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Revamping of wind farms: a case study, technical optimization and economic analysis

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Abstract

Assuming wind turbines' lifetime of 20 years, first-generation WTGs, installed between early 1990s and 2000s, are approaching the end of their design life. Old wind turbines use obsolete and low-efficiency technologies while exploiting the highly productive sites, with the consequence that most countries are running short of productive sites. Revamping old wind farms, replacing lower rated power old turbines with new modern multi-megawatt ones, reducing meanwhile the number of installed WTGs, could allow a better utilization of high-value resource areas, reaching faster the medium and long-term goals defined by Paris Agreement COP21, with positive effects also in terms of environmental impacts, energy price, expenditure for incentives policy and employment. While countries like Denmark and Germany, pioneers in developing wind power, already introduced targeted programs aimed to revamp/repower old wind farms, in Italy there are still legal and bureaucratic obstacles that do not allow investors to seize the opportunity, despite the growing potential for renewal.

This study refers to the revamping of an old wind farm located in South Italy, set up in 2005, analyzing some technical aspects of the process and relevant main financial indexes.

Objectives

Advantages of revamping:

- Increasing energy production (due to higher average capacity factor) in the brown-field highly productive sites without the need to use additional land.
- Smaller number of wind turbines with benefits in terms of avian mortality, visual appealing and land use per installed unit power.
- Better grid integration: newer wind turbine technology can better support the electrical grid in terms of power quality.
- Lower costs of production due to existing infrastructure like roads and substations.
- Respect Kyoto/COP21 commitments.
- Positive design/construction employment impacts.

Against the several advantages, there are some **specific issues** that need to be properly addressed:

- Noise impact: replacing small wind turbines with modern multi-megawatt could, in some cases, increase the noise impact depending on the new layout configuration with respect to receptors' locations.
- Selection of new turbines' model must take in consideration also transportation issues, especially in complex brown-field sites where road were originally designed for transportation of smaller components.
- Large variance of investment costs (specifically regarding the BoP adjustment/refurbishment) due to site orography. Sustainability of each revamping project must be examined individually.
- Replacing of used wind turbines can lead to two extreme scenarios: either they can have a market value in the second-hand turbine market or could produce additional costs for dismantling, this depending on some key factors like age of the wind turbine model and state of certified maintenance.
- Optimizing the project schedule in order to reduce loss of production during off-grid period.

Methods

Starting from the original layout of the old wind farm (set up in 2005) a new DTM and roughness model was implemented using the CFD software WindSim. Met station consists of a 10 m mast on site, with data collected from 2005 to 2013 (8 years). Besides, three more climatologies were implemented, using three nacelle anemometers correlated with long term historical data of neighbor met stations. The 10 m mast on site was used to evaluate the IEC class of the site.

Optimization of the new layout of the revamp design was performed on the basis of the following constraints:

- preserve the overall power of the wind farm;
- use the same land parcels of the previous project ;
- take into account neighbor wind farms in terms of wake effects and required inter-distance;
- maximum hub height of new wind turbines equal to 80m (conservative environmental hypothesis).

As first approximation, technical losses, evaluated/calculated in the design phase of the original project (8.5%) have been considered unchanged in the new layout.

Under the above constraints an analysis of several alternatives was performed in order to indentify the most favorable ones in terms of energy production. Among the best alternatives a noise impact evaluation was performed.

In order to present an overall picture of financial return for similar projects, in terms of P50 equivalent operating hours, several simulations, with a financial business model, have been carried out with different hypothesis on the most sensitive parameters affecting the economic result.

Conclusions

Around 23% of energy increase (in reference to these case study) confirms the potential interest in the complete redesign of old wind farms, despite the several conservative constraints considered (same installed power and 80m maximum hub height). Considering the less environmental impact, both the above constraints could not be necessarily respected with consequent further optimization. The economics, that have been conservatively evaluated with revenues arising only from energy purchase, lead to challenging scenarios. Energy price is therefore a key factor and investors can just try to sharpen its long time forecast, without any possibility to affect the real prices. Investors should therefore focus on the design phase and specifically on energy assessment in order to select the optimum layout/WTG model, taking into account both production and costs.

Depending on the model, revenues from dismounted WTGs on second-hand market are also an important plus that could be provided by a good state of maintenance. Also BOP design/cost optimization can support economics, even if they affect the overall cost just for a limited portion (20-30%).

Considering the challenging economic scenario, new innovative and alternative supporting policies would be desirable and reasonable, overcoming the constraints of "*spalmaincentivi*" (Italian Law n. 9 of 2014).

As already done in other countries, a further aspect for the success of such initiative is a simplification of authorization procedures in terms of EIA and permission to build, also in order to reduce development costs.

Results

The original layout consists of 10 WTGs V47-660kW deployed, on the top of a ridge, well exposed to prevailing winds (*Fig.1*). On the North (80 m far from WTG no. 10) there's a neighbor wind farm (in green) consisting of 15 E44-600kW HH 50m (*Fig.5*). IEC class is IB at 80 m height, for all wind turbines. On the basis of the wind resource map (*Fig.4*), several layouts (varying in configuration and suitable wind turbine model) have been analyzed in order to maximize energy production. Results show two alternatives, almost equivalent (*Fig.3*), both using Vestas V112-3.3 MW HH80m (*Fig.2*):

- Alternative A: 2xV112 in the original positions no.1 and no.5
- Alternative B: 2xV112 in the original positions no.2 and no.8

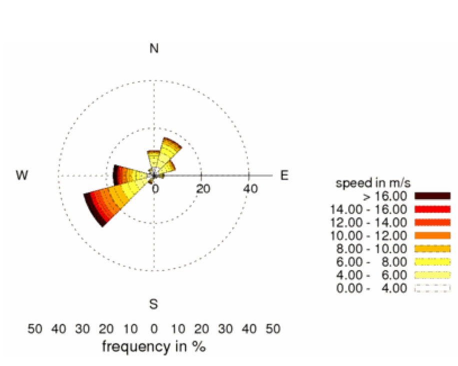

Fig. 1 – Wind distribution at 10 m met Mast in site.

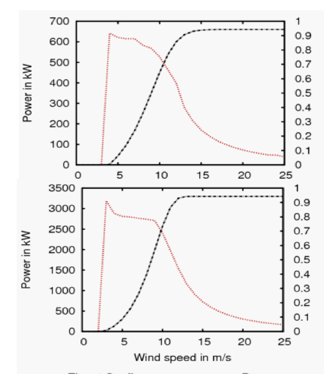

Fig. 2 – V47 and V112 power curves.

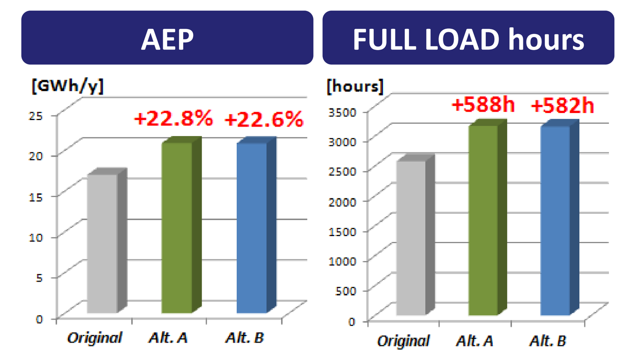

Fig. 3 – Comparison between the original scenario and the two alternatives.

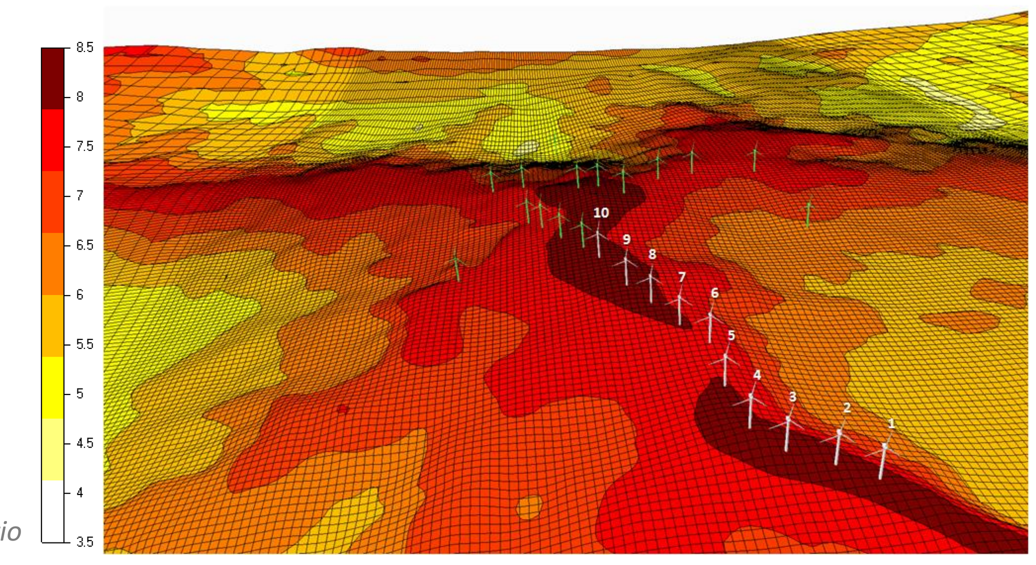

Fig. 4 – Wind resource map at 80 m (hub height).

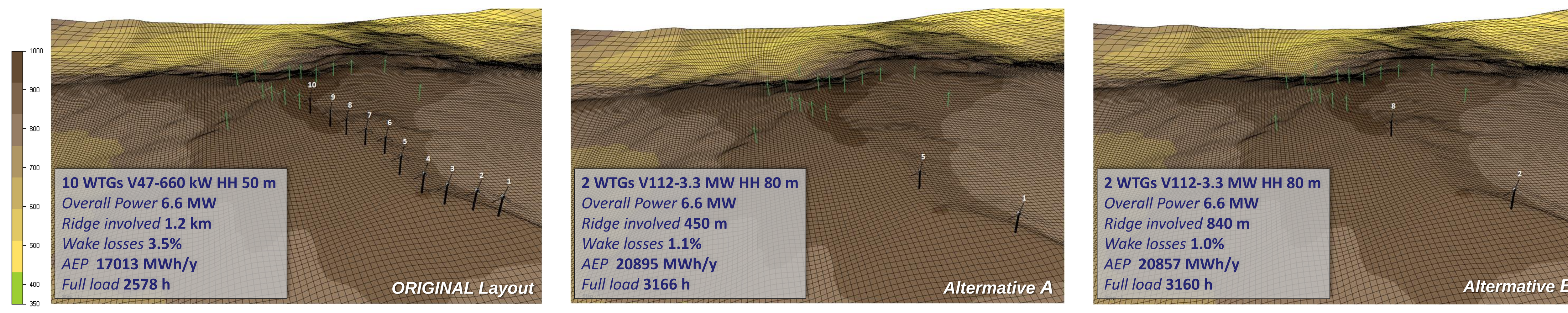

Fig. 5 – Comparison between the original layout (10xV47-660kW HH50M) and the two alternatives of revamping (2xV112-3.3MW HH80M) - black turbines - and a neighbor wind farm (15x E44-600kW HH50m) - green turbines - WindSim views from South.

Fig. 6 – Original layout (10xV47), Google Earth image, view from NE.

Fig. 7 – Photo-montage landscape view (Alternative A).

Fig. 8 – Photo-montage landscape view (Alternative B).

WIND FARM VISUAL IMPACT AFTER REVAMPING

The visual effect on the local landscape improves with such a strong reduction of turbines, going from 10 (*Fig. 6*) to 2 wind turbines (*Fig. 7* and *Fig. 8*). If in the current situation we could say that the ridge is "invaded" by turbines, in the revamped situation the effect is of isolated turbines. From an energy point of view it can be stated that part of the site remains unused, with the possibility to increase wind resource exploitation.

WIND FARM NOISE IMPACT AFTER REVAMPING

Fig. 9 shows the increase/decrease of noise following the revamping. Most of the site experiences a reduction in noise (green colors). The analysis, performed with Cadna-A, compares the scenario with 10 turbines V47 (102dB @ 8 m/s) with 2 turbines V112 (106.5dB @ 8 m/s).

Just a small increase of noise (grey and yellow zones) occurs at a longer distance due to the higher hub height of new turbines (+30 m) so that noise can go beyond some obstacles. Alternatives A and B do not differ qualitatively. *Fig. 9* refers to Alternative A.

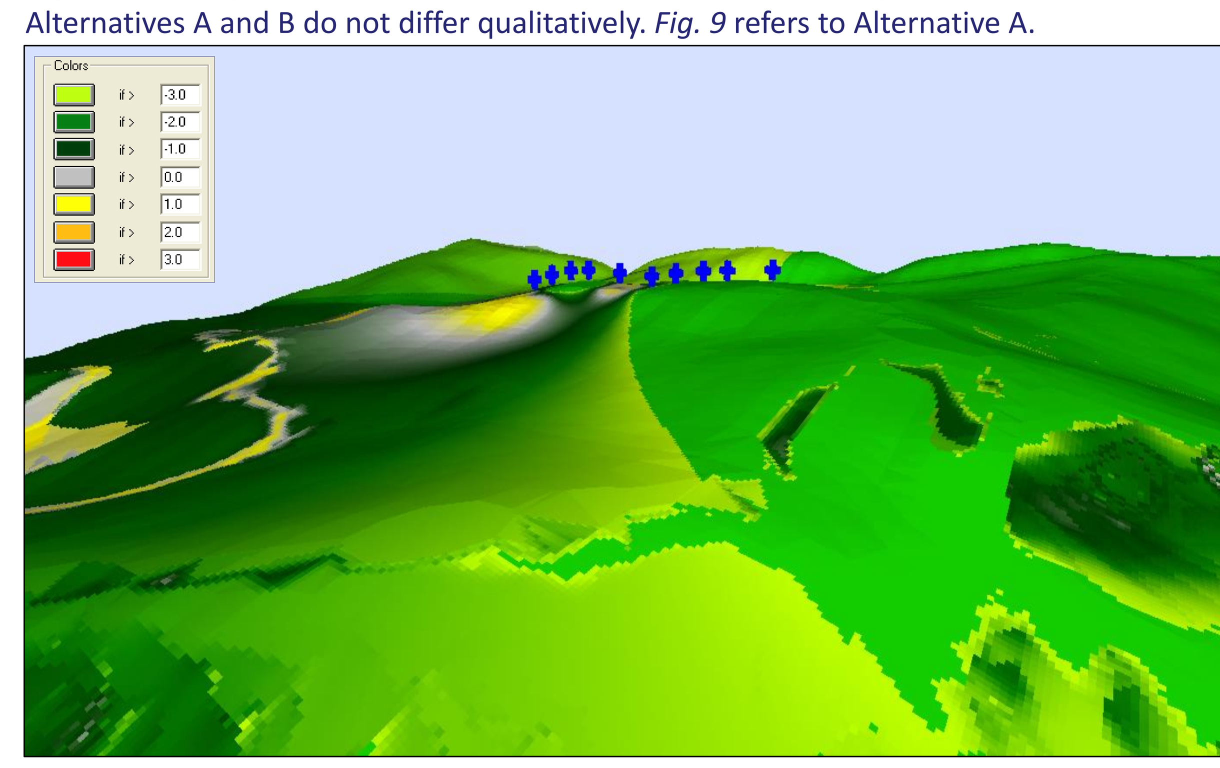

Fig. 9 – Noise simulation – increase/decrease of noise after revamping.

FINANCIAL OUTPUT

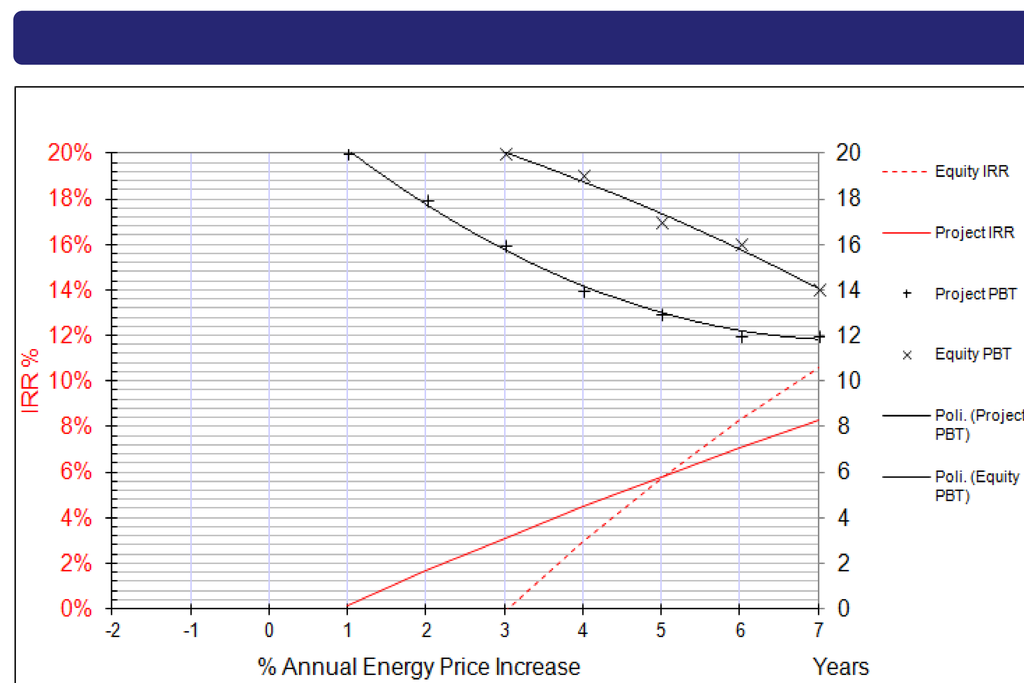

Fig. 10 – Heq 3166, Severe CAPEX scenario (1,5 MM€/MW).

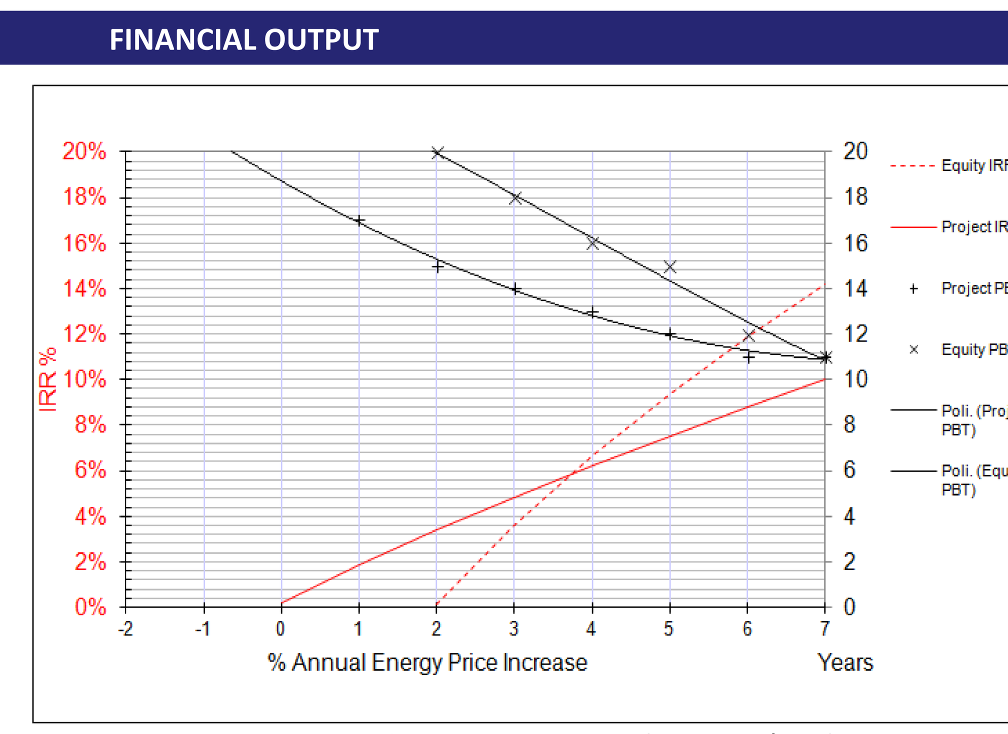

Fig. 11 – Heq 3166, Intermediate CAPEX scenario (1,3 MM€/MW).

Three different CAPEX scenarios (High, Intermediate, Low) have been considered with respectively 1.5, 1.3 and 1.1 MM€/MW installed and, for each of them, revenues with a different linear increase of energy price, from -2 to 7% per year, have been verified, starting from 40 €/MWh.

On conservative approach no contribution of any kind of government support has been taken in account (i.e. CV or incentives, taxes, different amortization).

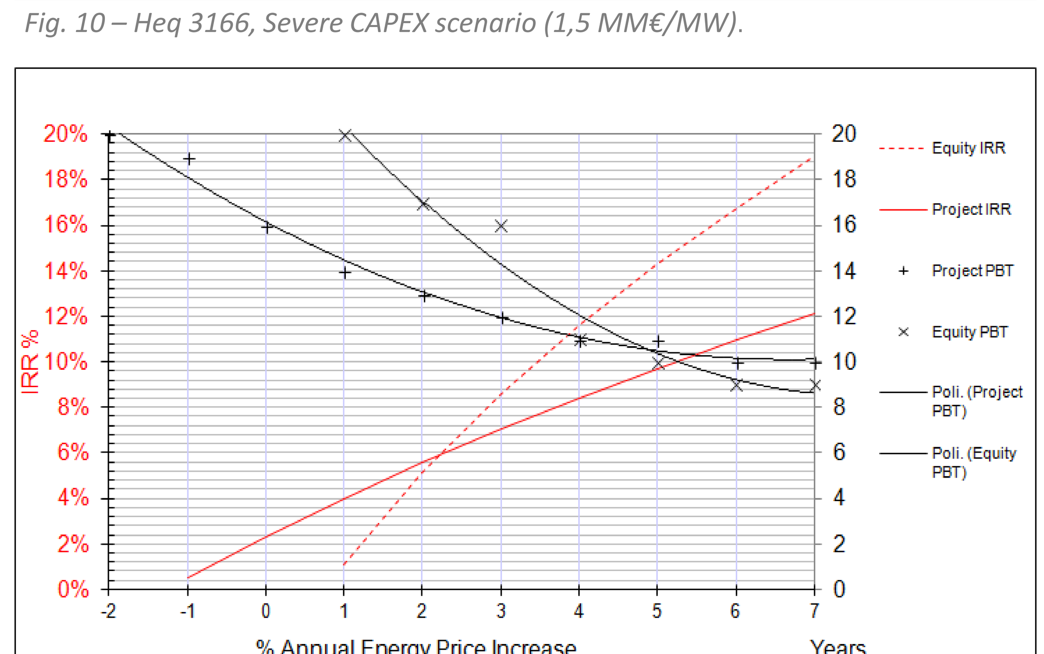

Fig. 12 – Heq 3166, Smiling CAPEX scenario (1,1 MM€/MW).

OPEX have been considered stable at 44 k€/MW with 1,5 % increase per year.

Production has been imputed at 3166 Heq, as per P50 case study result, and a 0,3% of production decrease per year has been also considered for technical degradation.

Fig. 10 to *12* show IRR and PBT for the whole project (100% equity) and for equity portion in a possible financial scenarios (25% equity, overall rate 5%, repayment period 12 years).

Fig.13 shows for easy reading the energy selling price during the years on the above mentioned hypothesis of % linear increase.

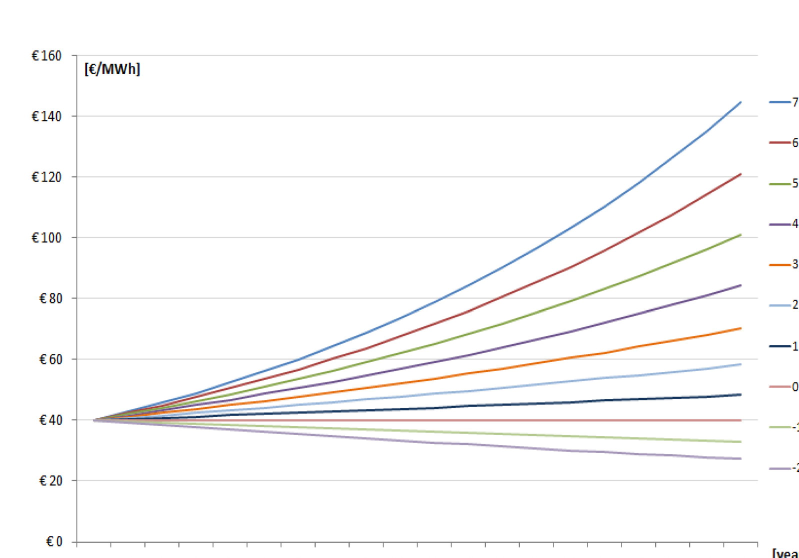

Fig. 13 – Energy price trend for different % of annual increase.