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Re-Powering Italian Wind Farms: a Feasibility Study from Theory to Practice

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Abstract. The installation of new renewable power plants in Italy is currently hindered by various concurrent factors, the length of the authorization process above all. The average time to authorize a wind farm is about five and a half years, mainly due to the binding judgment of the EIA (Environmental Impact Assessment). Italy however is now in a phase where many of the first-installed wind farms are close to their end of life. In this perspective, a promising solution is given by the re-powering of existing wind farms, since they can access a simplified authorization procedure under the Legislative Decree 08/11/2021, n. 199 et seq., which reduces by one third the bureaucratic burden and it lets non-binding the evaluation of the landscape authorities. Moving from this background, the study provides a feasibility study on the re-powering of Italian wind farms. Starting from the database available at GSE (Gestore dei Servizi Energetici), a new re-powering scenario has been defined, accounting for the constraints on the site area, number and dimension of the turbines imposed by the art. 32 of Law 29/07/2021, n. 108. The effectiveness of the re-powering intervention has been evaluated in terms of energetic yield, considering the increased capacity factor of the new turbines, economic revenue and environmental footprint. To verify its feasibility on a real application, a wind farm owned by AGSM-AIM S.p.A., for which wind, terrain, and production data were available, has been selected. Different plant layouts have been analyzed in the WindPro software, and compared in terms of power, producibility and capacity factor. The feasibility of the different layouts has also been verified by on-field inspections.

Keywords: Re-powering, Wind, Siting, HAWT

1. Introduction and objectives of the study

In the frame of the PNIEC (Piano Nazionale Integrato Energia e Clima), Italy is committed to reach 30% of gross final energy consumption from renewables by 2030, although this target will be further revised due to the more ambitious targets outlined by the European Union as part of the recovery plan after the Covid-19 pandemics. Nonetheless, the installation of new renewable power plants is currently hindered by various concurrent factors, the length of the authorization process above all [1]. This is even more relevant for wind farms, where the social acceptance is still quite low. The average time to authorize a wind farm is about five and a half years, mainly due to the binding judgment of the EIA (Environmental Impact Assessment). Like many pioneering countries for wind energy, however, Italy is now in a phase where many of the first-installed wind farms are close to their end of life. In this perspective, a promising solution is given by the re-powering of existing wind farms, since they can be considered yet as *eligible areas* under the latest Italian legislation on the matter (Legislative Decree 08/11/2021, n. 199). This status allows to reduce by one third the procedure terms and it lets non-binding the evaluation of the landscape authorities. On top of that, the possibility of exploiting existing sites is particularly valuable in a country like Italy, which suffers from a low geographical availability of the wind resource and chronical land consumption [2].

Moving from this background, the study provides a feasibility analysis on the re-powering of Italian power plants with capacity greater than 1 MW, with incentive contracts expired or expiring by 2030 and that have not been modified already with non-incentivized modernization or upgrading interventions. These have been identified starting from the database available at GSE (Gestore dei Servizi Energetici). According to art. 32 of Law 29/07/2021, n. 108, the minimum number of new wind turbines, their size and installation area have been evaluated; furthermore, the producibility of the new power plants has been estimated taking into account the technological evolution of new turbines and therefore their ability to make the most of the resource by increasing the equivalent hours of operation in a year. The effectiveness of the re-powering intervention was analyzed in its different aspects, using as the Net Present Value and Pay Back Time as indicators for the economic analysis, while the long-term carbon dioxide deficit for the environmental one. Job generation and land use benefits were also considered.

Eventually, a wind farm owned by AGSM-AIM S.p.A., for which wind, terrain, and production data were available, has been selected as a test case for a real re-powering application. The scope of this second part of the work was to show to what extent real projects can meet the theoretical predictions based on the regulation. Different plant layouts have been analyzed in the WindPro software, which currently represents the state-of-the-art for wind farm assessment, and compared in terms of power, producibility and capacity factor. The feasibility of the different layouts has also been verified by on-field inspections.

2. Legislative framework

The Legislative Decree 08/11/2021, n.199 implements the EU Directive 2018/2001, promoting the use of energy from renewable sources. The title n. III in particular, "Authorization Procedures, Codes and Technical Regulations", simplifies the procedures for the authorization of new wind farms, facilitating the achievement of the targets set by the PNIEC. Among the different articles composing the decree, the number 20 is the most relevant for onshore wind, as it introduces the new concept of *"eligible areas"*, together with rigorous criteria to define them:

a) sites where plants of the same source are already installed and where *non-substantial modifications* are carried out (see article 5, paragraphs 3 et seq. of Legislative Decree 3/03/2011, n. 28);
b) site-remediation areas identified in title V, part 4 of Legislative Decree 3/04/2006, n.152;
c) quarries and mines, which are in a condition of abandon or environmental degradation;
d) Italian railways' sites and companies.

As a matter of fact, new wind farm projects involving a site identified as *eligible area* can take advantage of a simplified authorization procedure (art. 12 of Law Decree 1/03/2022 n.17, later converted with modifications to Law 28/04/2022, n. 98), which makes the opinion of the authority in charge of the landscape non-binding. On top of that, the bureaucratic burden associated to the application is reduced by one third. To better understand the relevancy of this measure, Figure 1 schematically reports the typical timeline for the authorization of a new wind farm project in Italy, for rated powers higher than 60 kW. The assessment of the environmental impact of the installation (in Italian *Valutazione di Impatto*

Ambientale, VIA) by the competent authorities notably slows down the overall procedure, raising the completion time to more than 5 years.

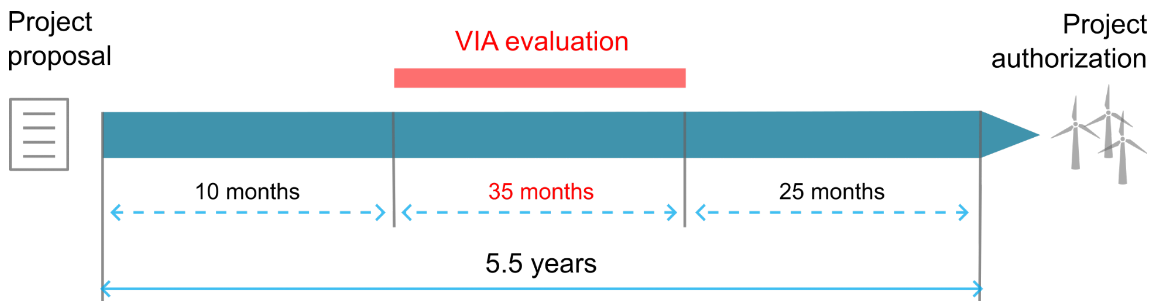

Figure 1. Typical timeline for the authorization of a wind farm with rated power higher than 60 kW in Italy. Adapted from [1].

2.1. Definition of non-substantial modifications

As pointed out in the previous paragraph, the status of *eligible area* can be applied to an existing wind farm (point (a)) only if the new project involves *non-substantial modifications* of the original one. In this perspective, the article n. 32. "Simplification rules on electricity production from renewable sources and simplification of re-powering procedures" of Law 29/07/2021, n. 108 defines three main constraints to the design of the re-powered plant:

- *dimensions of the wind turbines:* the maximum height of the new machine $h_{2,max}$ shall not exceed the one of the existing turbine h_1, scaled by the ratio of the two rotor diameters, as in Eq. 1:

$$\mathrm{h_{2max}} \leq \frac{\mathrm{d_2}}{\mathrm{d_1}} \cdot \mathrm{h_1} \qquad where \qquad h_{2,max} = \begin{cases} 2.5 \cdot h_1 & if\ d_1 \leq 70m \\ 2 \cdot h_1 & if\ d_1 > 70m \end{cases} \tag{1}$$

- *number of wind turbines:* the number of turbines should be reduced with respect to the existing installation, $n_2 < n_1$. The magnitude of such reduction depends on the size ratio between the two layouts, as in Eq. 2:

$$n_2 = \begin{cases} \min\left[n_1 * \frac{2}{3};\ n_1 \cdot \frac{d_1}{(d_2-d_1)}\right] & if\ d_1 \leq 70m \\ \mathrm{n_1} \cdot \frac{\mathrm{d_1}}{\mathrm{d_2}} & if\ d_1 > 70m \end{cases} \tag{2}$$

- *site area:* the area occupied by the new installation can exceed the old one by maximum 15%. The latter is computed depending on the plant layout. For sites developing along one direction, the length of the line connecting the two machines at the extremes is used. Otherwise, the extension of the farm is evaluated from the imaginary convex polygon connecting the outer turbines.

As explained in detail in Section 3.1, this set of constraints was used in the present work to create a new database of *eligible areas* from the one of the current installations available at GSE.

3. Data

The present work adopted a *top-down* approach, using as starting point for the definition of the re-powering scenario the extensive database available at GSE of wind farm installations in Italy, which are close to their end-of-life and therefore suitable for replacement (see Section 3.1). To verify the feasibility of the proposed re-powering strategy, the latter was applied to the existing wind farm of *Casoni di*

Romagna, for which detailed terrain and on-site wind data were made available by the operator AGSM-AIM, as reported in section 3.2.

3.1. Wind farm database

For the construction of the database, only wind farms with a rated power $P_0 > 1$ MW were selected. A total of 408 plants, put in operation before the year 2012, therefore at the end of their life, and certified by GSE as IAFR *(Impianti Alimentati da Fonti Rinnovabili*) were analyzed. The latter denomination includes all installations with GRIN incentives, either already expired or to be expired by the year 2030, so to fall in the timeline of the PNIEC. This initial dataset was then narrowed down by removing plants that have not already been modified with non-incentivized modernization or upgrading interventions or with access to new incentives (FER).

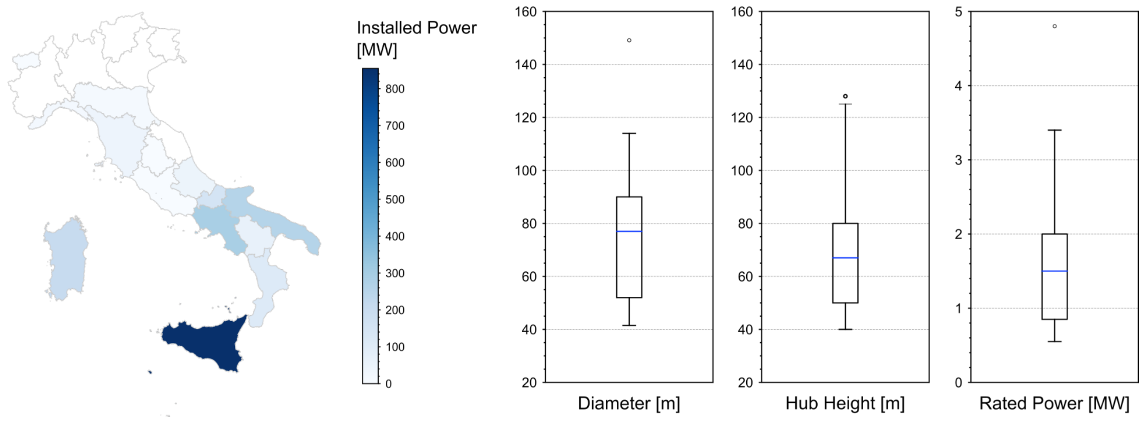

Figure 2. General characterization of the wind turbine database: (left) distribution of the installed power; (right) diameter, hub height and rated power of the installed wind turbines

The final result was a database of 395 plants, of which 275 with active contracts and 120 with expired ones and therefore ready for immediate re-powering. Figure 2 reports in a synthetic way the main features of the assembled dataset. Most of the re-powering potential lies in the southern regions such as Puglia and Sicilia, where the majority of the installations were performed in the early stages of wind energy development in Italy [2]. The North of Italy on the other hand is barely interested by this intervention, as many potential installation sites are in complex terrains and could only be exploited in the recent years [2]. The installed wind turbines are predominantly of the old generation, with an inter-quartile range of 50-90 m for the rotor diameter and 1-2 MW for the machine rated power.

3.2. Test site – Casoni di Romagna

Installed in the year 2009 by AGSM-AIM Spa, the wind farm of *Casoni di Romagna* (BO) is located on the Appennino Tosco-Emiliano mountain range and features 16 Enercon E-53 800kW turbines, for a total rated power of 12.8 MW. Each machine is characterized by a rotor diameter of 53 m and a hub height of 60 m. Given its lifespan and dimension, this plant perfectly fits the re-powering scenario outlined in the present work.

The site extends along two separate ridges for ca. 4 km, as shown in Figure 3. This layout allows to exploit the local acceleration induced by the presence of the mountain top on the synoptic wind (*hill effect* [3]), which, according to the on-site measurements acquired by the company for a period of 5 years at a height of 30 m (see Figure 3 for the mast location), blows predominantly in the SSW direction. The wind distribution is on the other hand shifted towards the lower wind speeds, as reported by the Weibull diagram in Figure 3. Due to confidentiality issues, this data is presented as normalized over the site mean wind speed V_{avg}.

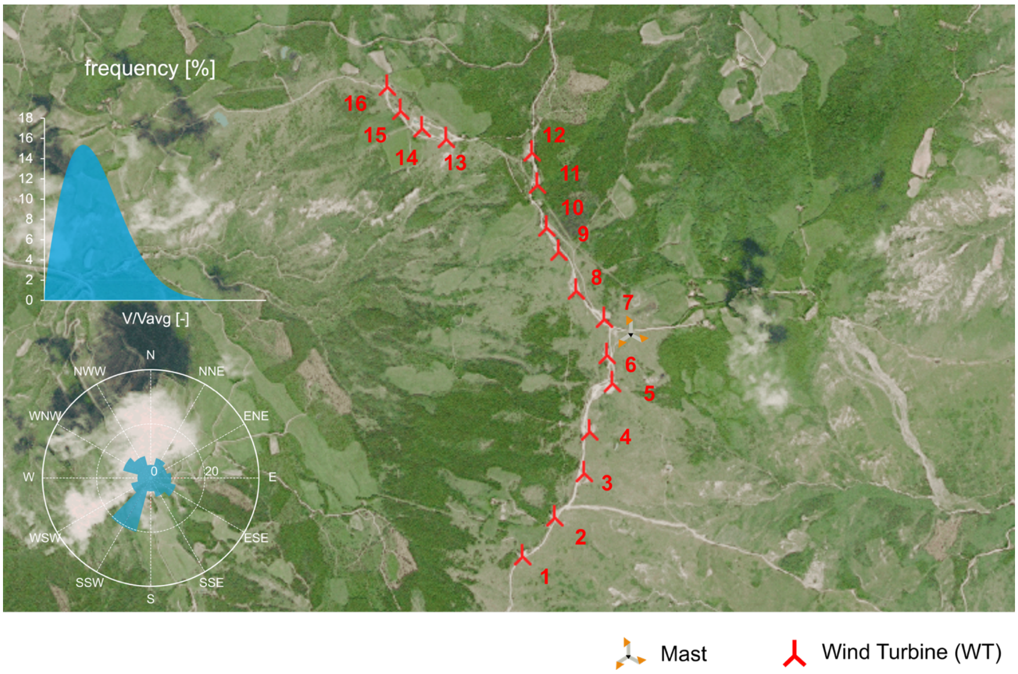

Figure 3. Overview in terms of terrain, wind data and turbine layout for the site of *Casoni di Romagna*

4. Methodology

4.1. Definition of the re-powering scenario

In order to improve the quality of the initial data and therefore the efficiency of the re-powering model, the turbines from the database described in Section 3.1, were divided between machines with a rated power lower (2585 turbines) and higher than 1 MW (2712 turbines).

Turbines with $P_0 < 1$ MW were directly used for the definition of the re-powering scenario, applying the constraints in terms of rotor diameter, number of machines and site area imposed by the regulation (see Section 2.1). In absence of reliable wind data for the considered installations sites, the new turbines were selected to match the same *wind class* of the existing models. According to the IEC 61400 standard [4], this is defined by the annual average wind speed, the maximum wind speed in a 50-year period over 10 minutes and 3 seconds, and the turbulence intensity. Taking as an example 0.85 MW machines, which account for 70% of this subgroup, the Vestas V52 model, wind class IEC IA with rotor diameter of 52 m and average tower height of 55 m can be replaced by a model of the same wind class and size of diameter 130 m and average height 134 m (e.g., the Siemens SWT-DD-130 4 MW turbine).

The same procedure was applied to turbines with $P_0 > 1$ MW. Nevertheless, as for the biggest machines the re-powering intervention risks being redundant, only *"underproducing"* turbines were considered. The latter were identified upon comparison of their actual equivalent hours of operation at full power h_{eq} (see Eq. 3) with the reference values available at GSE for the corresponding power range [5]. On top of that, as many of these turbines already have rotor diameters between 80 and 150 m, the constraint on the maximum tip height from the regulation (see Eq. 1) was limited to $h_{2,max}$=1.5 h_1, to comply with the current maximum dimensions for onshore applications [4].

4.1.1. Energy analysis. To assess the effectiveness of the re-powering intervention in increasing the actual power production of Italian wind farms, a dedicated energy analysis was performed. In absence of detailed terrain, layout and wind data for the considered plants, the yield of the new installations was computed using the Capacity Factor (CF), since it allows to estimate the Annual Energy Production (AEP) of the farm by only knowing its rated power P_0, as in Eq. 3:

$$\mathrm{CF} = \frac{AEP}{AEP|_0} = \frac{P_0 \cdot h_{eq}}{P_0 \cdot 8760} \quad (3)$$

For the estimation of capacity factor, two different approaches were employed, a more *conservative* and a more *realistic* one. In the former, the CF for each existing plant was evaluated from the corresponding average electricity production data under incentives available at GSE, starting from the year 2016. The CF for the repowered site was then taken equal to the existing one, therefore assuming a linear increase in the AEP with the rated power of the park.

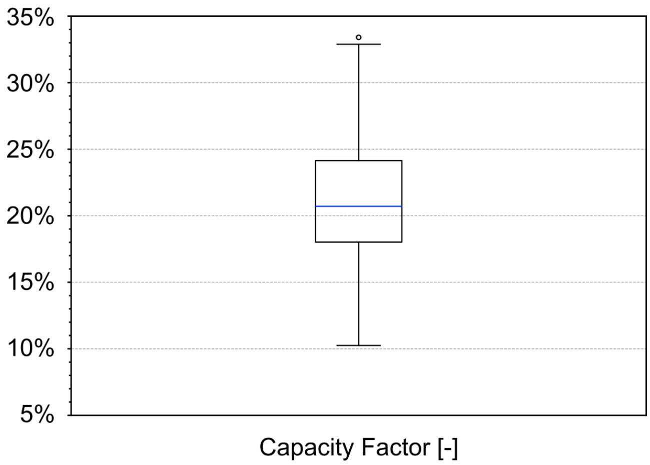

Figure 4. Capacity factor [%] distribution for the considered database – conservative scenario

A second, more *realistic* modelling strategy was also adopted, which took into account the higher efficiency of modern wind turbines. Starting from a recent study from JRC [6], where the capacity factor of three turbine models, i.e., a 2 MW Enercon E-82, a 3.45 MW Vestas V117 and a 1.8 MW IEA Siemens-Gamesa was computed for three different sites of increasing wind availability, a new classification criterion was synthetized. As shown in Table 1, the latter allows to estimate the CF of the plant from the turbine wind class and specific power, i.e., the ratio between the rotor rated power and the swept area. It must be noted how the wind class I, corresponding to the highest wind availability, has been excluded, since it is not possible to find such sites in Italy [2].

Table 1. Capacity factor [%] as a function of rotor power density and wind class for the realistic scenario

Specific power class [W/m2]	wind class IEC II	wind class IEC I
< 250	40	50
250 ≤ p ≤ 360	30	35
> 360	25	30

4.1.2. Economic analysis. The economic feasibility of the re-powering intervention was assessed using as an indicator the Net Present Value (NPV), considering an interest rate of i=10% and a duration of n=20 years, as in Eq. 4:

$$NPV = \sum_{\mathrm{k}=0}^{\mathrm{n}} (\mathrm{R} - \mathrm{C})_{\mathrm{k}} \cdot \frac{1}{(1+\mathrm{i})^{\mathrm{k}}} \quad (4)$$

where R are the revenues and C the costs. The initial investment cost was evaluated around 1 million euros/MW, based on the recent report of the Lazard investment bank [7], and includes the decommissioning of the existing turbines. Since the Capital Expenditure (CAPEX) for this kind of installations is decreasing over the years due to the improvement of the technology, a 5% decrease was considered over the next 5 years. Maintenance costs were estimated on the other hand at 30'000 euros/MW/year [7]. Regarding the revenues R, two scenarios were taken into consideration, one with an energy price (PUN) of 120 €/MWh, computed as an average of the actual over the period 2020-2023 (data for future years are from GSE projections [8]), and one with 90 €/MWh.

4.2. WindPro
All layout analyses for the site of *Casoni di Romagna* were performed with the WindPro software, which currently represents the state-of-the-art for siting applications.

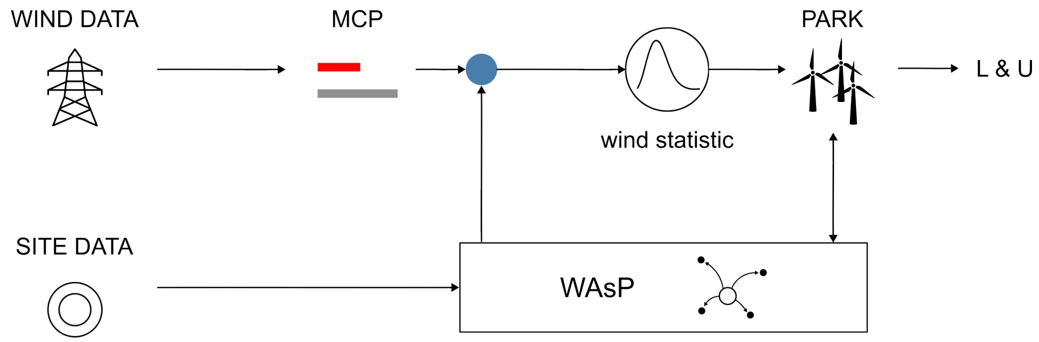

Figure 5. Workflow of the AEP calculation for the considered test site

Figure 5 reports schematically the adopted workflow. After a proper quality check, wind data acquired by AGSM-AIM for a year at the center of the site and at a height of 30 m (see Figure 3), were corrected for year-to-year variability using the MCP (Measure-Correlate-Predict) approach. More in detail, a transfer function between on-site measurements and reference 20-year data, in this case from the ERA5-WRF [9] reanalysis database, was generated for both wind speed and direction. Given the fair correlation coefficient between the two series (R^2=0.764), the *Matrix* technique [10] was adopted for the purpose. The obtained relationship was then used to correct the reference data.

The WAsP [11] linear extrapolation strategy was employed instead to model the effect of the site orography and terrain roughness on the local wind distribution. The corresponding maps were taken from the TINITALY [12] (10 m resolution) and Corine Land Cover 2018 [13] (100 m resolution) databases, respectively. No atmospheric stability effects were considered, as the site presented a contained diurnal heat cycling. This tool was used at first to filter out local disturbances of the flow due to the terrain from the mast data, so to obtain a general wind statistic, i.e., a Weibull distribution for each wind sector, for the site. The latter was then mapped with the same strategy to the position of the turbine hubs, in order to compute the AEP of the plant (PARK module). Wake interference effects were evaluated via the N.O. Jensen Park 2 model [14]. Eventually, additional losses and uncertainty (L & U) were included to achieve the net annual production of the wind farm.

5. Results

5.1. Re-powering scenario
Figure 6 reports in a synthetic way the comparison between the existing situation (*current*) and the one after the re-powering intervention has been performed (*re-powering scenario*) for the GSE database, in terms of installed power, both globally and per region, and number of turbines.

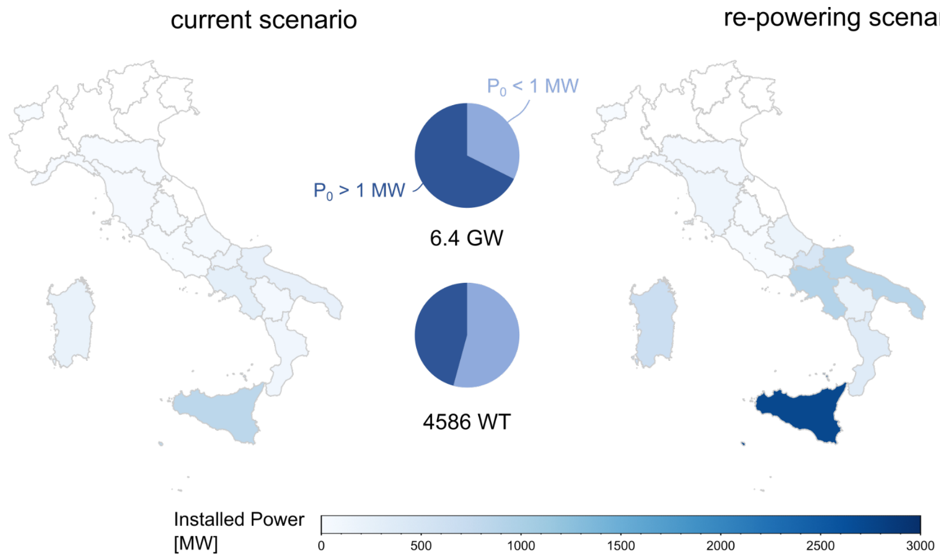

Figure 6. Comparison between the current and the re-powering scenario for the GSE database in terms of installed power per region, total installed power and number of turbines

In general, re-powering the existing wind farms according to regulations will nearly double the installed capacity, at the same time reducing of ca. 27% the number of turbines. The bulk of the intervention will be the replacement of smaller and older machines, i.e., with a rated power $P_0 < 1$ MW, since they are not only the most numerous, but also the most suitable for a performance upgrade. The regions that will be mostly affected by re-powering are the southern ones, especially Puglia and Campania, and the islands, i.e., Sicilia and Sardegna, where the majority of these smaller machines were installed in the early years of wind energy development in Italy.

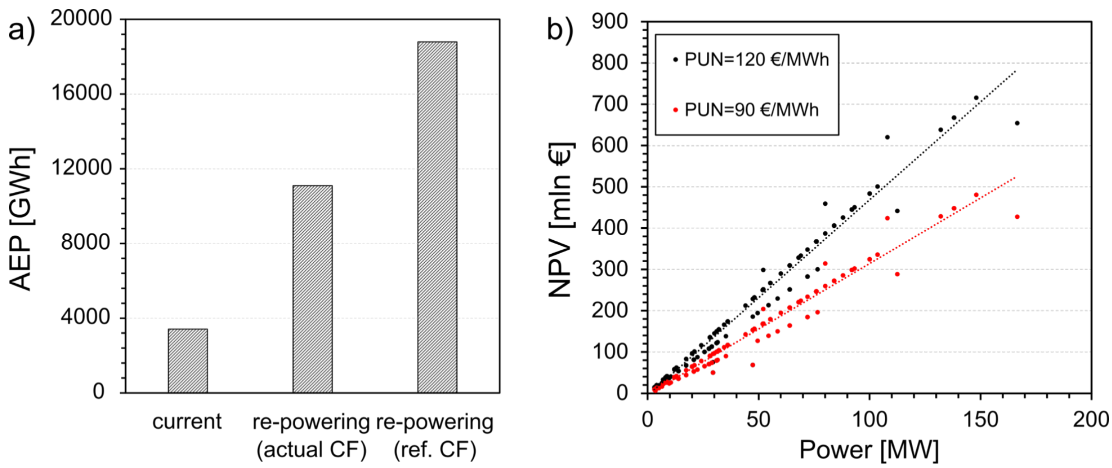

Figure 7. Annual Energy Production (a) and Net Present Value (NPV) (b) for the re-powering scenario

From an energetic point of view, the renewal of the existing plants will lead to an increase in the total Annual Energy Production (AEP) of ca. three times in the more *conservative* scenario, i.e., when considering a value of the Capacity Factor (CF) equal to the current one (see Figure 7a). Using CF values closer to the ones of modern turbines instead (*realistic* scenario), the potential energy production becomes five times the current one. As shown in Figure 7b, this result is achieved in an economically feasible way, with a Net Present Value of the investment that is always positive, regardless of the size of the plant and the projected energy selling price (PUN). It can also be observed how the revenue increases linearly with the installed power. Payback times oscillate between 5 and 7 years, depending on the PUN value.

5.2. *Test site – Casoni di Romagna*

Figure 8 reports the comparison in terms of turbine arrangement, AEP and Capacity Factor for the three different re-powering layouts considered for the test site of *Casoni di Romagna*, whose characteristics are reported in Table 2. Values are normalized over the ones of the current site (subscript "ref").

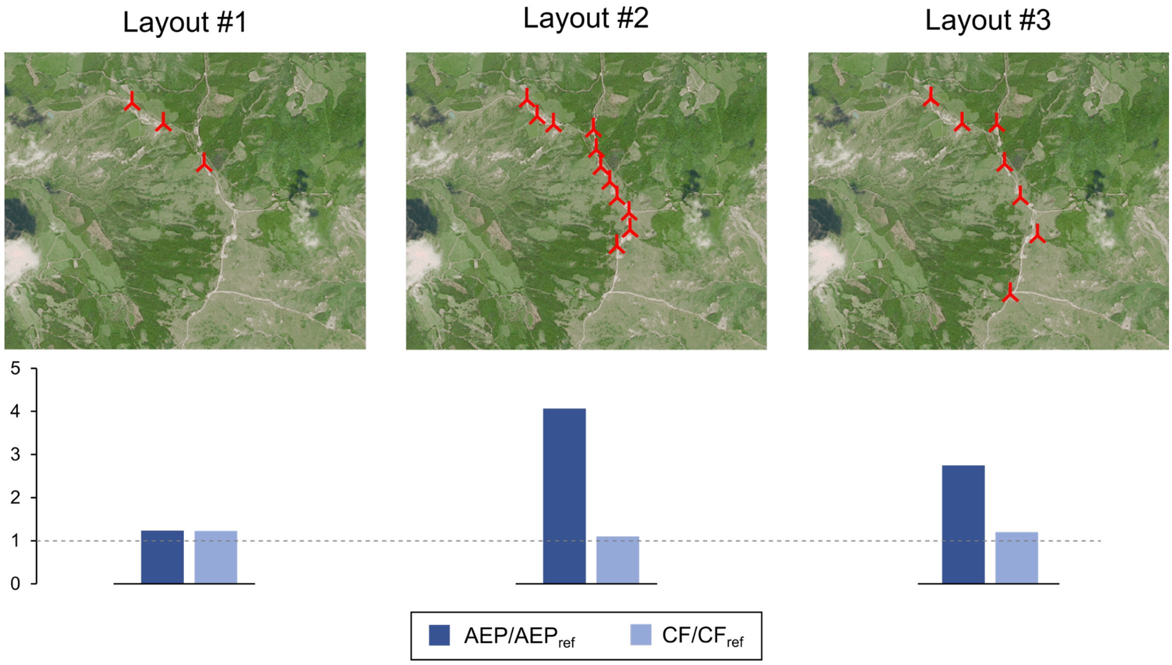

Figure 8. Comparison in terms of AEP and CF between the three layouts under consideration

Table 2. Overview of the different layouts under testing

Layout	Strategy	P_0 [MW]	WT model	D [m]	HH [m]
current	-	12.8	16 x Enercon E53 0.8 MW	53	60
1	same installed power, max(D), min(# WTs)	12.8	3 x Siemens SWT-DD-130 4.3 MW	130	135
2	max(D), min(# WTs)	47.3	11 x Siemens SWT-DD-130 4.3 MW	130	135
3	max(D), min(# WTs), site inspection	29.4	7 x Enercon E138 4.2 MW	138	130

Layout #1 has the same installed power of the current site. Nevertheless, thanks to the combination of higher hub height, lower specific power and reduced wake losses of the new turbines (1% instead of 13% of the current layout, it is able to increase the capacity factor of ca. 20%. The maximum gain in terms of annual energy production, up to 3.7 times the current one, is given by *layout #2*, which represents the theoretical case according to regulations. Due to higher wake interference though, the corresponding capacity factor is slightly lower than the one of *layout #1*.

Upon inspection of the installation site and exchange of information with the operator, AGSM-AIM, *layout #2* was not considered feasible. Therefore, the proposed wind turbines were replaced with Enercon E138 machines and their number was reduced to 7 (*layout #3*, see Table 2). Due to these modifications, the potential AEP for the site decreased from 3.7, as in *layout #2*, to ca. 2.8 times the current one. Conversely, the capacity factor of the plant improved, mainly due to the lower wake interference and better suitability of the Enercon E138 to the wind speed range of interest for the site of *Casoni di Romagna*.

6. Conclusions

The study presents a feasibility analysis on the re-powering of Italian power plants with capacity greater than 1 MW, with incentive contracts expired or expiring by 2030 and that have not been modified already with non-incentivized modernization or upgrading interventions.

Following the guidelines given by Art. 32 of Law 29/07/2021, n. 108, the re-powering intervention would double the currently installed power and reduce the number of turbines by almost one-third, especially in the southern Italy and on the islands. The annual energy production would increase three-fold in the *conservative* scenario and five-fold in a more *realistic* one, where the capacity factors of modern turbines are considered, generating revenues already after five years from the intervention.

The feasibility of the proposed strategy has been validated on a real test site, for which terrain and wind data were available. The combination of local wind effects such as wake interference and a series of technological and practical constraints have led to an annual energy production 25% lower than the one coming from the theoretical application of the regulation. Therefore, a more realistic analysis will include in the future terrain and wind data for all considered sites. This is particularly important in Italy, where “complex” terrains make up for the majority of the available installation sites.

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