In synthetic terms regarding the greenhouse gas the LCA analysis of a turbine shows that in order to produce 1 kWh of electric power from a wind offshore plant, it is generated an impact equal to 5,23 g of CO_2 per kWh of energy produced during the entire cycle of life.

Subdivision of the environmental impacts

The third phase of the LCA analysis foresees the subdivision of the environmental impacts into predefined categories.

In Table 3 the total environmental impacts are reported, splitted in categories, coming from the entire life cycle of a turbine V 90 offshore during the phases of production, transport, dismantlement, materials collection as it is established by the rule ISO 14042 about the impacts evaluation. These data have been obtained by the LCA report done by VESTAS which consider as Functional Unit of the analysis 1 KW of energy produced by a single turbine (column two); in the third column the total impacts refer to the energy production of an entire offshore plant which foresees the use of 8 turbines during a period of time of 20 years.

However, it is necessary to underline that the turbine production phase, as it is demonstrated by the scientific literature, is the one which gives much environmental impacts respect to the other phases of the life cycle because during this phase a lot of hazardous waste are produced and they have to be properly discharged. During the maintenance phase, on the contrary, the more significative environmental impact category seems to be the one connected to the ecotoxicity of water. Considering also that it is possible to recycle a lot of the metallic components of the turbine, after 20 years of "useful" life, the environmental advantages could be really significative.

TABLE 3

ENVIRONMENTAL IMPACT COMING FROM THE V90 TURBINE, DIVIDED INTO CATEGORIES OF IMPACT

Categories of impact	**for a Kwh produced**	**for totals Kwh produced**
Produced Waste (kg)	4.85E-06	4,779.966
Human Toxicity (kg Toluene e PCB eq)	2.67E-06	2,631.44
Global Warming (kg CO_2 eq)	1.02E-06	1,005.271
Ashes (kg)	9.80E-07	965.8488
Acidification (kg SO_2 eq)	8.00E-08	78.8448
Nuclear Waste Formation (kg)	6.00E-08	59.1336
Photochemical Oxidants (kg C_2H_4 eq)	5.00E-08	49.278
Eutrophication of water (kg NP eq)	3.00E-08	29.5668

Source: Our Elaboration from VESTAS, Life cycle assessment of offshore and onshore sited wind power plants based on Vestas V90-3.0 MW turbines, 2006

3) Environmental Impacts coming from the foundations building.

Table 4 shows the single quantity of the different products used for the building of the plant foundations; we have been chosen a gravity foundation because pointing out that in the absence of a specific Italian technical regulation, the most updated international standards have been applied with the effort of particularizing them to the Sicilian situation (14).

TABLE 4

QUANTITY OF THE MATERIAL USED FOR THE FOUNDATIONS REALIZATION

Material	Quantity for 1 foundation (Kg)	Quantity for 8 foundations (Kg)
Bed	1,573,600	12,588,800
Formworks	13,950	111,600
Excavated soil	13,368,000	106,944,000
Concrete	4,442,400	35,539,200
Cement	555,300	4,442,400

Note: bed formed by calcareous or lavic rocks; formworks made with wood or with reinforced monolithic steel plate boards

From the data reported in the last column of the table related to the quantity of the total materials used for the building of the 8 foundations, through the use of GEMIS software it has been obtained the different environmental impacts related to the considered functional unit equal to 1 Kg of foundations. The individuated impacts classified for impact typology and emissions section have been reported in Tables 5-9.

TABLE 5

EMISSIONS IN TO AIR SECTOR- (kg/kg OF FOUNDATION)

Emissions in the air	
Tipology	**Quantity**
SO_2 equivalente	$5.9796*10^{-3}$
TOPP equivalente	$1.2883*10^{-3}$
SO_2	$6.7083*10^{-3}$
NO_x	$19.957*10^{-6}$
HCl	$1.0131*10^{-6}$
HF	$914.77*10^{-6}$
PARTICULATES	$1.1439*10^{-3}$
CO	$213.11*10^{-6}$
NMVOC	$130.6*10^{-12}$
H_2S	$772.52*10^{-9}$
NH_3	$3.8616*10^{-9}$
As	$3.1341*10^{-9}$
Cd	$4.1004*10^{-9}$
Cr	$3.1522*10^{-9}$
Hg	$52.154*10^{-9}$
Ni	$15.605*10^{-9}$
Pb	$3.617*10^{-12}$
PCDD/F	$13.24*10^{-15}$

Source: Personal Elaboration

TABLE 6

EMISSIONS IN THE AIR OF GREENHOUSE GAS (kg/kg OF FOUNDATION)

Greenhouse Gas	
Tipology	**Quantità**
CO_2 equivalente	3.0218645
CO_2	2.9237129
CH_4	$68.179*10^{-6}$
N_2O	$3.38667*10^{-3}$
Perfluorometano	$10.770*10^{-9}$
Perfluoroetano	$1.3536*10^{-9}$

Source: personal Elaboration

TABLE 7

FLOWING BACK INTO THE WATERS (kg/kg OF FOUNDATION)

Emissions into the water	
Tipology	**Quantity**
P	$5.9190*10^{-9}$
N	$347.26*10^{-9}$
AOX	$450.1*10^{-12}$
COD	$60.162*10^{-6}$
BOD5	$1.7513*10^{-6}$
INORGANIC SALT	$8.0215*10^{-6}$
As	$1.584*10^{-15}$
Cd	$3.868*10^{-15}$
Cr	$3.826*10^{-15}$

Source: personal Elaboration

TABLE 8

WASTE PROUCTIONI FOR EACH FUNCTIONAL UNIT (kg/kg OF FOUNDATION)

Solid Waste	
Tipology	**Quantity**
Ashes	$144.39*10^{-3}$
Residues of fumes desulphurization	$32.805*10^{-3}$
Mud from wastewater	$30.913*10^{-6}$
Waste Production	$17.096*10^{-3}$
Acid overload	23.143383
Residual Nuclear fuel	$812.33*10^{-9}$

Source: personal Elaboration

TABLE 9

CONSUMPTION OF THE MATERIALS AND RENEWABLE AND NOT RENEWABLE RESOURCES (kg/kg FOUNDATIONS)

Total Energy requested	
Tipology	**Quantity (kWh)**
CER not renewable	5.10390600000
CER renewable	0.05247400000
CER other	0.08875900000
CER total	5.06762070000
Total Materials requested	
Tipology	**Quantity (Kg)**
CER not renewable	25.06257000000
CER renewable	11.38674600000
CER other	0.00053689000
CER total	36.44994100000

Source: personal Elaboration

Subdivision of foundations environmental impacts

As it is foreseen by LCA third phase, also for the foundations, the most significative impact categories have been presented (15-18); all the environmental output quantity analysed by the precedent tables have been considered but also the input coming from the quantity of material and of energy used for the building of the foundations. The method used to reach this goal is the EDIP method (19).

From table 10 it is immediately clear that, apart from the great quantity of material necessary for the building of eight foundations, the impact category which weight upon on this phase is the global warming (*Global Warming Potential*), due to the high greenhouse gas emissions produced.

Doing an addition of the data presented in the second columns of Table 3, related to the impacts coming from the building of the eight blades, and in the Table 10 related to the impacts divided into sectors concerning the foundations building necessary for the plant, we obtain the data reported in Table 11 which describes the total impacts individuated by the LCA analysis of the studied offshore wind plant.

TABLE 10

ENVIRONMENTAL IMPACTS COMING FROM THE FOUNDATIONS BUILDING, DIVIDED INTO IMPACT SECTOR

Impact Sectors	For a Kg of foundation	For Kg total foundations
Total requested materials (kg)	36.449941	2,029,707,966.196328
Global Warming (kg CO_2 eq)	5.9510909190	331,385,355.2
Total Energy used (kWh)	5.0676207	282,189,485.6963
Produced Waste (kg)	0.17	9,466,417.36
Ashes (kg)	0.14	8,040,385.112
Acidification (kg SO_2 eq)	0.007289643	405,922.3497
Photochemical oxidant (kg C_2H_4 eq)	0.00692141	385,417.3869
HumanToxicity (kg Toluene e PCB eq)	0.0012058277	67,146.28284
Waters Eutrophication (kg NP eq)	0.0000003536	19.69181865304
Formation of Radioactive waste (kg)	8.12E-08	4.52160641

Source: Personal elaboration

TABLE 11

ENVIRONMENTAL IMPACTS COMING FROM THE FOUNDATIONS AND BLADES BUILDING, DIVIDED INTO IMPACT SECTORS

Impact Sectors	for total kWh produced (Kg)	for one kWh produced
Global warming (kg CO_2 eq)	331,386,360	3.36E-01
Produced Waste (kg)	9,471,197.3	9.61E-03
Ashes (kg)	8,041,351	8.16E-03
Photochemical oxidant (kg C_2H_4 eq)	385,466.66	3.91E-04
Acidification (kg SO_2 eq)	406,001.19	4.12E-04
Human Toxicity (kg Toluene e PCB eq)	69,777.728	7.08E-05
Formation of Radioactive waste (kg)	511.29424	5.19E-07
Waters Eutrophication (kg NP eq)	49.258619	5.00E-08

Source: Personal elaboration

It is analysed the incidence of the impact sectors during the foundations and the rotors building phase, it can be noticed that the most significative impacts, expressed in percentage, are quite all connected to the foundations, except for the sector regarding the eutrophication of the water resources which is due to the wind blades building.

In order to quantify economically the environmantal damage coming from the blades and foundations building it has been researched first in literature (20) the environmental unitary costs related to each pollutant substance taking into exam. These data have been reported in Table 12.

TABLE 12

ENVIRONMENTAL COSTS DUE TO POLLUTANTS (€/T)

Pollutants	Economic damage (€/t)
CO_2 equiv	19
Sulphur Dioxide SO_2	2,939
Nitrogen Oxide No_x	2,908
Volatile Organic compounds VOC	11,723
As= arsenic	80,000
Cd= cadmium	39,000
Cr= chromium	31,500
Pb* lead	1,600,000
Ni= nickel	3,800
NMVOC	1,124

Energy- Related Transport Externalities, 2005

Afterwards, according to the unitary data presented in the previous table, it has been individuated the environmental damages, expressed in monetary values (€), respectively referred to the blades and the foundations, during the entire life cycle of the plant. These costs are obtained multiplying the environmental cost of each ton of single pollutant substance let in the water and air compartments by the total quantity of pollutant (expressed in tons) let during the entire life cycle of the blades and of the foundations. As far as the total quantities of pollutant substances are concerned, they are calculated as following:

a) As regards the impacts coming from the blades: multiplying the quantity of pollutant emitted for 1 kWh of produced energy by the total quantity of kWh produced by the wind plant (985.560.000 kWh);

b) As regards the impacts coming from the foundations: multiplying the quantity of pollutant emitted for one Kg of foundation by the total weight of the same foundations (6.960.601 kg).

On the basis of the foregoing considerations it has been finally quantified the economic environmental damage for the blades and the foundations in relation to each pollutant substance let in the environment (Tabb. 13-14).

TABLE 13

ENVIRONMENTAL DAMAGES COMING FROM THE BLADES, EXPRESSED IN MONETARY VALUES (€)

Pollutants	**Quantity (g/kWh produced) by blade**	**Total economic damage through 20 years of work (€)**
Carbon dioxide (CO_2)	5.23	97,935.10
Sulphur dioxide (SO_2)	0.0215	62,276.06
Nitrogen Oxide (NO_x)	0.0206	59,039.77
Volatile organic Compounds (VOC)	0.0125	144,421.50
Total		363,672.43

Source: Personal Elaboration

TABLE 14

ENVIRONMENTAL DAMAGES COMING FROM THE FOUNDATIONS, EXPRESSED IN MONETARY VALUES (€)

Pollutants	**Quantity (kg/1 kg of foundations)**	**Total quantity (kg)**	**Total economic damage (€)**
CO_2 equiv	3.0218645000	16,8271,944.5	3,197,166.95
Sulphur dioxide SO_2	0.0012883000	71,738.73815	210,840.15
NitrogenOxides Nox	0.0067083000	373,550.3975	1,086,284.56
Volatile organic Compounds VOC	0.0009147700	50,938.79181	597,155.46
As= arsenic	0.0000000039	0.215032455	17.20
Cd= cadmium	0.0000000031	0.174521757	6.81
Cr= chromium	0.0000000041	0.228329987	7.19
Pb* lead	0.0000000156	0.868961429	1,390.34
Ni= nickel	0.0000000522	2.904185476	11.04
NMVOC	0.0002131100	11,866.98943	13,338.50
Total			**5,106,218.18**

Source: Personal Elaboration

Costs for Construction, Operation, Maintenance and Disposal of the Plant

The economic information which precedes the LCCA analysis are principally addressed to the monetary capital supply first invested to realize the work, the evaluation of the interest rates and of the other financial parameters necessary to discounting back the costs and the total proceeds during the entire plant life cycle (21).

Regarding the financial backing of the investment it is needed to specify if it is owner's or borrowed capital and, in this last case, if the capital has been granted by public or private bodies and if there are forgivable loans. In detail, the capital can be divided among forgivable loans (or capital account), owner's capital and borrowed capital (or working account).

Regarding the capital account loans, in the last years it has not been registered important intervention by the local and regional administrations about the production of the wind energy. Just the Ministry of Productive Activities with the Lex 488 of 2001 and the Environmental Ministry have allocated some funds connected with the construction of plants which can exploit renewable energy sources. More substantial funds could come from new supports from structural loans. As a consequence and considering the uncertainty of the public financing participation, in this paper the financial resources necessary for the realization of the wind farm have been evaluated as project financing forms, with the participation of sector Purchasers and Managers. From the analysis of the data related to the public financing given for similar projects it has been noticed that the more reliable solution could be a forgivable loan contribute of 20%. Therefore, for the studied case, two different hypothesis have been supposed: the first considers the possibility to obtain a forgivable loan equal to 20% of the initial investment cost, with charges net and the remaining 80% equally divided between owner's capital and bank funding, while the second hypothesis doesn't consider public fundings and the entire project can be financed with owner's capital (50%) and borrowed capital (50%). The percentages have been quantified just to illustrate the idea.

Regarding the interest bank rates on the fundings for similar projects, it has been noticed that they depend on different conditions as the return on investment, the risk of the same investment and the life of the loan still less the contingent market situation. Therefore, the individuated and considered interest rates fluctuate from 5% to 7% because they are linked to EURIBOR (Europe Interbank Offered Rate), which during the examined period, the first months of 2008, states around 4,5% to which the bank spread has been added. The supposed time to refund the barrows money given by the bank is 8 years long: this period has been also considered as the time necessary to amortize the used fixed capital except for the eventual forgivable loan.

Pointed out the fundings conditions, it has been defined and quantified in monetary terms the more relevant heading costs which interfere during the offshore wind park building phase still less their monetary quantification (done on the base of economic enquires and considering the official price lists supplied by the professional associations involved in the plant realization) are briefly illustrated in Table 15.

TABLE 15

COSTS FOR OFFSHORE WIND PLANT REALIZATION

Costs headings	**Cost (€)**	**Cost (%)**	**Source**
Aerogenerats	30,400,000.00	57.44%	VESTAS
Foundations	8,040,000,00	15.19%	Study done by the structural engineer
Marine cables for cluster connection	1,776,424.00	3.36%	Price lists + productives info (Nexans)
Tower internal cable	18,700.00	0.04%	
Cable for earth connection	3,641,860.00	6.88%	
Cost for safety and manoeuvre device	150,000.00	0.28%	Estimate on the base of the information provided by ABB local agent
Net pipe cost	3,070,167.00	5.80%	TERNA Document: “Conventional technical solutions for RTN connection. Report on medium conventional costs”
General Minimal Technical Solution			
Detail Minimal Technical Solution			
Extra cost pipes			
Cost stall in-out			
Cost stall user link			
Cost new switching			
HV Net Connection	500,000.00	0.94%	Estimated maximum cost
Partial Total	47,597,151.00	89.93%	
General expences	475,971.51	0.90%	
VAT on works	4,759,715.10	8.99%	
VAT on general expences	95,194.30	0.18%	
Total for work realization	52,928,031.91	100.00%	

The second type of costs which interfere during the life cycle of the investment refers to the plant exercise and maintenance. In detail, the costs of exercise and maintenance consider the following cost subgroups: 1) staff cost (8 units) involved in the plant management; 2) insurance premiums; 3) costs for the control and remote monitoring of the plant and of the marine forecasts; 4) cost for a service agreement with skilled companies; 5) cost for special maintenance interventions (rotor replacement, gear wheels to mutiplicate the shaft rotations, etc.); 6) cost to substitute the installed machines with technologically advanced aereogenerators (22-24); 7) cost to protect the machines from the marine aggressive; 8) additional cost related to the possibility to the accessibility at the plant during adverse weather conditions

Regarding the machineries maintenance cost, it is increasing with time, because it is related to the physical wear and tear of certain components. For this reason, we consider appropriate to evaluate the costs related to the exercise and the maintenance of the plants using an inclusive year value, variable during 20 years of life useful for the plant, and not as a fixed cost as it has been suggested by other feasibility studies. (23-24). Here below it has been reported the annual costs which intervene during the period of exercise and maintenance of the wind plant, expressed in €/kWh product (22), net by tax charges (Table 16).

TABLE 16

EXCERCISE AND MAINTENANCE COSTS (€/KWH)

Years 1 - 5	**Years 6 - 10**	**Years 11 - 20**
0.007	0.009	0.014

Source: PIRAZZI L.- VIGOTTI R., Le vie del vento. Tecnica, economia e prospettive del mercato dell'energia eolica, ISES Italia, Roma 2004, pag. 132.

At the end of the useful life cycle the offshore wind plant has to be dismantled even if this step doesn't mean automatically the definitive abandonment of the interested area. It is, in fact, quite reasonable to suppose that a site with good wind resources could be later used substituting the installed machineries with technological advanced aereogenereators.

Similarly to what has been already done with other project cost voices, also to the decommissioning costs it could be associated the following subgroups:

- *Plant decommissioning costs* related to the removal of the old wind machineries, dismantlement of the other components, personal involved during the dismantlement operations, etc.;

-*Costs for the restoration of the area original conditions* (costs for the operative restoration of the environmental site, costs for the structural restoration of the environmental site, etc).

The dismiss ion costs quantification (estimated on the basis of the market prices), reported in the Table 17, is obtained collecting the single cost voice, listed before, into four macro-voices concerning the dismission of the examined plant.

On the contrary, regarding the quantification of the costs to restore the original conditions of the area, it is pointed out the necessity to do first an analysis of the site to value the peculiar flora and faunistic conditions of the habitat of the interested macrosystem.

TABLE 17

COSTS FOR PLANT DISMANTLEMENT

Cost voices	**Cost (€)**
Cost for the removal and the dismantlement of the plant	1,800,000.00
Costs for the involved personal (n. 3 units)	180,000.00
Transportation costs	35,000.00
Costs for the use of mechanical means	100,000.00
Total cost for the dismantlement	*2,115,000.00*

Source: personal elaboration

Proceeds Coming from the Energy Production

The economic benefits linked to the realization of an offshore wind plant mainly depend on the quantity of the produced energy; in particolarly they are determined by the electricity transfer to the network and by the sale of the so-called Renewable Energies Certiticates.

Electricity tranfer to the net

From April 1st, 2004 it is effective the Electricity Exchange a meeting place market of supply and demand of the electricity which determines the price for each hour a day. All the producers with a plant capacity/performance high than 10 MW can offer their production to the electrical net manager.

With the total effectivness of the Electricity Exchange, the electricity generates by the wind source can be brought on the electric system following the D.L. n. 387 of December 29th, 2003 which concerns the European directives for the promotion of electricity production using renewable sources (25-26). In particular, the article 11, which treats the energy questions concerning the participation to the electricity market, foresees for the plant supplied by renewable sources the following managing conditions:

- the electricity produced by the plants with a capacity equal or high than 10MW is brought into the market following the relative control and respecting the dispatching rules defined by the network manager;
- the electricity produced by the plants with a capacity less than 10 MW will be withdrawn on request of the producer, by the network manager to which the plant is connected, upon the price acknowledgement made on the electrical market.

In the examined case, the expected yearly electric energy production, based on a statistic analysis of the annual wind velocity distribution over the sea area selected for the installation is yearly 49.278 MWh of electricity (27), it has been considered the medium price (referred to April 2008) of electricity selling on the Sicilian country equal to 110,23 euro/MWh(VAT included) (28).

Supply, demand and price of renewable energy certificates

The renewable energy certificates are annual titles which certify the production of a value equal to a multiple of 100.000 kWh, enacted by the electrical net manager and conferred to the renewable energy produced during the first 8 eight years by plants which go into operation after April 1st, 1999. These titles can be negotiable in a market in which the demand is defined by the obligation of 2% defined by Bersani Decrete and the the supply is constituted by renewable energy certificates delivered in favour of private plants or in favour of those owned by the same electrical network manager (GSE). He places on the market his own certificates at the supply prices established following the criteria indicated in the above mentioned national legislative decrete.

Beginning from March 5th, 2008, date of publication of the new price of reference for the market of the renewable energy certificates calculated according to article 2, paragraph 148 of the Law n. 244 December 24, 2007 (Finanziaria 2008), the independent system operator (GSE) offers the market the renewable energy certificates in his own availability at a price equal to 112,88 € for MWh of produced energy, VAT net, for a period of time not greater than 15 years of plant operation (Source: GSE (29)). According to the just mentioned data, the proceeds which can be obtained through the examined offshore wind plant are reported in Table 18.

TABLE 18

ANNUAL PROCEEDS OBTAINED BY THE PLANT (VAT NET)

Voices	Value
Energy production (MWh/year)	49,278
Energy selling price (€/MWh)	100.21
Supply price for renewable energy certificates (€/MWh)	112.88
Annual proceeds – energy selling (€)	4,938,148.38
Annual proceeds – renewable energy certificates placing (€)	5,562,500.64

Source: personal elaboration

Results and Discussion

On the base of the economic data reported in the previous paragraphs, it is possible to quantify the costs which intervene during the entire life cycle of the plant determining also the effect (in percentage) that each voice has on the building, exercise maintenance and dismission of the plant. These costs and their percentage division are reported in Table 19.

TABLE 19

DIVISION OF THE COSTS SUSTAINED DURING THE LIFE CYCLE OF THE PLANT

Costs	Value(€)	Value (%)
Realization costs	52,928,031.91	80.33
Exercise and maintenance costs	10,841,160.00	16.46
Dismantlement costs	2,115,000.00	3.21
TOTALE	65,884,191.91	100.00

Source: personal elaboration

On the basis of these last data and of those related to the proceeds it is possible to define the cash flows concerning the initiative of the project in exam as well as the financial synthetic indicators able to determine the sustainability of the investment.

For a offshore wind plant it can be supposed a life cycle of 24 years investment. Moreover, considering what it has been found in literature about this type of investment, it has been assumed that the first two years for the above mentioned life cycle are necessary to build the plant and the last two years are necessary for the plant dismantlement. As a result of this, the years of real activity are quite 20 (available life cycle) as regards the different types of investment, as it has already said, it has been taken into account two different sets. In both cases, the borrowed capital fee to realize the plant will be amortize in 8 years with constant instalment. The depreciation instalment has been determined through the following expression (eq 1):

$$R_{annua} = C_i \alpha_{n,j} \tag{1}$$

where C_i is the stating capital, j is the applied interest rate, n is the overall length of financing and $\alpha_{n,j}$ indicates the constant unitary year instalment of the amortization.

On the basis of these information, the different cash flows which pass during the plant life cycle have been determined. Just as an example, in Table 20 here below it is reported the cash flow during the different phases of the life cycle related to the example of a loan granted, with an interest rate of 5% and with a forgivable loan of 20%.

TABLE 20

MONETARY FLUXES COMING BY AN INVESTMENT WITH A LOAN RATE EQUAL TO 5% AND A FORGIVABLE LOAN OF 20% (VAT NET)

Life cycle	Own capital	Capital in exercise account	Loan (i = 5%)	O&M	Dismant-lement	Environmental damage	Energy	Renewable energy certificate	Financial flows
0	-19,229,249.00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-19.229.249,00
1	0.00	-9,614,624.50	19,229,249.00	0.00	0.00	-227,912.11	0.00	0.00	9,386,712.39
2	0.00	-9,614,624.50	-2,975,184.28	0.00	0.00	-227,912.11	0.00	0.00	-12,817,720.89
3	0.00	0.00	-2,975,184.28	-344,946.00	0.00	-227,912.11	4,938,148.38	5,562,500.64	6,952,606.63
4	0.00	0.00	-2,975,184.28	-344,946.00	0.00	-227,912.11	4,938,148.38	5,562,500.64	6,952,606.63
5	0.00	0.00	-2,975,184.28	-344,946.00	0.00	-227,912.11	4,938,148.38	5,562,500.64	6,952,606.63
6	0.00	0.00	-2,975,184.28	-344,946.00	0.00	-227,912.11	4,938.148.38	5,562,500.64	6,952,606.63
7	0.00	0.00	-2,975,184.28	-344,946.00	0.00	-227,912.11	4,938,148.38	5,562,500.64	6,952,606.63
8	0.00	0.00	-2,975,184.28	-443,502.00	0.00	-227,912.11	4,938,148.38	5,562,500.64	6,854,050.63
9	0.00	0.00	-2,975,184.28	-443,502.00	0.00	-227,912.11	4,938,148.38	5,562,500.64	6,854,050.63
10	0.00	0.00	0.00	-443,502.00	0.00	-227,912.11	4,938,148.38	5,562,500.64	9,829,234.91
11	0.00	0.00	0.00	-443,502.00	0.00	-227,912.11	4,938,148.38	5,562,500.64	9,829,234.91
……	……	……	……	……	……	……	……	……	……
21	0.00	0.00	0.00	-689,892.00	0.00	-227,912.11	4,938,148.38	0.00	4,020,344.27
22	0.00	0.00	0.00	-689,892.00	0.00	-227,912.11	4,938,148.38	0.00	4,020,344.27
23	0.00	0.00	0.00	0.00	-881,250.00	-227,912.11	0.00	0.00	-1,109,162.11
24	0.00	0.00	0.00	0.00	-881,250.00	-227,912.11	0.00	0.00	-1,109,162.11

Source: personal elaboration

As regards the data reported in the table, it is necessary to make clear some points listed here below:
1) regarding the using of own capital, it has been assumed that it can be used at the beginning of zero year in order to start-up the project hypothesis;
2) in order to complete the plant it is necessary also to accede to the allocated load by the bank; in this case it has been supposed that the loan (positive cash flow) can be grant at year "one" while the loan installments (constant) will be paid in the following 8 years with a prefixed interest rate;
3) so the capital, borrowed by the bank, (capital in exercise account) has been used during the year "one" and "two" to arrive just to the work realization;
4) the dismantlement costs have been equally dived in the last two years considering vat net;
5) the environmental damage coming from the use of wind generator and from the realization of the foundations has been divided in proportion to the 24 years plant life cycle;
6) as it has already said, the proceeds coming from the selling of the produced energy and from the issue of the renewable energy certificates (both VAT net) have been respectively shared during 20 and 15 years of plant life cycle.

On the basis of the debt and credit cash flows estimated during the plant life cycle it has been valuated NPV, IRR and the pay back. At the end it has been done the analysis of the sensitivity for the considered parameters (with or without a forgivable loan) and for both parameters it has been hypothesized that the bank offers the borrowed capital with an interest rate variable from 5% to 7%. Here below the results of the sensitivity analysis are reported considering a actualization rate variable from 0 to 10% (Table 21). In particularly, the aforesaid Table shows the sensibility of the net present value (NPV) and of the Payback Period (PbP) as regards the different discounting back rates. Moreover inside the tables are reported the NPV values and the present value of costs sustained during the entire life cycle of the investment referring to one MWh of produced energy. Moreover it has been calculated the IRR in relation with different six scenarios (Table 22).

From a brief analysis of the results exposed in the above mentioned Table it can been drawn some interesting conclusions:

1) with reference to the hypothesis of how to accede to a forgivable loan which figures up at 20% of the initial cost of the investment, the pay back period varies from six to 8 years;

2) failing of forgivable loans, the financial profit of the loan lightly decreases because the period for refunding the invested capital assumes values fluctuating from 7 to 10 year;

3) the IRR values for the six hypothesized scenarios, presented in Table 22, both in case of forgivable loans at 20% (FEP 20%) and in case the plant will be realized without FFP, have values which lie from 18% to 24%; this data points out that the discount back rates lower than those just mentioned, produce a positive effect into the discounted cash flows;

4) the data about the NPV and about the substained costs in referred to one MWh produced by the plant along its usable lyfe cycle depend in particularly on the discount rate i; considering as a reference values i = 7% as reported in literature (20), there are NPV between 37 and 48 euros/MWh and total costs of energy production between 63 and 76 euroMWh.

The real convenience for this type of investment increases in strength when the just mentioned results are compared with those related to similar studies reported in literature concerning onshore and offshore plants. In particularly Pirazzi's and Pigotti's studies on certain wind plants present results in line with the present study.

TABLE 21

SENSITIVITY ANALYSIS OF THE PROJECT FOR 6 DIFFERENT SCENERIES

	i	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
FFP at 20%	NPV (M€)	121.096	105.601	92.210	80.600	70.502	61.690	53.977	47.206	41.244	35.979	31.316
	PbP	6	6	6	6	6	6	7	7	7	7	7
i = 5%	NPV/MWh	122.87	107.15	93.56	81.78	71.54	62.59	54.77	47.90	41.85	36.51	31.78
	Cost (€/MWh)	-81.51	-77.52	-74.02	-70.94	-68.20	-65.76	-63.57	-61.60	-59.81	-58.18	-56.69
	i	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
FFP at 20%	NPV (M€)	120.124	104.681	91.338	79.773	69.716	60.943	53.266	46.529	40.598	35.363	30.728
	PbP	6	6	6	6	6	7	7	7	7	7	7
i = 6%	NPV/MWh	121.88	106.22	92.68	80.94	70.74	61.84	54.05	47.21	41.19	35.88	31.18
	Cost (€/MWh)	-82.50	-78.45	-74.90	-71.77	-69.00	-66.52	-64.29	-62.29	-60.47	-58.81	-57.29
	i	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
FFP at 20%	NPV (M€)	119.135	103.744	90.450	78.930	68.915	60.181	52.542	45.839	39.940	34.735	30.128
	PbP	6	6	6	6	6	7	7	7	7	7	8
i = 7%	NPV/MWh	120.88	105.26	91.78	80.09	69.93	61.06	53.31	46.51	40.53	35.24	30.57
	Cost (€/MWh)	-83.50	-79.40	-75.81	-72.63	-69.81	-67.29	-65.03	-62.99	-61.13	-59.44	-57.90
	i	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
FFP at 0%	NPV (M€)	110.338	95.182	82.107	70.792	60.968	52.413	44.941	38.395	32.644	27.577	23.100
	PbP	7	7	7	8	8	8	9	9	9	10	10
i = 5%	NPV/MWh	111.96	96.58	83.31	71.83	61.86	53.18	45.60	38.96	33.12	27.98	23.44
	Cost (€/MWh)	-97.30	-92.92	-89.05	-85.62	-82.56	-79.82	-77.34	-75.10	-73.05	-71.18	-69.46
	i	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
FFP at 0%	NPV (M€)	109.124	94.032	81.017	69.757	59.986	51.479	44.052	37.548	31.837	26.806	22.364
	PbP	7	7	8	8	8	8	9	9	10	10	10
i = 6%	NPV/MWh	110.72	95.41	82.20	70.78	60.86	52.23	44.70	38.10	32.30	27.20	22.69
	Cost (€/MWh)	-98.54	-94.08	-90.16	-86.67	-83.56	-80.77	-78.24	-75.96	-73.87	-71.96	-70.21
	i	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
FFP at 0%	NPV (M€)	107.887	92.861	79.907	68.704	58.985	50.527	43.146	36.685	31.014	26.021	21.615
	PbP	7	8	8	8	8	9	9	9	10	10	10
i = 7%	NPV/MWh	109.47	94.22	81.08	69.71	59.85	51.27	43.78	37.22	31.47	26.40	21.93
	Cost (€/MWh)	-99.79	-95.27	-91.28	-87.74	-84.58	-81.73	-79.16	-76.83	-74.71	-72.76	-70.97

Source: personal elaboration

TABLE 22

IRR FOR THE DIFFERENT INVESTMENT HYPOTHESIS

		IRR
FFP at 20%	Loan at 5%	0.24
	Loan at 6%	0.23
	Loan at 7%	0.23
without FFP	Loan at 5%	0.19
	Loan at 6%	0.18
	Loan at 7%	0.18

Source: personal elaboration

Conclusions

The LCCA study applied on offshore wind generator, presented in this paper, points out the multiple advantages which derive from the adoption of this innovative instrument of environmental accountancy to examine all the information which intervene on the process of decision which points out the real economic-environmental convenience of the investment, because this methodology allows a precise evaluation of the costs and the total environmental impacts coming from the entire life cycle of the plant. In particularly, from the planning phases to the acquisition of row materials to the maintenance, dismantlement and some other costs directly imputable to the property, production and use of a specific good.

In particularly the LCCA analysis applied on the considered plant underlines the certain economic-financial convenience of the investment, because it indicates pay back period of 6 and 7 years for the forgivable loans and in 8 or 9 years in case these loans are absent. These considerations are strengthened by the data on NPV, which point out the net present value equal to 40 euro/MWh and by the information on IRR which point out that just for very high discount rates the investment does not produce any profit. On the basis of the economic data it can be confirmed that the offshore wind plant realization is a profitable investment.

For what concerns the external cost analysis produced by the wind farm in consideration, it is pointed out how the LCCA instrument allows the exact quantification, both physical and economic, of all impacts concerning the different phases of the entire plant life cycle. In this specific case the environmental costs related only to the foundations and V90 turbines building phases, result equal to 0,55 c€/kWh of produced energy, higher than the include values from 0,05-0,25 c€/kWh reported in literature for the wind sources; this could be explained by the incidence of the specific foundation for the analyses offshore plant. This environmental costs are closed to the value of 0,6 c€/kWh expected for photovoltaic plants and which have an impact lower than the plans which use traditional combustibles (gasiform 1-3 c€/kWh; liquid 3-11 c€/kWh; solid 2-15 c€/kWh).

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