Towards optimum macro-sitting of wind farms in the Greek power supply system using Generalized Evolutionary Algorithms

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Abstract

To meet the wind energy national targets, effective implementation of massive wind power installed capacity into the power supply system is required. In such a perspective, the wind capacity credit and the effective absorption of wind energy production are two of the most important technological issues. The effect of spatial dispersion of wind power installations within a very wide area (e.g. national level) on the two above mentioned issues should be accounted for. The whole approach is based on probability theory and makes use of wind forecasting models to represent the wind energy potential over any candidate area for future wind farm installations in the country. Additionally, the Generalized Evolutionary Algorithm EASY created in the laboratory of thermal turbomachines at NTUA, has been used to define the optimum solution of wind installed capacity in the several candidate macro-sites in the Greek power supply system. Results show that the spatial dispersion of wind power plants contributes beneficially to the wind capacity credit and the wind energy penetration levels into the power system.

Key words: Wind energy integration, capacity credit, wind energy absorbed, spatial dispersion, generalized evolutionary algorithms

1. Introduction

Wind energy is now a mature technology and can be considered as a significant contributor in reducing CO_2 emissions and protecting the environment. To meet the wind energy national targets in Greece, effective implementation of massive wind power installed capacity into the power supply system is required. At first sight, wind farm developments should take place in windy areas. The higher the wind speed at a candidate area the more the wind energy production. On the other hand, the substitution of conventional installed capacity and the ability of the power supply system to absorb the wind power depend on various factors. In a previous work [1] representative wind power development scenarios has been studied and evaluated, showing the benefits from the spatial dispersion of wind power plants to the wind capacity credit and the wind energy penetration levels into the power system. Here the use of a generalized evolutionary algorithm permits the evaluation of much more scenarios of wind farms spatial dispersion towards the definition of the optimum solution.

Both wind capacity credit and wind power absorption (WPA) (or equivalently its complement the wind power curtailment) are associated with the variability of wind power production due to the stochastic nature of wind [2, 3]. The annual distribution of wind power is strongly affected by the spatial distribution of wind farms [4]. Reliable estimate of wind capacity credit can contribute to the long term national energy planning through the calculation of the required wind power capacity while ensuring the reliability of the power supply system. On the other hand, dealing with wind power absorption, technical constraints such as the units' commitment and the power dispatch should be considered to maximize wind energy absorption while ensuring safe operation of the system. Both issues are of crucial importance in an unstable and relatively weak power system as that of Greece due to the limited existing interconnections with the neighboring countries and the limited power installed capacity [5].

Additionally, the above issue clearly affects the economic viability of wind farms and, consequently, the achievement of the national targets in terms of renewable energy contribution levels and reduction of the greenhouse gas emissions.

2. Methodology

2.1. Required data

The probability function is calculated through probability theory analysis for the following variables: the power demand, the available conventional power and the produced wind power. These variables are considered independent from each other. Data for System's power demand, availability figures of the conventional power plants as well as wind data are required.

Simultaneous information on wind statistics over every potential area for wind farm development has been provided by the application of a Numerical Weather Prediction (NWP) model. In this connection, the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) developed at the US Naval Research Laboratory is used [5]. COAMPS is a three-dimensional non-hydrostatic model that has been used for operational forecasting since 1996 for a wide range of research purposes for both idealized as well as real data simulations. Appropriate adjustment of the numerical parameters, systematic application on a yearly (and beyond) basis and thorough analysis and processing of wind characteristics provide simultaneous wind speed time series at the mesoscale over the whole territory of interest. The grid domains used for the present work are shown in Figure 1.

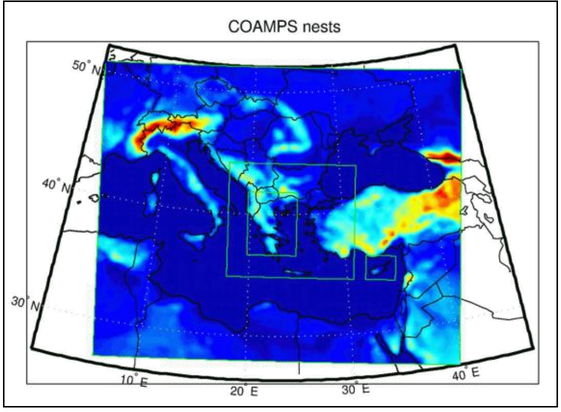

Figure 1: COAMPS computational domain showing topography and grid nests

2.2. Probability considerations

The methodology is based on the probability analysis of the Greek power system and has been developed and applied in several previous works [1, 2, 3]. The probability functions of the three main parameters and the required convolution between them are described in the following steps:

- M different power load[1] situations, N different situations of wind power production and L different situations of conventional power availability. For each of them, the power load is P_{Li}, the wind power production is P_{Wj} , the available conventional power is Pc_k and their durations in hours annually are known. Then, the corresponding probability of occurrence is $f(P_{Li})$, $g(P_{Wj})$ and $h(Pc_k)$. Calculations for all the situations, results in the probability distribution functions and annual duration curves.
- For the calculation of the capacity credit, the convolution of $f(P_{Li})$,$h(Pc_k)$ and $g(P_{Wj})$ results in a 3-D matrix M×L×N whose elements correspond to the probability of occurrence of every possible operational mode: $\Pi_{ijk}(P_{Li}, P_{Ck}, P_{Wj}) = f(P_{Li}) \cdot h(P_{Ck}) \cdot g(P_{Wj})$, $\{i=1,M\ ,\ k=1,L\ ,\ j=1,N\}$.
- For the calculation of the wind power absorption, the convolution of $f(P_{Li})$ and $g(P_{Wj})$ results in a 2-D matrix M×N whose elements correspond to the probability of occurrence of every possible operational mode: $\Pi ij(P_{Li},P_{Wj})=f(P_{Li})g(P_{Wj})$, $\{i=1,M,\ j=1,N\}$.

2.3. Capacity credit

In general, capacity credit [7, 8, 9, 10] of any power production unit is related to its capability to increase the reliability of the power supply system. The reliability of the system can be measured [2] by the probability of power loss occurrence (Loss of Load Probability - LOLP) and corresponds to the percentage of time in which the system cannot respond to the power demand. LOLP depends among other factors on demand characteristics, availability, reliability and number of power production units etc. Certainly, the power supply systems are designed so as to keep LOLP at a very low level. When a new power unit is implemented into the system, its cost increases while LOLP decreases and its reliability rises. Its effect on system's reliability varies depending on the unit character (stochastic, intermittent or steady) and its availability percentage.

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[1] It is noted that the availability of hydroelectric power stations is not a stochastic variable due to their inter-seasonal storage capabilities and their scheduled operation. Their power production is dependent on the power load itself and thus it is excluded from the load duration curve.

The Loss of Load Probability of a System $LOLP_S$ without wind power plant installations is first calculated. Next, the Loss of Load Probability of a System $LOLP_w$ with wind power plant installations is calculated. Obviously, $LOLP_W<LOLP_S$, i.e. wind power installations enhance the System's reliability. The Effective Load Carrying Capability (ELCC) of the wind power is defined as: "Which can be the increase in power demand, so as the System's reliability is kept at the same level as before the wind power has been installed". ELCC can be calculated via an iterative procedure. Finally, the Capacity Credit (CC) coefficient of wind power in the System is defined as $CC=ELCC/P_{W,R}$,where $P_{W,R}$ is the rated installed wind capacity. The CC expresses the equivalent conventional capacity which can be effectively replaced by the wind installed capacity.

2.4. Wind power absorption

The grid's ability to directly absorb wind power $P_{Absorbed\_i,j}$ is calculated taking into consideration the load demand P_{Li} and the prediction of the wind power production P'_{Wj}. The grid's ability to directly absorb wind power is calculated [3] under two conditions: the technical minimum of the committed conventional power stations and the maximum permitted instantaneous wind penetration (basic value assumed: $\delta=50\%$). Given the operation schedule of the hydro plants and the prediction of the wind power production, the required conventional units (together with their technical minimums) can be calculated. In case of peak demand, hydro power plants are accordingly scheduled, and the scheduled hydro power production P_{Hi} is calculated. Variations of the wind power production – due to the use of forecast models and the wide spatial dispersion of the wind farms - are considered predictable at a high degree of confidence, so the required thermal reserve is reduced only for a small part of the wind power production, ε. A figure of 20% for ε is assumed. From the comparison of the grid's ability wind absorption with the actual wind power production P_{Wi} for each situation (i,j), the actual wind power absorbed $P_{W\rightarrow A\_ij}$ and the wind curtailment $P_{W\rightarrow C\_ij}$ are calculated. A correction is required which is related to the rational assumption that hydro plants should not reduce the wind power absorption. Thus, the hydro production may be reduced in order to avoid wind power curtailment. The final wind power curtailment $P_{W\rightarrow C\_ij\_final}$ and the final hydro production P_{Hij_final} are then derived. Probability of occurrence for every situation, the annual wind energy absorption, the actual wind capacity factor and the wind contribution are calculated. Finally, the probability of occurrence for every situation, the annual wind energy absorption, the actual wind capacity factor and the wind contribution are calculated.

3. Application in Greece

3.1. Definition of candidate macro-sites

Initially, the regions of wind interest within the territory are identified, taking into consideration the sites with existing wind farms [11] (Figure 2a) and aeolian wind maps [12] (Figure 2b).

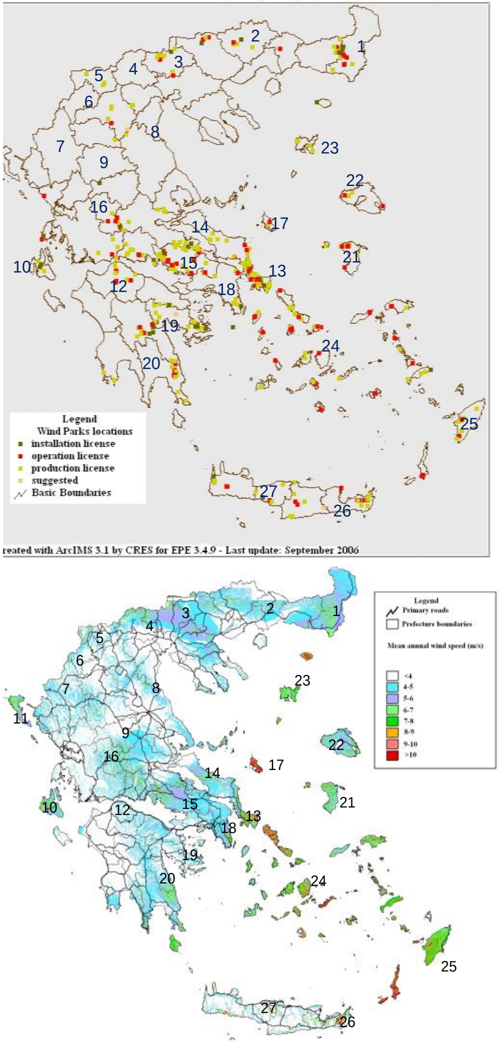

Figure 2: (a). Current development of wind farms in Greece provided by the national information system for energy [11], (b). Aeolian map of Greece [12]

To meet the national target for electricity production from renewable energy sources in Greece (29% by 2020), wind power plants of total capacity of at least 5000MW should be installed in the mainland power supply system. Two different applications were carried out, towards the definition of the optimum spatial dispersion in case of 3000MW and 5000MW.

The execution of EASY [13] produces for every individual generation, one file which contains 27 values representing the installed wind power location in each candidate site (figure 3). The upper limit of the free variables is 300 and 500 MW for the two examined cases. For every new individual generation produced by EASY, the distribution for the production of wind energy is calculated. Then using the above described methodology the capacity credit and the wind energy contribution are evaluated for the current individual generation. The evolutionary algorithm was programmed to execute 50,000 evaluations, namely different cases of possible installations. The result of this procedure is the creation of two plots, called Paretto fronts, which are demonstrating 20 best solutions between all the examined cases.

Site		1	2	3	4	23	8	9	11	22	17	16	21	13	14	10	19	24	20	25	5	6	7	15	12	18	26	27	
	Perfecture	**Evros**	**Drama**	**Kilkis**	**Pella**	**Limnos**	**Larissa**	**Trikala**	**Kerkyra**	**Lesvos**	**Skyros**	**Evritania**	**Chios**	**South Evoia**	**Cental Evoia**	**Kefallinia**	**Argolida**	**Naxos**	**Lakonia**	**Rhodos**	**Florina**	**Kastoria**	**Ioannina**	**Viotia**	**Achaia**	**Attiki**	**Lassithi**	**Rethymno**	**Mean Wind Speed (m/s)**
27	**Rethymno**	29%	26%	24%	18%	41%	24%	18%	15%	56%	50%	23%	60%	52%	48%	32%	36%	65%	52%	30%	9%	9%	17%	37%	29%	47%	69%	☒	7.3
26	**Lassithi**	11%	9%	8%	5%	24%	0%	-8%	1%	48%	35%	-9%	58%	44%	30%	12%	22%	70%	31%	39%	-10%	-11%	0%	12%	1%	38%	☒	69%	7.6
18	**Attiki**	44%	34%	8%	7%	64%	26%	17%	11%	68%	72%	22%	67%	83%	78%	36%	62%	65%	68%	4%	-2%	-2%	26%	60%	38%	☒	38%	47%	6.7
12	**Achaia**	39%	37%	26%	18%	40%	48%	64%	29%	32%	33%	70%	28%	30%	38%	55%	42%	17%	56%	11%	44%	47%	58%	62%	☒	38%	1%	29%	7.1
15	**Viotia**	53%	47%	23%	21%	59%	54%	56%	26%	52%	58%	64%	47%	56%	64%	44%	62%	36%	62%	3%	31%	35%	52%	☒	62%	60%	12%	37%	5.7
7	**Ioannina**	42%	52%	42%	40%	41%	66%	79%	42%	30%	33%	59%	23%	22%	31%	59%	34%	12%	40%	9%	67%	67%	☒	52%	58%	26%	0%	17%	6.9
6	**Kastoria**	27%	32%	40%	41%	13%	61%	82%	32%	4%	5%	68%	-1%	-8%	6%	37%	9%	-11%	13%	14%	86%	☒	67%	35%	47%	-2%	-11%	9%	6.4
5	**Florina**	28%	38%	49%	51%	15%	62%	73%	36%	6%	7%	59%	0%	-7%	6%	42%	10%	-9%	14%	17%	☒	86%	67%	31%	44%	-2%	-10%	9%	6.2
25	**Rhodos**	7%	10%	25%	21%	2%	13%	8%	14%	18%	5%	10%	24%	1%	2%	20%	1%	21%	5%	☒	17%	14%	9%	3%	11%	4%	39%	30%	7.0
20	**Lakonia**	41%	42%	18%	15%	55%	37%	35%	13%	55%	58%	40%	56%	65%	64%	43%	63%	53%	☒	5%	14%	13%	40%	62%	56%	68%	31%	52%	7.1
24	**Naxos**	28%	21%	9%	4%	50%	10%	2%	8%	74%	64%	3%	81%	74%	59%	25%	41%	☒	53%	21%	-9%	-11%	12%	36%	17%	65%	70%	65%	7.6
19	**Argolida**	36%	38%	12%	13%	48%	29%	24%	14%	47%	54%	29%	45%	56%	56%	33%	☒	41%	63%	1%	10%	9%	34%	62%	42%	62%	22%	36%	5.4
10	**Kefallinia**	41%	41%	39%	32%	40%	47%	48%	60%	37%	37%	45%	34%	32%	36%	☒	33%	25%	43%	20%	42%	37%	59%	44%	55%	36%	12%	32%	6.5
14	**Cental Evoia**	51%	40%	14%	10%	71%	32%	24%	16%	67%	85%	30%	65%	85%	☒	36%	56%	59%	64%	2%	6%	6%	31%	64%	38%	78%	30%	48%	7.3
13	**South Evoia**	48%	34%	8%	3%	70%	21%	12%	7%	71%	84%	14%	72%	☒	85%	32%	56%	74%	65%	1%	-7%	-8%	22%	56%	30%	83%	44%	52%	7.4
21	**Chios**	38%	30%	15%	10%	61%	22%	15%	18%	90%	69%	17%	☒	72%	65%	34%	45%	81%	56%	24%	0%	-1%	23%	47%	28%	67%	58%	60%	7.4
16	**Evritania**	40%	35%	33%	30%	31%	66%	83%	32%	23%	23%	☒	17%	14%	30%	45%	29%	3%	40%	10%	59%	68%	59%	64%	70%	22%	-9%	23%	6.8
17	**Skyros**	57%	47%	20%	16%	81%	33%	23%	15%	72%	☒	23%	69%	84%	85%	37%	54%	64%	58%	5%	7%	5%	33%	58%	33%	72%	35%	50%	7.5
22	**Lesvos**	45%	36%	17%	12%	69%	28%	22%	22%	☒	72%	23%	90%	71%	67%	37%	47%	74%	55%	18%	6%	4%	30%	52%	32%	68%	48%	56%	7.2
11	**Kerkyra**	25%	26%	31%	24%	20%	34%	34%	☒	22%	15%	32%	18%	7%	16%	60%	14%	8%	13%	14%	36%	32%	42%	26%	29%	11%	1%	15%	6.2
9	**Trikala**	41%	42%	38%	35%	33%	71%	☒	34%	22%	23%	83%	15%	12%	24%	48%	24%	2%	35%	8%	73%	82%	79%	56%	64%	17%	-8%	18%	7.0
8	**Larissa**	48%	56%	54%	58%	41%	☒	71%	34%	28%	33%	66%	22%	21%	32%	47%	29%	10%	37%	13%	62%	61%	66%	54%	48%	26%	0%	24%	6.0
23	**Limnos**	69%	57%	21%	16%	☒	41%	33%	20%	69%	81%	31%	61%	70%	71%	40%	48%	50%	55%	2%	15%	13%	41%	59%	40%	64%	24%	41%	7.1
4	**Pella**	27%	43%	68%	☒	16%	58%	35%	24%	12%	16%	30%	10%	3%	10%	32%	13%	4%	15%	21%	51%	41%	40%	21%	18%	7%	5%	18%	5.3
3	**Kilkis**	29%	44%	☒	68%	21%	54%	38%	31%	17%	20%	33%	15%	8%	14%	39%	12%	9%	18%	25%	49%	40%	42%	23%	26%	8%	8%	24%	5.7
2	**Drama**	65%	☒	44%	43%	57%	56%	42%	26%	36%	47%	35%	30%	34%	40%	41%	38%	21%	42%	10%	38%	32%	52%	47%	37%	34%	9%	26%	5.9
1	**Evros**	☒	65%	29%	27%	69%	48%	41%	25%	45%	57%	40%	38%	48%	51%	41%	36%	28%	41%	7%	28%	27%	42%	53%	39%	44%	11%	29%	6.5

Table 1: Correlation factors between all sites of interest calculated by the wind time series delivered by the meteorological model COAMPS

3.2. Evaluation of wind data

The correlation factor[2] of the annual wind time series between two points of interest is calculated by the following formula:

$$f = \frac{\sum_{h=1}^{8760}\left(v_{1,h}-\overline{v_1}\right)\cdot\left(v_{2,h}-\overline{v_2}\right)}{\sqrt{\sum_{h=1}^{8760}\left(v_{1,h}-\overline{v_1}\right)^2\cdot\sum_{h=1}^{8760}\left(v_{2,h}-\overline{v_2}\right)^2}}$$

Where $v_{1,h}$, $v_{2,h}$ are the simultaneous values of wind speed in the two considered sites for the h hour of the year and $\overline{v_1}$, $\overline{v_2}$ are the annual mean wind speeds at the two considered sites 1 and 2. Correlation factor takes values from -1 up to 1. Positive correlation factor indicates positive correlation; values around 0 indicate uncorrelated wind features and negative values close indicate negative correlation between the two examined sites.

Table 1 shows the correlation factors between all wind time series delivered by the meteorological model COAMPS.

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[2] Correlation coefficient of simultaneous wind time series obtained by the meteorological model COAMPS

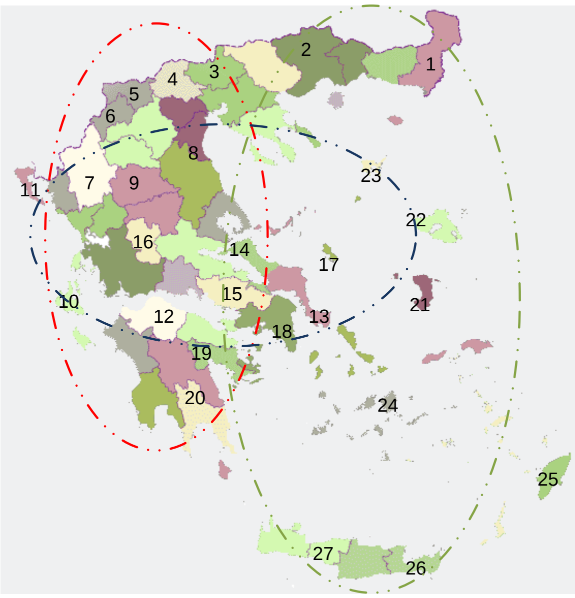

Figure 3: Candidate macro-sites and main correlated areas in the Greek territory

As shown in the above table, the wind features in the Greek territory are highly correlated. Negative values are very rare between any two sites. Especially, the area of the Aegean sea (East Greece) from north to south seems to be highly correlated. On the other hand, west Greece is the second correlated area and there is also a third correlated area in central Greece. The main correlated areas in the Greek territory are presented in the figure 3.

3.3. Results

In figure 4, the main two indexes (capacity credit and capacity factor) are presented for ten optimum solutions produced by EASY for scenarios of 3000MW and 5000MW. The following conclusions are drawn:

- Capacity credit and capacity factor (wind potential and wind curtailment are taken into consideration) are reduced when wind installed capacity is increased.
- Capacity credit is reduced from 27.5-27.8% in the “3000MW” scenario to 24.7-25.1% in the “5000MW” scenario.
- Capacity factor is reduced from 26.3-26.7% in the “3000MW” scenario to 24.3-24.6% in the “5000MW” scenario.

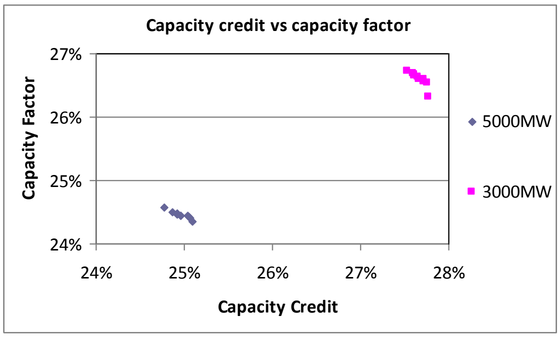

Figure 4: Capacity credit vs capacity factor for 10 optimum solutions in the two scenarios of 3000 and 5000MW.

In Tables 2 and 3, the wind installed capacity in the 27 predefined macro sites of interest is presented for 10 optimum solutions produced by EASY in the two scenarios of “3000MW” and “5000MW”.

Observation of the installed capacity at each area for different points on the optimal solutions front and for every scenario reveals that high values of the optimization targets, CC and CF, could be achieved for several alternative solutions. This gives the opportunity to the transmission system operator and to energy policy makers to choose from a wide range of solutions.

	1	2	3	4	5	6	7	8	9	10
1	2%	4%	2%	2%	4%	4%	0%	0%	1%	4%
2	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3	1%	2%	1%	2%	2%	2%	1%	2%	2%	1%
4	1%	1%	1%	1%	1%	1%	1%	2%	2%	1%
5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
6	8%	6%	8%	2%	1%	8%	2%	2%	2%	6%
7	1%	1%	1%	1%	1%	1%	4%	4%	4%	4%
8	7%	6%	9%	7%	6%	4%	5%	4%	4%	9%
9	2%	2%	2%	2%	2%	4%	2%	2%	2%	2%
10	2%	2%	2%	2%	2%	2%	0%	0%	0%	0%
11	3%	3%	3%	3%	9%	3%	3%	5%	5%	3%
12	94%	100%	94%	93%	93%	93%	95%	95%	95%	93%
13	97%	97%	97%	97%	95%	92%	89%	89%	89%	92%
14	2%	2%	2%	1%	1%	1%	1%	1%	1%	2%
15	3%	0%	3%	0%	0%	0%	2%	2%	2%	1%
16	97%	97%	97%	97%	99%	90%	99%	99%	99%	99%
17	2%	23%	23%	11%	14%	2%	14%	11%	11%	25%
18	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
19	23%	3%	3%	3%	2%	2%	2%	1%	1%	3%
20	91%	98%	92%	96%	92%	96%	92%	92%	92%	54%
21	100%	100%	100%	95%	94%	99%	89%	88%	88%	99%
22	60%	40%	40%	59%	58%	53%	60%	60%	60%	53%
23	98%	97%	97%	98%	98%	98%	91%	91%	91%	98%
24	19%	38%	38%	49%	50%	62%	75%	75%	75%	75%
25	92%	92%	95%	95%	95%	95%	94%	95%	95%	94%
26	99%	89%	95%	93%	95%	92%	95%	95%	95%	95%
27	93%	93%	93%	93%	82%	92%	81%	81%	81%	83%

Table 2. Wind installed capacity levelized by maximum permitted capacity (in this case 300MW) in the 27 macro sites, in “3000MW” scenario (10 optimum solutions)

	1	2	3	4	5	6	7	8	9	10
1	4%	2%	2%	2%	2%	2%	3%	11%	10%	10%
2	1%	1%	2%	2%	2%	5%	2%	1%	5%	5%
3	5%	1%	0%	1%	1%	1%	2%	2%	0%	0%
4	0%	6%	1%	1%	1%	5%	1%	1%	1%	1%
5	11%	6%	11%	0%	11%	0%	11%	1%	1%	9%
6	31%	28%	22%	28%	22%	22%	28%	22%	22%	19%
7	13%	6%	16%	17%	16%	16%	19%	15%	15%	15%
8	28%	27%	30%	27%	27%	27%	27%	27%	28%	20%
9	6%	31%	32%	34%	32%	32%	46%	31%	31%	43%
10	3%	0%	0%	0%	6%	0%	3%	4%	4%	4%
11	5%	20%	18%	17%	18%	18%	5%	7%	7%	7%
12	97%	98%	97%	97%	97%	92%	97%	97%	97%	97%
13	66%	66%	65%	65%	65%	60%	62%	90%	90%	90%
14	60%	35%	37%	35%	38%	37%	34%	37%	37%	37%
15	3%	0%	3%	1%	2%	3%	2%	3%	0%	1%
16	66%	48%	48%	48%	48%	47%	49%	45%	45%	48%
17	40%	50%	49%	38%	49%	50%	61%	51%	55%	48%
18	1%	4%	0%	0%	3%	5%	1%	4%	4%	1%
19	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
20	61%	51%	55%	74%	52%	51%	44%	46%	45%	55%
21	93%	96%	93%	93%	95%	96%	80%	95%	94%	96%
22	23%	26%	24%	26%	24%	24%	24%	24%	24%	24%
23	33%	43%	41%	42%	34%	43%	46%	41%	41%	11%
24	65%	81%	83%	94%	83%	82%	69%	66%	68%	82%
25	95%	95%	95%	80%	95%	95%	96%	95%	95%	96%
26	97%	83%	91%	92%	96%	96%	95%	98%	98%	97%
27	92%	91%	84%	84%	84%	92%	92%	84%	84%	82%

Table 3. Wind installed capacity capacity levelized by maximum permitted capacity (in this case 500MW) in the 27 macro sites, in “5000MW” scenario (10 optimum solutions)

Comparison of the optimal solutions obtained for the two considered scenarios results in the following conclusions:

- In certain areas, for example in Achaia (12), Chios (21), Rhodes (25), Lassithi (26) and Naxos (24) the optimization algorithm selects to install high wind power capacity in both considered scenarios due to the high wind potential in most of these sites. Additionally, Achaia (12) represents low correlation coefficients with the windiest areas of Greece.
- In the scenario of 3000MW there is a large concentration of wind power in areas with high wind potential. On the contrary, for the scenario of 5 GW it can be observed that although some regions still have high concentration of wind power, generally the optimization method choose to distribute the power required using higher spatial dispersion. This observation confirms the importance of spatial dispersion.
- In “3000MW” the optimization algorithm chooses to place considerably more power in Lesvos (22), Limnos (23) and Evritania (26) than in “5000MW” scenario. In the scenario of “3000MW” in the prefecture of South Evvoia (13) appears in almost all solutions the installed capacity to be at a rate near or over 90% of the allowed value, while in the prefecture of Central Evvoia (14) and Skyros (17) is lower. On the other hand, in the scenario of “5000MW”, higher capacity is proposed in these windy and correlated areas. In most cases these areas appear to be treated by the algorithm as a compound area. The same treatment seems to occur with the cumulative capacity in the regions of Evritania (16), Kastoria (6), Trikala (9), Larisa (8), Florina (5) and Ioannina (7).
- Areas with high correlation, over 50%, are grouped and the cumulative wind capacity for the two main wider correlated areas of East and West Greece (scenario of 5000MW) are presented in the following diagrams. It is obvious, that the optimization method takes into account the existing correlations during the optimization process because the cumulative installed wind capacity in the correlated areas seems to be almost constant among different optimum solutions (Figure 5).

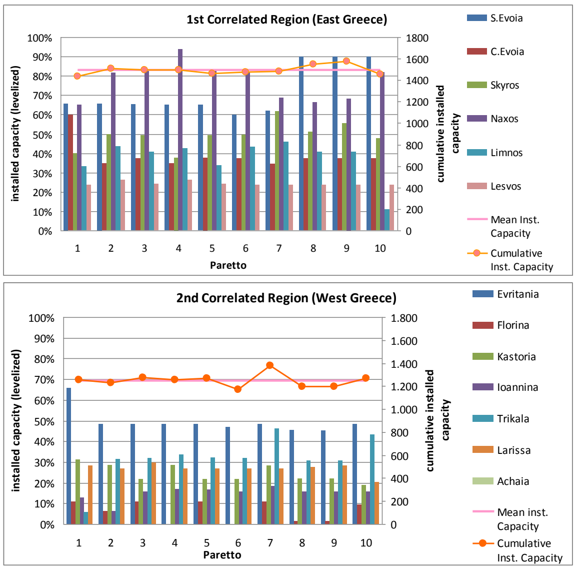

Figure 5: Installed capacity in correlated macro sites and cumulative capacity in wider correlated regions in “5000MW” scenario

The following two maps show the size of installed wind power per macro sites based on the results of the optimization method for each of the two scenarios considered (3000MW and 5000MW), reflecting the gradual increase of wind power throughout the Greek territory. The selected solutions are indicative and consistent with the gradual increase per macro site.

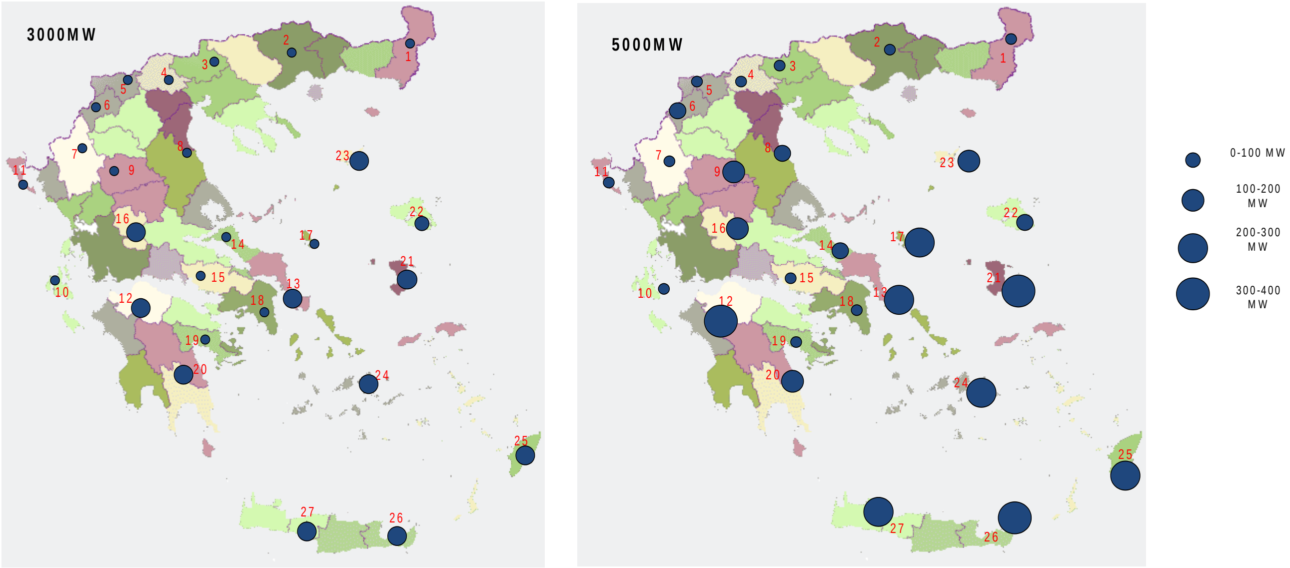

Figure 6. Optimum wind energy development in Greece for 3000MW and 5000MW

5. Conclusions - Discussion

Spatial dispersion of wind energy is very important. Adopting better spatial dispersion strategies could result in additional substitution of conventional power, better wind energy absorption and more wind energy contribution. The broader the spatial dispersion of wind plants, the higher the wind power capacity credit, and the wind energy absorption.

In Greece most of the windy areas are located in Aegean Sea and the East coasts of the mainland. The area of the Aegean Sea from north to south is highly correlated. West Greece is the second correlated area and there is also a third correlated area in central Greece.

When high wind capacity scenarios are examined, there are significant benefits associated with the shape of wind energy distribution, the ability of the system to absorb wind power, and the effect on the reliability of the electrical system, that lead to solutions with wider spatial dispersion even in areas with moderate wind potential. In these solutions, despite the lower wind potential, wind energy absorption, wind energy contribution and wind capacity credit are increased.

Consequently, hyper-accumulation of wind turbines, even in wider regions is not always the best case scenario.

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