Feasibility study of 6.6MW wind farm in Greek mainland

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Abstract: Wind energy has the advantage of being a priority sector of the Greek government. Greece has a considerable potential for electricity generation from wind not only in the island area but also in mainland. This paper deals with the current status of wind energy in Greece and the presentation of technical and economical feasibility of a 6.6MW wind farm applied to a potential wind farm site located in Greek mainland (Rentina-Karditsa). Wind speed, prevailing wind direction and temperature measurements are performed for a period of one (1) year (from 11/5/2009 to 11/5/2010). For economic consideration two different technological scenarios based on capacity factor (CF) are investigated and compared with respect to net present value (NPV), internal rate of return (IRR) and payback period (PBP) criteria. The profitability analysis shows that larger installed capacity with larger rated power wind turbines present higher IRR of the investment. The sensitivity analysis backs up the findings.

Keywords: *Renewable energy, Wind energy, Wind farm techno-economic assessment, RES legislation*

1. Introduction

Recently, there has been a considerable expansion of distributed generation (DG) technologies, thanks to progress in reliability, in competitiveness and operation know-how and incentive policies adopted by many developed countries. The presence of DG facilities brings benefits both to the electric power system and the total energy system. With DGs energy can be generated directly where it is consumed. As a consequence, transmission and distribution networks are less charged; safety operation margins increase, and transmission costs and power losses are reduced. The spread of DG technologies enhances supply safety in the energy field by reducing dependence on fossil fuels [1-4].

Wind power is driving growth in the renewables sector and represents a huge investment potential in Greece. The superb wind resources in Greece are among the most attractive in Europe, with a profile of more than 8 m/s and/or 2,500 wind hours in many parts of the country. Capacity increased by an average of 30% annually between 1990 and 2003 and almost 30% of total capacity was installed in the period of 2003-2004. It is estimated that in addition to the 1200-plus MW operating currently at wind farms, a further 7,500 MW will be installed by 2020. A detailed presentation of current and future wind farm installations on Greek islands is given in Ref. [5].

Electricity from Renewable Energy Sources, High Efficiency Cogeneration of Heat and Power and Other Devices». The main scope of the Law 3468 is to establish an adequate legislative and regulatory framework in order to support investments in renewable energy sources (RES) and High Efficiency cogeneration of heat and power (HE-CHP) energy sectors and eventually increase the penetration of these resources in the energy mix of the country. Aiming at conveying to the Hellenic legislation Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the «Promotion of Electricity Produced from RES in the Internal Electricity Market», the National target is set to a 20.1% RES contribution on the total electricity production by 2010 while for 2020 the target is 29%. In the internal electricity market, the production of electricity from RES and HE-CHP are promoted in priority over other means of power production with specific regulations and principles. Until 2020, in Greece to achieve the target set by EC, the remaining RES contribution to total electricity (excluding the large hydro) should be 58,37% wind, 2,73% Small Hydro, 2,73% biomass, 1,94% solar thermal, 22,95% photovoltaic energy (PV) and 11,28% other technologies.

On 4 June 2010, the Hellenic Parliament approved Law 3851 referring to "*Acceleration of RES growing facing climate change and other legislation related to Ministry of Environment, Energy and Climate Change subjects*". Law 3851/10 was published in the Official Gazette of the Hellenic Republic and is in effect since then. The main scope of New Law 3851 is the increased utilisation of the vast renewable energy resource of the country together with complying with the environmental targets of the Kyoto protocol. The attraction of large scale energy investments is also envisaged, in parallel with simplification measures for the necessary licensing procedures.

Wind energy has the advantage of being a priority sector of the Greek government. Greece has a considerable potential for electricity generation from wind not only in the island area but also in mainland. This paper deals with the current status of wind energy in Greece and the presentation of technical and economical feasibility of a 6.6MW wind farm applied to a potential wind farm site located in Greek mainland (Rentina-Karditsa). For economic consideration two different technological scenarios based on CF are investigated and compared with respect to NPV, IRR and PBP criteria. The profitability analysis shows that larger installed capacity with larger rated power wind turbines present higher IRR of the investment. The sensitivity analysis backs up the findings.

2. Case study: 6.6 MW wind farm in Greek mainland

The proposed wind farm site is located in the Prefecture of Thessaly (Karditsa-Rentina) in the heart of Greek mainland. The site, known to local people as "Lepouchi", covers an area of 200.000 m^2 (Photos 1, 2) and is situated 3km from Rentina village. It is near to Rentina-Fourna national road and therefore quite favorable for wind turbines transportation. However, an improvement of an existing 500m forest road would be required to provide easy access to wind farm site. The proposed site is almost a flat-shrubbery area with presence of rocks, suitable for placement of tower foundations, roadways and crane pads. It is also favorable from the environmental point of view due to absence of wildlife, noise and visual issues. However, an important drawback is its distance (25km) from the nearest electrical substation (situated at Makrakomi-Lamia). The excessive cost associated with electrical issues is considered in economic analysis and affected the economic performance of proposed wind farm installation.

2.1. Analysis of wind power generation input parameters

The data was collected for the period from 11/5/2009 to 11/5/2010 with availability 98,7%. The wind speed data was the major parameter for wind energy generation and utmost care was taken in its collection. Two cup anemometers (one as primary and the other as auxiliary), wind direction vanes, temperature sensor and humidity sensor, certified according to ISO 17025:2005, were installed within the wind farm area (latitude 39^{o} 05' 02,4'' and longitude 21^{o} 56' 46,8'') placed on the top of a 30m metallic pole. A data recorder STYLITIS 40/41 (SYMMETRON) and a PV 10Wp/12V connected to a lead battery 12V/12Ah were also used.

Wind Speed

Significant variations in seasonal or monthly average wind speed are common over most parts of Greece. In the proposed site, the monthly average wind speed (Table 1) is high during

November-February and reaches a maximum of 7,5m/s because of South-West winds. The annual average wind speed is estimated 6m/s ($\pm 0{,}26$m/s) at wind turbine height of 80m.

Fig 1: Geographic location of wind farm site

Fig 2: Wind farm site

Table 1: Monthly average wind speed

Month	Average Wind Speed (m/s)	Data Availability (%)
January	7,3	96,1
February	7,5	97,0
March	5,3	96,0
April	4,4	100,0
May	4,0	98,0
June	5,0	100,0
July	4,0	95,0
August	2,9	100,0
September	2,9	100,0
October	5,2	95,7
November	5,9	97,1
December	7,4	95,2

Relative Humidity

The relative humidity of air depends on the amount of water vapor in the air, which in turn affects the air density. Moist air is less dense than dry air since water molecules is lighter than either a nitrogen molecule or an oxygen molecule, which are the major constituents of dry air. As the relative humidity increases air density decreases. The air density also depends on temperature and pressure and is given as follows:

$$airdensity = D\left(\frac{273{,}15}{T}\right)\left[\frac{B-0{,}3783e}{760}\right] \qquad (1)$$

where D is the density of dry air at standard atmospheric temperature (25 C) and pressure (100kPa) (D=1,168kg/m^3), T is the absolute temperature in Kelvin, B is the barometric pressure in torr and e is the vapour pressure of the moist air in torr. For the proposed site of wind farm installation, the mean yearly temperature is 10,4C and the monthly variation of relative humidity for the given period is between 50% and 70%.

Generation Hours

The generation hour is the period in which the wind turbine produces electric power from the energy available in the wind:

Generation hour = total number of hours in a year – (low wind hours + wind turbine maintenance hours + turbine breakdown hours + grid maintenance hours + grid breakdown hours)

Wind power generation hour is directly governed by the design of wind turbine, especially the cut-in and cut-out speed of wind turbines. A lesser cut-in speed and higher cut-out speed significantly improves the generation hours. Reduction in stoppage hours of wind turbine due to uncontrollable factors such as grid unavailability and mechanical breakdown improves the wind power generation. Periodic maintenance of turbine and grid are unavoidable and if done during off-seasonal period (when the average wind speed is below the cut-in speed) reduces energy loss and increases the total energy generation of wind turbine.

2.2. Wind farm energy generation

In order to calculate the wind farm energy generation is essential to perform the wind flow calculations. This is carried out using the *MS3D3H/3R* model which is integrated to *WindFarm* code. Then the *WindRose* code was used to estimate the total energy production for different capacity wind turbines. Net energy production is calculated using the energy losses related to wind turbine availability due to technical reasons (such as wind turbine malfunction, stoppage time for maintenance etc), wake and transmission losses. Two different technological scenarios were investigated where different capacity wind turbines were proposed.

Technological Scenario I (TS-I)

Four (4) wind turbines VESTAS V82 – 1,65MW were considered forming a 6.6MW wind farm. Table 2 shows the yearly total energy production per wind turbine, the wind direction and wake losses. Figs. 3-4 show the yearly energy yield (net) and the changes of energy yield due to wake losses per turbine respectively. It was calculated that gross energy production of 12,77GWh/year would be delivered to the grid resulting to 1930 generation hours and CF of 22,1%.

Table 2: Yearly total energy production per wind turbine, the wind direction and wake losses (TS-I)

TOTAL ENERGY YIELD

Wind Turbine Identifier	Base Yield GWh	Wake Losses % Loss	Total Yield GWh
1	3.63	-1.44%	3.58
2	3.34	-1.76%	3.28
3	3.32	-2.01%	3.25
4	3.23	-1.14%	3.19
Total	13.52	-1.59%	13.30

TOTAL ENERGY YIELD

Wind Direction	Base Yield GWh	Wake Losses % Loss	Total Yield GWh
0	0.24	-21.17%	0.19
22.5	0.38	-1.99%	0.38
45	0.28	0.00%	0.28
67.5	0.03	0.00%	0.03
90	0.02	0.00%	0.02
112.5	0.03	-4.52%	0.03
135	0.06	-15.74%	0.05
157.5	0.10	-32.59%	0.07
180	0.28	-16.77%	0.23
202.5	1.08	-0.83%	1.07
225	1.74	0.00%	1.74
247.5	2.97	0.00%	2.97
270	5.38	0.00%	5.38
292.5	0.70	-2.09%	0.69
315	0.13	-12.34%	0.11
337.5	0.08	-31.80%	0.06
Total	13.52	-1.59%	13.30

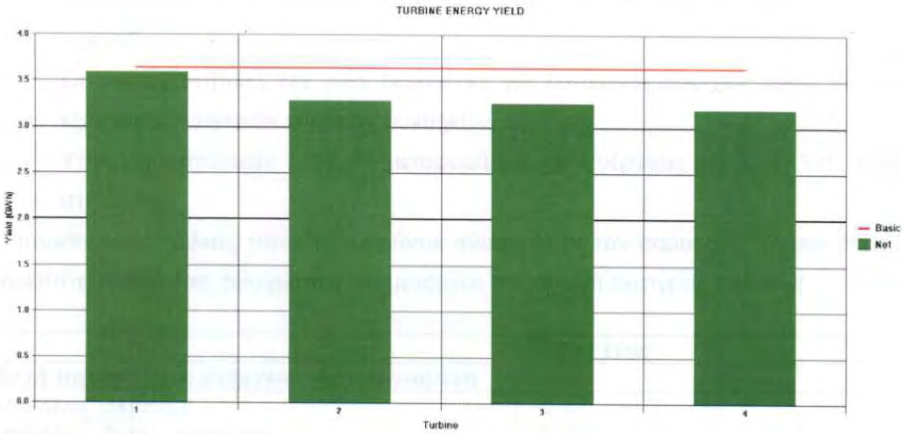

Fig. 3: Yearly net energy yield per turbine (TS-I)

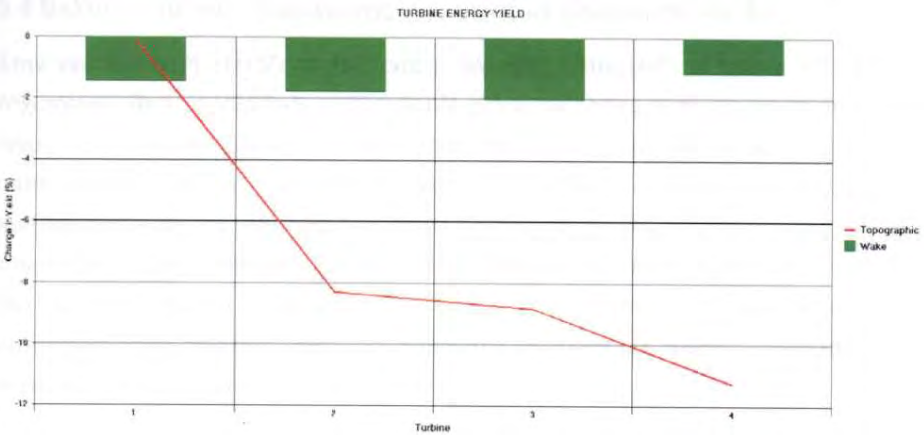

Fig. 4: Wake losses per turbine (TS-I)

Technological Scenario II (TS-II)

Four (4) wind turbines VESTAS V100 – 1,8MW were considered forming a 7.2 MW wind farm. Table 3 shows the yearly total energy production per wind turbine, the wind direction and wake losses. Figs. 5-6 show the yearly energy yield (net) and the changes of energy yield due to wake losses per turbine respectively. It was calculated that gross energy production of

17,30GWh/year would be delivered to the grid corresponding to 2400 generation hours and CF of 27,4%.

Table 3: Yearly total energy production per wind turbine, the wind direction and wake losses (TS-II)

TOTAL ENERGY YIELD

Wind Turbine Identifier	Base Yield GWh	Wake Losses % Loss	Total Yield GWh
1	4.85	-1.88%	4.76
2	4.58	-2.49%	4.47
3	4.55	-2.83%	4.42
4	4.45	-1.54%	4.38
Total	18.43	-2.18%	18.03

TOTAL ENERGY YIELD

Wind Direction	Base Yield GWh	Wake Losses % Loss	Total Yield GWh
0	0.40	-22.71%	0.31
22.5	0.64	-3.26%	0.62
45	0.48	0.00%	0.48
67.5	0.08	0.00%	0.08
90	0.04	0.00%	0.04
112.5	0.06	-4.37%	0.06
135	0.10	-17.22%	0.09
157.5	0.17	-35.90%	0.11
180	0.41	-18.47%	0.33
202.5	1.42	-1.51%	1.40
225	2.18	0.00%	2.18
247.5	3.76	0.00%	3.76
270	7.31	0.00%	7.31
292.5	1.04	-3.17%	1.01
315	0.20	-13.86%	0.17
337.5	0.15	-34.90%	0.10
Total	18.43	-2.19%	18.03

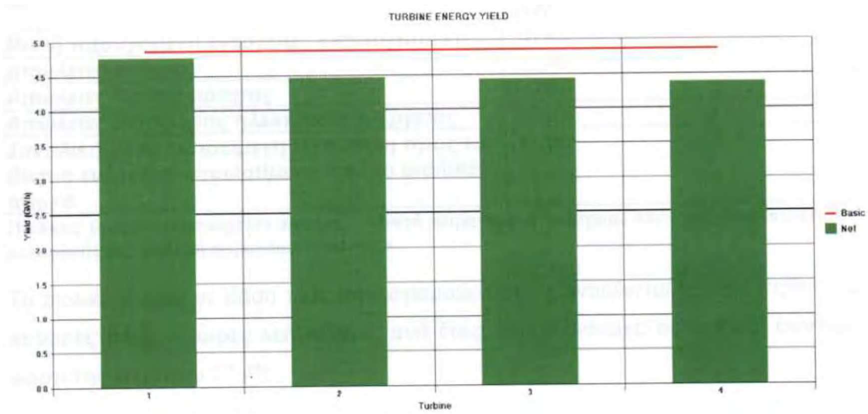

Fig. 5: Yearly net energy yield per turbine (TS-II)

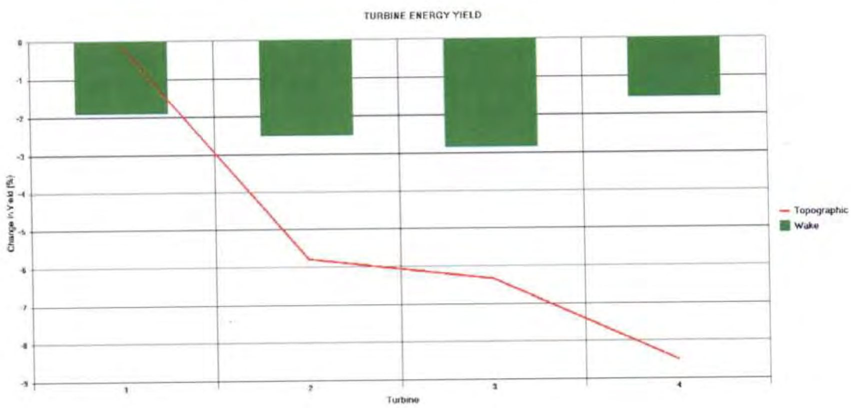

Fig. 6: Wake losses per turbine (TS-II)

2.3 A systematic economic assessment

The analytical technoeconomic general model is the computerized renewable energy technologies (RETs) assessment tool 'RETScreen' [6] which is used for preliminary evaluation of the technical feasibility and financial viability of potential grid-connected wind installations anywhere in the world. For Greece in particular, it takes into account the prevailing Greek national development and energy laws, the government's subsidy and the prices applicable for buying or selling energy to the PPC by the electric energy producer.

For the technological scenarios TS-I and TS-II, different economic and financial feasibility indices are calculated such as the year-to-positive cash flow, IRR, ROI and NPV. The results of the installed wind power plants are shown in Figs. 6-7 respectively. The initial capital cost for TS-I is 8.500.000€ and for TS-II is 9.500.000€. The owner covers 25% of initial cost and the rest 75% is provided as a loan by private banks (10-year period and interest rate of 6%). The owner also decided to use the extra bonus 20% increase of feed-in tariff provided by Law 3851/2010 (i.e. 105€/MWh).

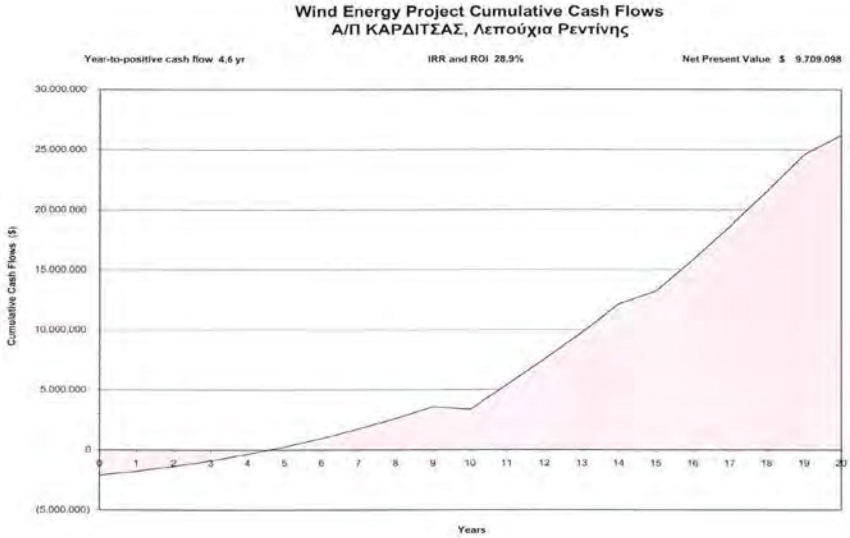

Fig. 6: Wind farm economic analysis (TS-I)

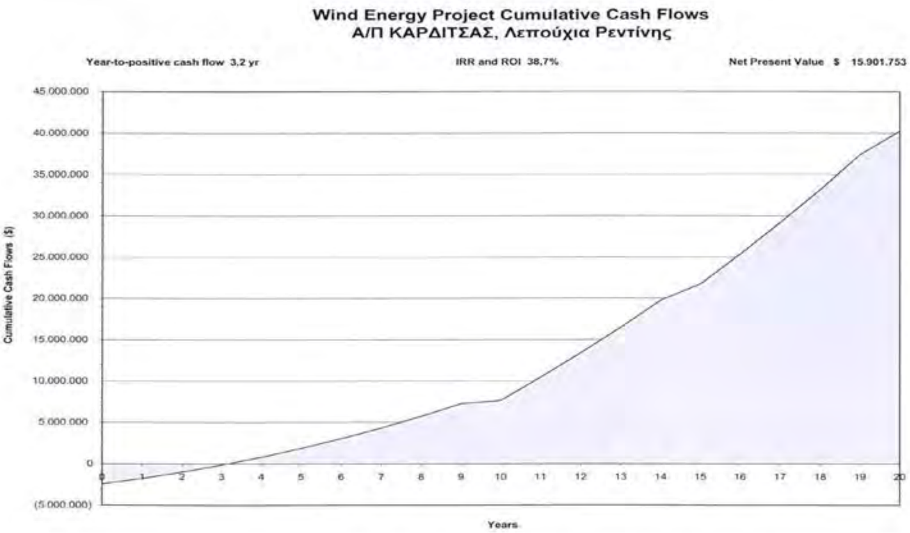

Fig. 7: Wind farm economic analysis (TS-II)

3. Conclusions

Two different technological scenarios were investigated and cash flow economic analysis was performed under the new legislation for RES penetration in Greece. From the results shown in Figs 5-6, it is concluded that Technological Scenario I [four (4) wind turbines VESTAS V82-1.65MW and installed capacity of 6.6MW] constitutes the less profitable investment in comparison to technological Scenario II [larger wind farm of 7.2MW consisted of four (4)

VESTAS V100-1.8MW]. This is due to increased performance of wind turbines in TS-II which compensates for the increased initial cost of the investment. For the particular wind farm installation in the Greek mainland, it was found that larger installed capacity with larger rated power wind turbines presented higher IRR of the investment. Furthermore, the PBP is 7,5 years and 6,2 years for TS-I and TS-II respectively. The results show that the implementation of wind farms in Greek mainland could present a profitable investment despite the fact that the sites are not so favorable compared to the islands. However, the experience of the implementation of wind farms in Greece emphasised the necessity for a simplified licensing procedure and a better coordination through institutions for Environmental Approvals.

The question becomes apparent: where does Greece go from here? According to Greek Ministry of Development, a wind total of 7500MW (including offshore) is planned to be installed until 2020 (while 4000MW of them until 2014). This capacity is limited due to grid stability, due to suggestions from Regulatory Authority for Energy (RAE) for possible excessive charging of consumers and due to public opposition in large scale wind farm installation, particularly in Greek islands. In order to achieve the goal of 7500MW, the Hellenic Parliament approved recently Law 3851 regarding RES electricity. According to this legislation, wind projects can get an extra bonus 20% increase of feed-in tariff, providing that the owner will not apply for a grant to the Greek State. This policy mechanism designed to promote mature wind projects for immediate connection to the grid. Also, the Hellenic State is planning to upgrade the existing grid to overcome grid stability problems and to offer more benefits to local people (such as discounted electricity bills) in order to overcome their opposition.

The main conclusion is that, with respect to electricity supply, wind farm applications will continue to play the most important role in Greece. The country high wind potential through out the year, the increasing environmental sense of Greek population, the elimination of time consuming license procedures, noticed during the implementation of first wind farm installations in Greece, and the improved financial incentives will increase the wind penetration in Greek electricity market.

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