Wind energy plants repowering potential in Italy: technical-economic assessment

LauraSerri [a], EttoreLembo [a], Davide Airoldi [a], CamillaGelli [a], Massimo Beccarello [b]

a Ricerca sul Sistema Energetico, RSE S.p.A., b University of Milano-Bicocca

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Abstract

In many countries, pioneers in wind plants installation during the last decades of XX century, there is a progressive shortage of land based sites suitable for new wind farms and, at the same time, many installed wind turbines are reaching the end-of-life. Three options can be considered for a wind plant at the end-of-life: the decommissioning, the revamping and the repowering. The main advantages of the repowering option are the better exploitation of wind resource, the reduction of the wind turbine number and the prevention of further "virgin" land consumption. However, there are some issues that may affect the success of repowering initiatives: the significantly high investment costs and long and the complex authorization process. In this frame, in order to support both operators and decision-makers, RSE undertook a research activity concerning the evaluation of the wind repowering potential in Italy. The main objectives of this work were to understand the amount, the features and the geographical distribution of wind capacity that will reach the end-of-life in 2020 and also to develop repowering scenarios and to evaluate their technical-economic sustainability. A three steps methodology was designed and applied for the evaluation of the national repowering potential.

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1. Introduction

The benefits of producing electricity from Renewable Energy (RE) sources, and, in particular, the reduction of greenhouse gas (GHG) emissions, are well known and promoted since 1997 with the adoption of Kyoto Protocol [1], [2]. Since that date, RE production has significantly grown thanks to the support policies put in place by several countries in the world. In particular, the European Union played a remarkable role in fostering RE production in its Member States [2], [3]. The share of renewables to at least 27% of EU energy consumption by 2030 has already been set as target by the 2014 EC Communication "A policy framework for climate and energy in the period from 2020 to 2030" [4]. Specific Member States targets are expected to be defined within 2018. In August 2015 President Obama and the U.S. Environmental Protection Agency (EPA) established the Clean Power Plan, announcing a path toward a 32% reduction in carbon pollution by 2030. This target will be achieve through a significant increase of the electric energy production by RE [5].

Among the RE technologies, on-land wind energy has nowadays reached a significant maturity level and a wide penetration. According to the Global Wind Energy Council (GWEC), at the end of 2015, the global amount of the installed wind capacity was 432 GW. China, with around 145 GW of installed wind capacity, has continued to establish itself as the most active country in this field and its contribution was decisive to allow Asia to overcome Europe and North America. After China, the United States were in the second place with around 74 GW, followed by Germany with 45 GW, India with 25 GW, Spain with 23 GW [6]. At the same date, Italy positioned itself at the ninth place, with about 9 GW of installed wind capacity. This is a quite significant result taking into account that Italy has a slightly lower wind resource compared to Northern European countries, quite small territorial extension, high terrain complexity, high population density, significant number of high value crops and archeological sites, strong touristic vocation and almost total lack of national manufacturers involved in the construction/assembling of large size wind turbines [7].

Italy, together with Germany, Denmark, Spain, The Netherlands, UK and U.S, can be fully included among the "pioneer" countries involved in the development of wind energy plants. In fact at the end of 2000, when wind energy had its great development with more ambitious goals, Italy was among the five countries with the biggest installed wind capacity [8]. In many of these countries, there is a progressive shortage of land-based sites suitable for new wind farm installations and, at the same time, many installed wind turbines are reaching the end-of-life.[1] In some cases (e.g. Germany, United Kingdom and Denmark), for further exploitation of wind energy they are looking to offshore installations [9], however, sooner or later, all the above mentioned countries will have to face the problem of a large amount of land-based wind turbines at the end-of-life, as recently highlighted by the European Commission [10].

Three options can be considered for the wind plants at the end-of-life: the decommissioning, the revamping and the repowering. In the first case, the whole power plant is dismantled. In the second case, some significant components of the wind turbines are replaced and the power plant goes on producing electricity. In the third case, the word "repowering" is intended as an intervention finalized to the complete replacement of the old wind turbines with new ones equipped with the latest advanced technologies and consequently capable to provide improved performance (e.g. higher efficiency, less noise) and probably higher installed capacity. The advantages of the repowering option are multiple [11], [12], [13], [14], [15], [16], [17] and can be mainly ascribed to the following aspects:

- increase of the specific energy production due to higher hub height of the wind turbine models adopted for the replacement of the old ones, improved performance of the new multi-megawatt wind turbine generators (WTGs) compared to the old ones, deeper knowledge of the wind resource in the sites involved in repowering activities and improved micro-siting practices;
- better exploitation of the resource in the most windy sites, generally the first ones occupied by installations at the beginning of the development of wind plants in a region and/or country;
- lower number of the WTGs and increased integration in the landscape, with a consequent reduction of the visual impact;
- expected reduction of the avian mortality due to the lowering of the WTG number in operation at the involved sites;
- prevention of further "virgin" land consumption for wind power production and use of sites already perceived by the community as wind energy landscapes ("All the visible features of an area of land, often considered in terms of their aesthetic appeal" [18]) and territories ("Land with a specified characteristic" or "An area of knowledge, activity, or experience" [18]);
- improvement of the electric grid integration because of the new WTG up-to-date connection systems;

- reduction of the overall capital costs for the installation of a wind plant in comparison to a new plant (a number of existing infrastructures could be re-used);
- reduction of the operation and maintenance costs in comparison to an old plant due to lesser maintenance interventions;
- creation of new job opportunities.

However, the significantly higher investment costs and the longer and more complex authorization process may affect the success of repowering initiative if compared to the revamping intervention. For these reasons, the sustainability of the repowering initiative deals not only with technical and environmental matters but also with economic and regulatory issues, as underlined in a study concerning the economics of wind plant repowering in California. In this study, the general lack of economic incentive was identified as the primary barrier to the repowering initiatives [12].

In Italy, the incentive measures implemented to support the RE sector in the last decade, led to a proliferation of new installations, especially with regard to photovoltaic and wind plants, with an annual increase of the wind capacity around 1 GW in the period 2009–2012. After that, a significant decrease has been registered (450 MW of new wind capacity in 2013, only 105 MW in 2014 and 295 MW in 2015 [19]) as a result of the combined effect of the economic crisis and of the changes in the incentive mechanism and tariffs introduced by Legislative Decree 06/07/2012 [20] This decree has regulated the transition from the "old" green certificates to a new less favorable incentive mechanism based on an auction procedure.

From one hand, the repowering of wind plants does not have any specific support measure, treating it as a completely new plant. This has discouraged the operators that prefer to undertake new projects in "virgin" sites instead of repowering interventions on their "old" wind plants, so very few repowering interventions have been registered up to now.

From the other hand, another 2012 decree, called "burden sharing" [21], has set the regional 2020 targets of RE production. The most of the Italian Regions are increasing the RE production in order to reach the above mentioned targets and the regional administrations are authorizing a number of new RE plants.

In this complex and multifaceted frame, RSE undertook a research activity concerning the evaluation of the wind repowering potential in Italy and its technical-economic assessment in order to support both the operators and the decision-makers at every level in Italy [22]. The main objectives of this work have been:

- to understand the amount, the features and the geographical distribution of wind capacity that is going to reach the end-of-life in 2020;
- to develop repowering scenarios, evaluate their technical-economic sustainability and estimate if and which incentive levels could guarantee the viability of repowering projects.

Firstly, due to the lack of literature in this specific field of wind energy, in order to assess repowering scenarios and potential in Italy it has been necessary to design (Chapter 2) and to apply (Chapter 3) a methodology on a national base. Next, three case studies have been considered in order to perform a first and preliminary validation of the assessment (Chapter 4). Lastly, an economic analysis has been carried out on the case studies with the aim to estimate their profitability, Internal Return Rate (IRR) and Pay-Back Time (PBT) (Chapter 5).

2. Methodology, data sources and tools

The methodological process is organized in three main steps:

1. Repowering potential assessment:

- census of the wind capacity at the end-of-life in 2020 in Italy (wind plants installed until 31st December 2005) by identifying the technical features of the plants (rated power, number and size of the WTGs, hub height, etc.) as well as the geo-location of all WTGs belonging to these plants;
- definition of three hypotheses of repowering of each plant in order to develop repowering scenarios at national scale;
- evaluation of the energy production from the wind capacity at the end-of-life with reference to the Current Status (CS)[2] of the plants and to the three repowering hypotheses. For the repowering scenarios and potential evaluation, a Geographical Information System (GIS) approach was adopted and the calculations, based on the ATLAEolico maps [23], [24], were performed by means of an open-source GIS;

2. Case studies: technical analysis

- selection of the three case studies;
- analysis of the plant layout and energy production of the three case studies by means of a micro-siting commercial code with reference to the CS and to the repowering scenarios;
- validation of the energy production calculation for the CS by means of in field collected operational data.

3. Case studies: economic analysis

- economic analysis of the three case studies based on realistic assumptions on costs (CAPEX and OPEX) and expected incomes from the energy selling;
- analysis of the economic sustainability of repowering scenarios under different incentive hypothesis.
- The main information/data sources and tools used to perform the above-mentioned activities, are listed hereunder:

  - National Wind Energy Association (ANEV) database concerning all the installed wind plants and their characteristics: number, size and model of WTGs, year of grid connection, name of the operator, name of the municipality(ies);

- bulletin by Gestore Servizi Energetici S. p.A. (GSE S. p.A.), a the state-owned company which promotes and supports RE sources in Italy and pays the relevant incentives;
- data about the geo-localization of WTGs supplied by Apulia Regional Administration in the frame of a collaboration agreement with RSE;
- virtual inspections for geo-localization of WTGs by means of the free web applications Google Earth [25] and Bing Aerial [26];
- ATLAEolico, RSE Wind Atlas containing information about the long term annual mean wind speed and the specific annual energy production at 25 m, 50 m, 75 m 100 m a.g.l./a.s.l. with 1 km spatial resolution;
- Administrative Borders updated to 2013 by the Italian National Institute of Statistics (ISTAT);
- open source software Quantum GIS (QGIS) [27];
- Wind Atlas Analysis and Application Program (WAsP), Danish Technical University (DTU-Dk) [28];
- operating data of two wind plants for the period 2003–2014 supplied by an important Italian wind operator.
- The details of the analysis and the results concerning the above-mentioned three steps are reported in the next three sections respectively.

3. Repowering potential assessment

3.1. Census of the wind capacity at end-of-life in 2020 in Italy

With the help of ANEV database the wind capacity at the end-of-life (wind plants installed in the period 1991–2005) has been evaluated. It totals 1625 MW, corresponding to 133 plants and to 2083 WTGs. The most of this end-of-life capacity is concentrated in four Southern regions: Campania (405 MW/31 plants/506 WTGs), Apulia (362 MW/28 plants/486 WTGs), Sicily (314 MW/21 plants/374 WTGs) and Sardinia (246 MW/16 plants/279 WTGs). The most of end-of-life WTGs, 1274 units, have a size lower or equal to 660 kW (typically old Vestas units), 633 units have a size between 660 kW and 850 kW, and only 176 units have greater size. The dataset of the WTGs geographic coordinates, required for the evaluation of the production by means of the ATLAEolico maps, was initially available only for the Apulia Region. After a long and laborious work, mainly based on virtual visits to the plant sites, carried out using Google Earth and Bing Aerial, it was possible to obtain the complete geo-database for the above mentioned 2083 WTGs.

3.2. GIS project

A GIS project was built using the open source software QGIS including the following information:

- the geographical coordinates, the hub height and size of each end-of-life WTG;
- the set of ATLAEolico maps (long term average annual mean wind speed and specific annual energy production at 25 m, 50 m, 75 m, 100 m a.g.l./a.s.l.);
- ISTAT municipal, provincial and regional administrative boundaries.

A map showing the distribution of the end-of-life WTGs in the whole Italian territory is shown in Fig. 1.

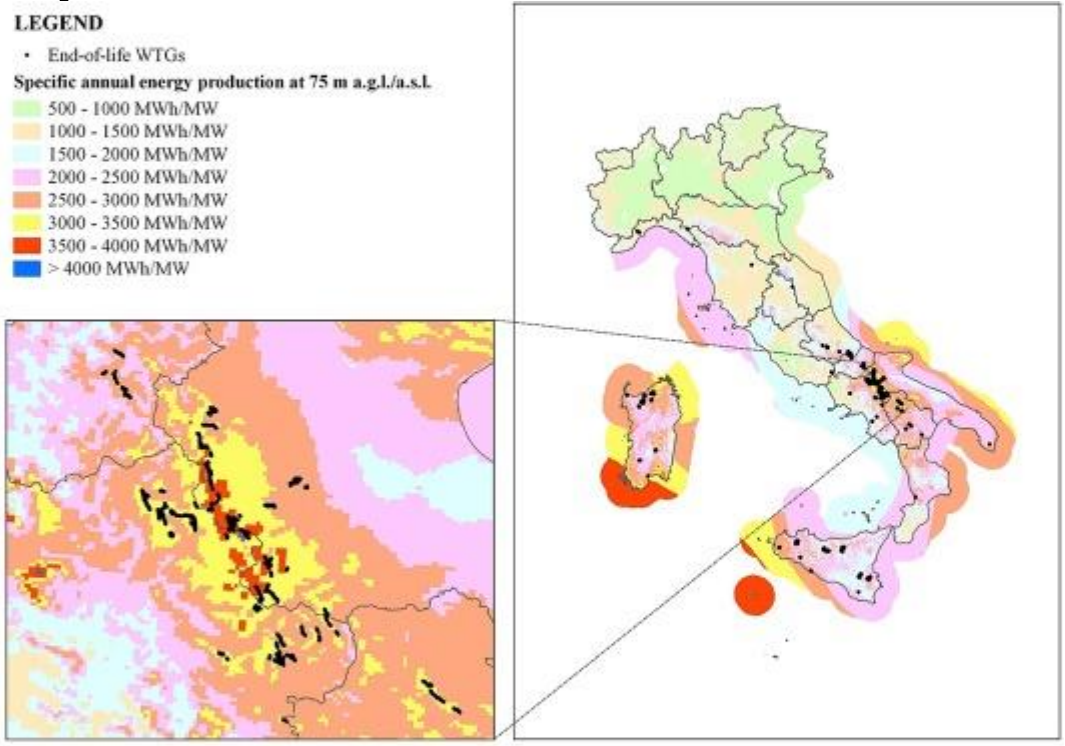

Fig. 1. ATLAEolico specific annual energy production map at 75 m a.g.l./a.s.l. and distribution of the end-of-life WTGs in the Italian territory. Zoom in the area of maximum concentration of end-of-life WTGs.

3.3. Definition of three hypothesis of repowering scenarios

Three repowering hypotheses have been defined:

- H1: the capacity of each repowered plant is the same as the end-of-life plant;
- H2: the capacity of each repowered plant is 1.5 time the one of the end-of-life plant;
- H3: the capacity of each repowered plant is 2 times the one of the end-of-life plant.

For the repowering hypotheses, it has been assumed that in plants with end-of-life WTG size lower than 2 MW, the new WTGs have size of 2 MW while in plants with end-of-life WTG size greater or equal than 2 MW, the new WTGs have size of 3 MW. All new WTGs are supposed to have the hub height at 80 m a.g.l..

According to the above mentioned assumptions, the number of new WTGs for each end-of-life plant was calculated and rounded, if necessary. As expected, there is an overall reduction of the WTGs number due to the greater size of the new ones.

3.4. Evaluation of the energy production using ATLAEolico

The energy production in the CS of the end-of-life wind plants was evaluated using the ATLAEolico maps. For each WTG, the gross annual energy production was calculated taking into account the value of the specific annual energy production (MWh/MW) at the WTG hub height in the grid cell (~1 km × 1 km) of the map in which the WTG was located. If the hub height does not correspond to any of the existing reference heights a.g.l. of the maps, the specific annual energy production at hub height was estimated by linear interpolation involving the two map values relevant to the closer heights. In practice, if P_{m1} and P_{m2} are the two appropriate map values to perform the linear interpolation and H_{m1} and H_{m2} the two reference heights a.g.l., said P_m and H_m respectively the specific annual energy production to be assessed and the WTG hub height, the P_m quantity was obtained according to the following relationship:(1)$P_m = (P_{m2} - P_{m1}) / (H_{m2} - H_{m1}) * (H_m - H_{m1}) + P_{m1}$ [MWh/MW]
The value of the specific annual energy production of each plant (P_{ma}) was calculated as arithmetic average of all P_m values of the end-of-life WTGs belonging to the plant.
The average specific annual energy production (P_{ma_rep}) to be coupled to each plant in the three repowering hypotheses was calculated in the same way assuming the hub height (H_{ma_rep}) equal to 80 m a.g.l..
The gross average annual energy production related to each single wind plant in the four configurations was obtained by multiplying the P_{ma} and P_{ma_rep} by its rated power (Prp in MW):(2)CS: $P_{ma} * Prp$ [MWh](3)H1: $Pma\_rep * Prp$ [MWh](4)H2: $Pma\_rep * 1.5 * Prp$ [MWh](5)H3: $Pma\_rep * 2.0 * Prp$ [MWh] .
The results of these assessments, aggregated on national basis for CS, H1, H2 and H3 are summarized in Table 1.

Table 1. National wind energy potential in the current status (CS) and in the three repowering hypotheses (H1, H2, H3).

Quantity	**CS**	**H1**	**H2**	**H3**
Capacity [MW]	1625	1625	2438	3250
No. WTGs [−]	2083	767	1150	1534
WTGs reduction [%]	N/A	63.2	44.8	26.4
Gross Annual Energy Production [TWh]	4.2	4.8	7.3	9.7
Gross Annual Energy Production Increase [%]	N/A	14.3	73.8	131
Average Gross Specific Production [MWh/MW]	2585	2954	2994	2985

In order to understand the importance of the energy contribution calculated for the repowering hypotheses, the Gross Annual Energy Production in Table 1 can be compared to the total wind energy production in Italy during the year 2015, accounting for 14.6 TWh [19].
Summarizing, in H1 (unchanged plant capacity with respect to the CS) there is an overall increase in energy production of about 15% and a reduction of WTG number greater than 63%. In H2 (plant capacity 1.5 times respect to CS), the energy production increase is very significant (74%) and the reduction of the WTG population is close to 45%. In H3 (doubled plant capacity with respect to CS), the energy production is more than doubled and the decrease of the WTG population is still considerable (more than 25%).

The assumptions set out for the assessment of the national wind repowering potential are merely theoretical and do not take into account possible limitations due to technical and/or impact issues as well as changes in regulations and constraints. In order to understand how these issues can affect the results, three repowering case studies were considered. Three plants have been chosen in Apulia Region thanks to a collaboration between RSE and Apulia Regional Administration. To reinforce the technical evaluation, for two of these plants, in field operational data were used for comparative purposes.

4. Case studies: technical analysis

4.1. Plant identification

In 2010, Apulia Region Government published the regional guidelines for RE plants installation [29]. These guidelines are more restrictive than the previous regulations. In particular, the criteria for identifying areas to be excluded (forbidden) from RE plant installations are clearly defined. More recently, in 2013, a revision of these criteria has been introduced by of the Regional Territorial and Landscape Plan [30]. For several end-of-life plants, the new criteria indicate that their locations fall in forbidden areas. In order to better understand the possible critical issues in real repowering applications, three case studies have been chosen among the plants grid connected before 2005 in this Region. Their main characteristics in the CS are summarized in Table 2.

Table 2. Main features relevant to the three plants in the CS.

Empty Cell	**Plant A**	**Plant B**	**Plant C**
Terrain orography	complex	complex	flat
Wind resource	High[a]	High[a]	Good[b]
WTG No.	12	42	19
WTG rated power (kW)	660	600	2000
Wind plant rated power (MW)	7.92	25.2	38

Empty Cell	Plant A	Plant B	Plant C
Operational data availability	yes	no	yes

Annual average wind speed at 75 m a.g.l.: [a]7÷8 m/s and [b]6÷7 m/s.

4.2. Micro-siting analysis and Wind Atlas results

According to the above mentioned repowering hypotheses, the combination of the three plants (A, B, C) and the four configurations (CS, H1, H2, H3) actually generated 12 case studies, whose main data are reported in Table 3.

Table 3. Table summarizing the main data of 12 case studies.

Plant	**Current Status**			**Repowering hypothesis**								
	CS			**H1**			**H2**			**H3**		
	WTG number	**WTG size**	**Rated power (*Prp*)**	**WTG number**	**WTG size**	**Rated power (*Prp*)**	**WTG number**	**WTG size**	**Rated power (1.5 *Prp*)**	**WTG number**	**WTG size**	**Rated power (2 *Prp*)**
	[–]	**[kW]**	**[MW]**	**[–]**	**[kW]**	**[MW]**	**[–]**	**[kW]**	**[MW]**	**[–]**	**[kW]**	**[MW]**
A	12	660	7.92	4	2000	8.0	6	2000	12.0	8	2000	16.0
B	42	600	25.2	13	2000	26.0	19	2000	38.0	25	2000	50.0
C	19	2000	38	13	3000	39.0	19	3000	57.0	25	3000	75.0

Micro-siting analysis of these configurations were carried out using the commercial code WAsP. The main inputs for the micro-siting code are the wind resource at the plant site and the plant layout.

In order to design the layouts of the repowering case studies, a GIS project was built including the maps of Apulia areas where wind energy plants are forbidden. Moreover, exploiting the peculiarities of the free web applications Google Earth and Bing Aerial, virtual on-the-spot-investigations at plant sites were performed. The defined new layouts, together with the CS one, were used for the evaluations based on WAsP code and on the ATLAEolico maps.

For all the layouts of the repowered plants:

- the WTG positions were identified trying to exploit, as far as possible, the locations occupied by the outdated WTGs in order to optimize the use of existing infrastructures (mainly the ones relevant to the electric grid connection);
- the good practice, concerning the spacing among WTGs to minimize “wake effect” losses, were observed as much as possible;
- the forbidden areas were taken into proper account.

Considering all the raised issues, the H3 repowering hypothesis for all cases resulted hard to be realized due to the greater number of multi-megawatt WTGs involved and to the high concentration of wind plants in the proximity. These issues affected the possibility to find a rational layout of the WTGs that would allow either the respect of the territorial and landscape constraints or a profitable energy production. Therefore the H3 hypothesis has been excluded from the micro-siting analysis performed with WAsP.

An example of the defined layouts for the plant B with reference to the H1 and H2 repowering hypothesis is shown in Fig. 2.

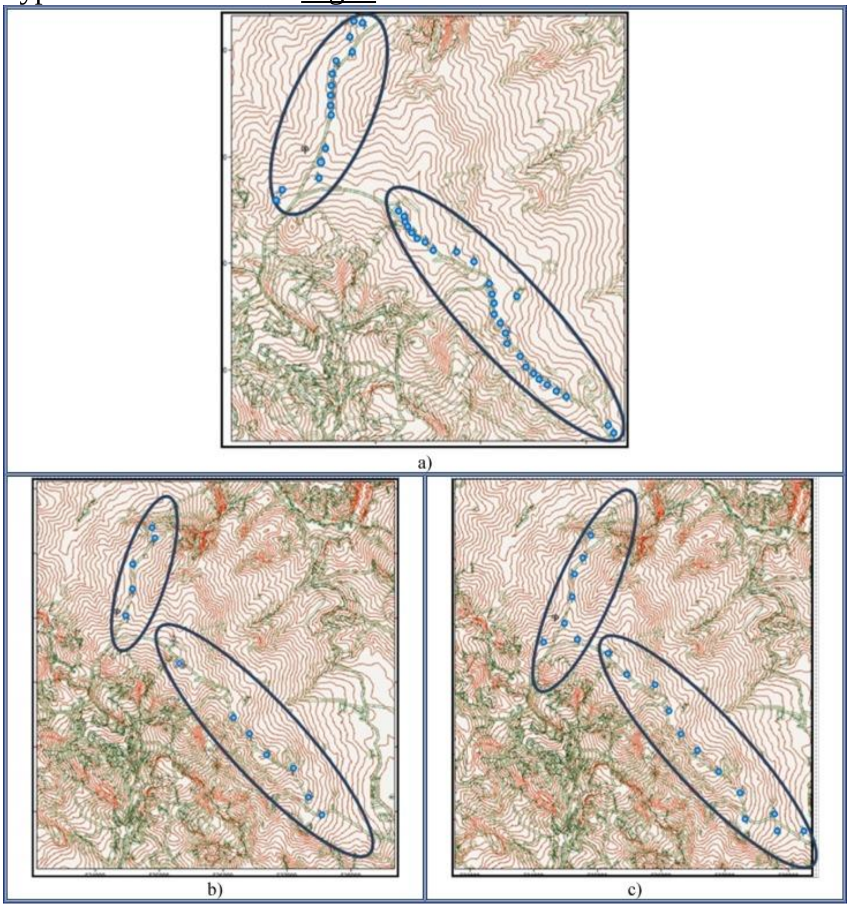

Fig. 2. Plant B: layouts (WTG: blue dots) relevant to the CS of the wind plant (a), and to the repowering hypothesis H1 (b) and H2 (c) shown on background the orography (brown lines) and roughness changes (green double lines) of the area represented in WAsP environment.

The landscape change resulting from the adoption of the H1 repowering hypothesis for plant B (restricted to the Southern area) are shown in Fig. 3. The most significant change in the landscape impact seems to be mainly related to the lower density of the WTGs, rather than to the greater WTG size.

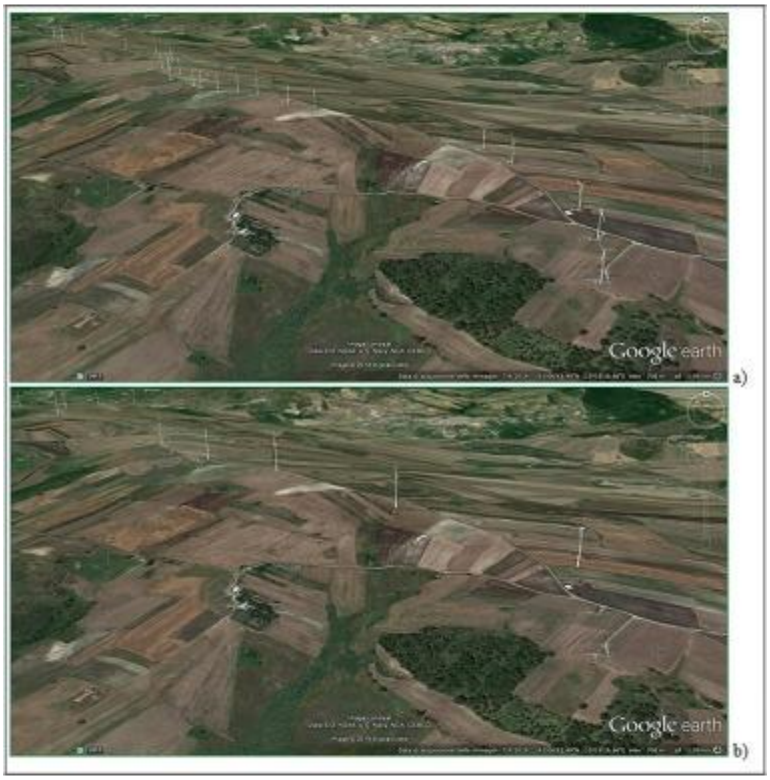

Fig. 3. Plant B (South): 3D pictures, built in Google Earth environment, showing the landscape changing of a portion of the CS plant (a) introduced by adopting the repowering H1 hypothesis (b).

The aim of the technical analysis is to calculate the net energy delivered to the grid connection point. Using WAsP code, the calculated annual energy production already takes into account terrain and wake effects. Using the process based on ATLAEolico maps, the results represent the gross annual energy production. In order to compare the two evaluations, for each case study, the value of the wake losses calculated by WAsP code was applied to the ATLAEolico process results. Moreover, the following penalizing effects were taken into account for all the evaluations in order to go as closer as possible to the actual net annual energy production:

a. overall electrical efficiency (e.g. electric losses, assumed 97%[3]);
b. annual availability index of the external electric grid (assumed 99.5%[3]);
c. environmental and degradation losses that could affect in a negative way the standard wind turbine power curve (assumed 5% for CS and 3% for repowering hypothesis)
d. annual availability index of the wind plant. The values are included in the range 95÷98% and come out mainly from the available operational data.

The results of all the calculations of net annual energy production are reported in Table 4.

Table 4. Results obtained by means of WAsP code (CS, H1, H2) and ATLAEolico maps (CS, H1, H2, H3) with reference to the three case studies.

Reference condition	Case study											
	Case A				Case B				Case C			
	Wind plant rated power	Estimate of net annual energy production at the grid connection			Wind plant rated power	Estimate of net annual energy production at the grid connection			Wind plant rated power	Estimate of net annual energy production at the grid connection		
		WAsP code (a)	ATLAEolico (b)	(b-a)/a		WAsP code (a)	ATLAEolico (b)	(b-a)/a		WAsP code (a)	ATLAEolico (b)	(b-a)/a
	[MW]	[MWh]	[MWh]	[%]	[MW]	[MWh]	[MWh]	[%]	[MW]	[MWh]	[MWh]	[%]
CS	7.9	20841	18773	−9.9	25.2	60192	60662	0.8	38.0	72865	84937	16.6
H1	8.0	26923	24020	−10.8	26.0	82608	77190	−6.6	39.0	92311	89330	−3.2
H2	12.0	37785	35808	−5.2	38.0	116174	111506	−4.0	57.0	127432	150770	18.3
H3	16.0	N/A	47334	N/A	50.0	N/A	149806	N/A	79.0	N/A	194989	N/A

The comparison between the energy results related to WAsP estimates (micro-siting studies) and those based on ATLAEolico maps for the same plant shows different deviations with a minimum of 0.8% to a maximum of 18.3%. However, in most cases the extent of the deviation is less than 10% and the ATLAEolico approach seems to underestimate the energy production compared to the WAsP one. Moreover, it must be pointed out that the CS WAsP net energy production is fairly consistent with the same quantity supplied by the operator for plants A and C. In general, the results of the simplified approach of ATLAEolico are fairly consistent with the ones coming from the more accurate WAsP analysis. According to the results reported in Table 4, the increase in annual energy production, compared to the same quantity relevant to CS, is included within the range 27%–37% for the H1 repowering hypothesis and in the range 75%–93% for the H2 hypothesis. The increase in annual energy production for the three case studies are slightly higher than in the national evaluation. This could be due to the fact that the three case studies sites are among the most windy ones in Italy.

5. Case studies: economic analysis

Some economic analysis were conducted for the case studies (CS and repowering hypotheses H1 and H2) to understand the feasibility of related investments. As previously explained, the H3 hypothesis resulted hard to be realized due to technical constraints, therefore, it was not included in the economic analysis. A simple economic model was built with the aim of understanding, in particular, if the increase of energy production of the repowering hypotheses would be sufficient to the economic sustainability of the investments without external incentives.

In order to represent the economic value of the different investments, two economic indicators, the IRR and the PBT, were calculated. IRR is the interest rate at which the net present value of all the cash flows (both positive and negative) from a project or investment is equal zero. PBT is the time in which the initial cash outflow of an investment is expected to be recovered from the cash inflows generated by the investment. It is one of the simplest investment appraisal techniques.

Model inputs are listed in the following and summarized in Table 5 for the three case studies:

1. characteristics of the plant (WTGs number and size, year of installation);
2. lifetime of all the plants assumed as 20 years from installation;
3. net annual energy production from WAsP estimates;
4. specific installation cost (€/kW): for each plant this specific cost is related to the year of installation (sources:”Libro bianco” of ENEA,[4] 1999, IEA Annual Reports and communication from ANEV). For the repowering cases, the value has been assumed considering some economic benefits such as: the second hand turbine selling, the use of existing grid infrastructures and roads, etc.;
5. costs of Operation and Maintenance (O&M): a standard value has been employed throughout the period of interest;
6. discount rate: the value has been assumed taking into account the actual inflation;
7. interest rate: the value has been defined taking into account the interest nowadays applied by the most of Italian banks.
8. past and expected future energy prices: for the past prices, the yearly reference price of energy purchased on the stock exchange, Single National Price, has been used (source: GSE S.p.A.). For the future prices, the results coming from EU project GridTech [31] have been considered;
9. economic incentive at the time of the plant intallation (only for CS): feed in tariff Green Certificates (GC) incentive and feed in premium CIP/6 system.

Table 5. Input data for the economic evaluations.

Empty Cell		PLANT A			PLANT B			PLANT C		
		CS	**H1**	**H2**	**CS**	**H1**	**H2**	**CS**	**H1**	**H2**
Technical data	Year of installation	2003	2015	2015	1998	2015	2015	2000	2015	2015
	Plant Capacity [MW]	7.92	8	12	25.2	26	38	38	39	57
	n.WTGs	12	4	6	42	13	19	19	13	19
	WAsP Net Annual Energy Production [MWh]	20841	26923	37785	60192	82608	116174	72865	92311	127432
Costs	Specific Installation Costs [€/kW]	1400	1250	1250	1000	1250	1250	1000	1250	1250
	O&M [€/MWh]	11.5			11.5			11.5		
	Interest rate	6%			6%			6%		
	Discount rate	2%			2%			2%		
Revenues	Economic incentive	GC 90 €/MWh	N/A	N/A	CIP/6 62 €/MWh	N/A	N/A	GC 90 €/MWh	N/A	N/A
	Energy Selling price [€/MWh]	Single National Price	70	70	Single National Price	70	70	Single National Price	70	70

In the above Table, the economic incentive granted to the wind energy production is intended as incentive component of the feed in premium mechanism that was adopted under different regimes

(CIP/6 and GC), to promote wind installations. These economic incentives have been added to the Single National Price for 8 years (CIP/6) and for 12 years (GC for the CS. In this study the project IRR over 20 years has been calculated).

In the following Table 6 the results of the economic evaluations for CS and for the repowering scenarios are reported.

Table 6. Results of the economic analysis concerning project IRR and PBT for all the case studies.

Empty Cell	**Plant A**			**Plant B**			**Plant C**		
	CS	**H1**	**H2**	**CS**	**H1**	**H2**	**CS**	**H1**	**H2**
IRR	18%	9%	8%	18%	9%	9%	19%	5%	4%
PBT years	4.5	8.5	9.5	4.5	9.5	9.5	4.5	12.5	13.5

From the results in Table 6, it emerges that the economic indicator IRR is always major in the CS than in the repowering hypotheses and, at the same time, the PBT for the repowering hypotheses is always longer than for the CS.

This is a consequence of the generous economic incentives in place for the plants in the first phase of the national incentive scheme application (CS), moreover the capital costs during the last ten years in Italy were fluctuating and the expected reduction did not happen, contrary to other technologies such as Photovoltaic.

However, in absence of incentives, project IRR within 6%–9% could be acceptable for a new or repowered wind plant in the current economic framework. This IRR range is compatible with the fact that wind production is now a mature and competitive technology and is comparable, for example, with the IRR of new recent not incentivized photovoltaic plants in Italy.

Due to the fact that there could be some repowered plants with IRR lower than 6%, like the plant C, a sensitivity study was performed in order to assess which is the energy prices that can guarantee an IRR in the range 6%–9% for this plant.

It can be observed from Fig. 4 that in order to achieve an expected project IRR from 6% to 9% and to guarantee reasonable continuity in repowering process, energy price range should be 80–95 €/MWh. Taking into account that a fixed price equal to 70 €/MWh for the energy selling during the whole lifetime has been assumed, at least a quite small incentive tariff, in the range of 10–25 €/MWh, should be added.

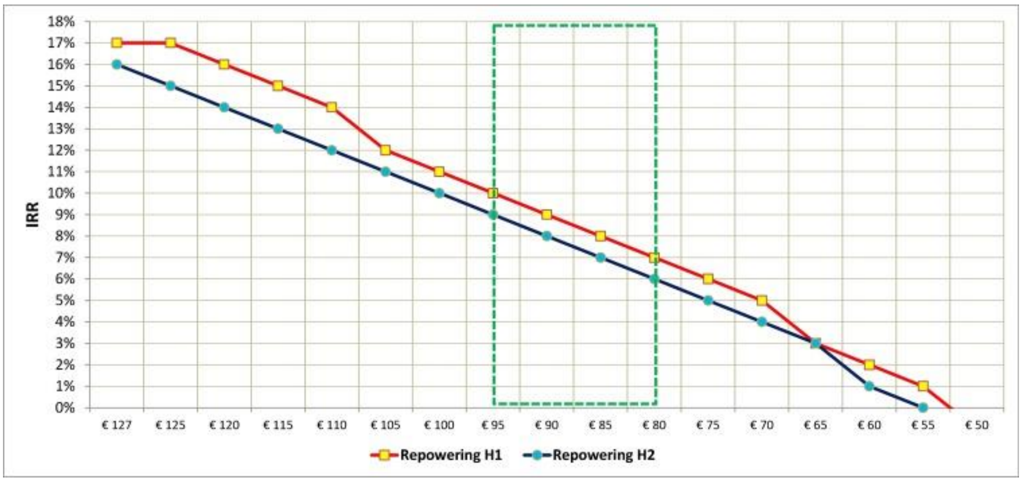

Fig. 4. Trend of the IRR for the two hypotheses relevant to the plant C versus energy prices.

6. Conclusions

In order to define the future development of the wind energy sector in Italy, the wind capacity that is reaching the end-of-life in few years cannot be neglected. Repowering initiatives have many benefits such as the implementation of the national energy produced by renewable sources, the achievement of the regional objectives, the improvements of aesthetic and landscape impacts, the reduction of "virgin" soil consumption and the more intensive exploitation of the local wind resource.

The new renewable 2030 target are expected to be set in a short term. The electricity RES target has been recently estimated for Italy next to 50% of the final consumption [32]. In consequence there will still be the need of increasing renewable energy capacity, including wind capacity. Taking into account the overall benefits of increasing the wind energy production through the repowering, special measures (i.e. dedicated annual capacity quota and feed in tariff, facilitated authorization process) should be put in place to foster this kind of intervention, thus deploying the windiest sites with the best available technology.

The simple economic model adopted in this analysis is based on a fixed energy selling price during the whole lifetime of the repowered plants. Regarding the future power markets, the authors observe that, at this stage, Emission Trading System (ETS) regime appears unable to fully incorporate the GHG externality on electricity prices.

This study can help wind energy stakeholders and decision makers in Italy to better understand the main features of repowering initiatives and could support future decisions concerning new regional and national regulations, e.g. rules and tariffs of the incentive mechanism as well as authorization process.

Moreover, the results of this study could be a starting point for a more holistic approach to the future of wind energy in Italy, taking into account not only the technical-economic aspects, but also environmental, landscape and public acceptance issues.

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References

[1] Kyoto Protocol to the United Nations Framework - Convention on Climate Change, 1998.

[2] Council Decision of 25 April 2002 concerning the approval, on behalf of the European Community, of the Kyoto Protocol to the United Nations Framework Convention on Climate Change and the joint fulfilment of commitments thereunder (2002/358/CE).

[3] Directive 2009/28/EC of the european parliament and of the council of 23 April 2009 on the promotion of the use of energy from renewable sources.

[4] A Policy Framework for Climate and Energy in the Period from 2020 to 2030, EC Communication COM, 2014, 15 final.

[5] https://www.epa.gov/cleanpowerplan.

[6] Global Wind Energy Council, Global Wind Report - Annual Market Update 2015, April 2016.

[7] D. Airoldi, C.A. Casale, E. Lembo, L. Serri, "6.5 GW of installed wind capacity in Italy: preliminary results of a statistical study for the support of future developments", EWEA2012 Europe's Premier Wind Energy Event, Copenhagen, April 2012.

[8] IEA WIND, Wind Energy Annual Report 2000, May 2001.

[9] European Wind Energy Association, The European Offshore Wind Industry - Key Trends and Statistics 2014, January 2015.

[10] R. Lacal Arantegui, "Wind deployment in Europe", IEA ExCo Meeting, Neuchatel, 5 May 2015.

[11] W. Hulshorst, Repowering and Used Wind Turbines, Leonardo Energy, EconInternational, April 2008.

[12] R. Wiser, R. O'Connell, M. Bolinge, A Scoping-level Study of the Economics of Wind-project Repowering Decisions in California, KEMA Inc., August 2008.

[13] L. Castro, A. Filgueira, M.A., Seijo, E. Mu~noz, L. Piegiari, Is it economically possible repowering Wind Farms. A general analysis in Spain", International Conference on Renewable Energies and Power Quality, (ICREPQ'11), Las Palmas de Gran Canaria (Spain), 13-15 April, 2011.

[14] D. HullSan, J. Mercury, Altamont Pass Celebrates 'repowering' of Wind Farm, May 2012 http://www.mercurynews.com/ci_20753019/california-altamont- pass-celebrates-repowering-wind-farm.

[15] E. Lantz, M. Leventhal, I. Baring-Gould, Wind Power Project Repowering: Financial Feasibility, Decision Drivers and Supply Chain Effects, Technical report, NREL/TP-6A20e60535, December 2013.

[16] J. Lawson, Repowering Gives New Life to Old Wind Sites, 17 June, 2013. http://www.aweablog.org/repowering-gives-new-life-to-old-wind-sites/.

[17] C. Ender, D.E.W.I. GmbH, Wilhelmshaven "Wind Energy Use in Germany e Status. Windenergienutzung in Deutschland e Stand", June 2014.

[18] www.oxforddictionaries.com.

[19] IEA WIND TCP, 2015 Annual Report, August 2016, ISBN 978-0-9905075-3-6. Italy Chapter.

[20] Legislative Decree, Attuazione dell'art. 24 del decreto legislativo 3 marzo

2011, n. 28, recante incentivazione della produzione di energia elettrica da impianti a fonti rinnovabili diversi dai fotovoltaici”, Italian Ministery of Economic Developoment, 6 July 2012.

[21] Legislative Decree “Definizione e qualificazione degli obiettivi regionali in materia di fonti rinnovabili e definizione della modalit a di gestione dei casi di mancato raggiungimento degli obiettivi da parte delle regioni e delle province autonome (c.d. Burden Sharing)”, Italian Ministery of Economic Developoment, 15 March 2012.

[22] L. Serri, E. Lembo, C. Gelli, Scenari di repowering di impianti eolici a scala nazionale, RdS report, 15000668, February 2015, www.rse-web.it.

[23] http://atlanteeolico.rse-web.it/.

[24] G. Botta, C.A. Casale, E. Lembo, S. Maran, L. Serri, G. Stella, S. Viani, The Italian wind atlas e status and progress, EWEC 2007, Milan 7-10 May 2007.

[25] https://earth.google.com/.

[26] http://mvexel.dev.openstreetmap.org/bing/.

[27] www.qgis.org.

[28] www.wasp.dk.

[29] Linee Guida per l’autorizzazione degli impianti alimentati da fonti rinnovabili, Regolamento Regionale n

24 published in the BURP n. 195 of 31 December 2010.

[30] Piano Paesaggistico Territoriale della Regione Puglia, Resolution of the Apulia Regional Council no. 176 of 16 February 2015, published in the BURP n. 39 of 3 Mars 2015.

[31] www.gridtech.eu.

[32] “Technical report on Member State results of the EUCO policy scenarios”, E3MLab & IIASA, December 2016 Ms. Ref. No.: RENE-D-16e00881 Title: Wind energy plants repowering potential in Italy: technical-economic assessment. L. Serri et al. / Renewable Energy 115 (2018) 382e390390