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Offshore wind energy and perspectives

A preliminary analysis based on the NDP - OWF

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CONTENTS

- Introduction
- Wind data sources – In situ and CERRA reanalysis
- Methodology - Statistical analysis of wind speed, power density, and energy production
- Evaluation of CERRA dataset
- Numerical results
- Conclusions

Introduction

25 potential OWFODA

Prioritization in the medium → and long-term horizon

10 potential OWFODA for the medium – term horizon (**2030 – 2032**)

13 potential OWFODA for the long – term horizon (**from 2030-2032 onwards**)

2 pilot projects (Pilot-1 & 2) with potential capacity of up to 600 MW

- Floating total estimated capacity: 10.4 GW
- Fixed-bottom total estimated capacity: 1.4 GW
- Total span of the potential OWFODA: 2712 km^2
- Minimum total foreseen capacity: 12.4 GW

Introduction

Medium and long– term potential OWFODA

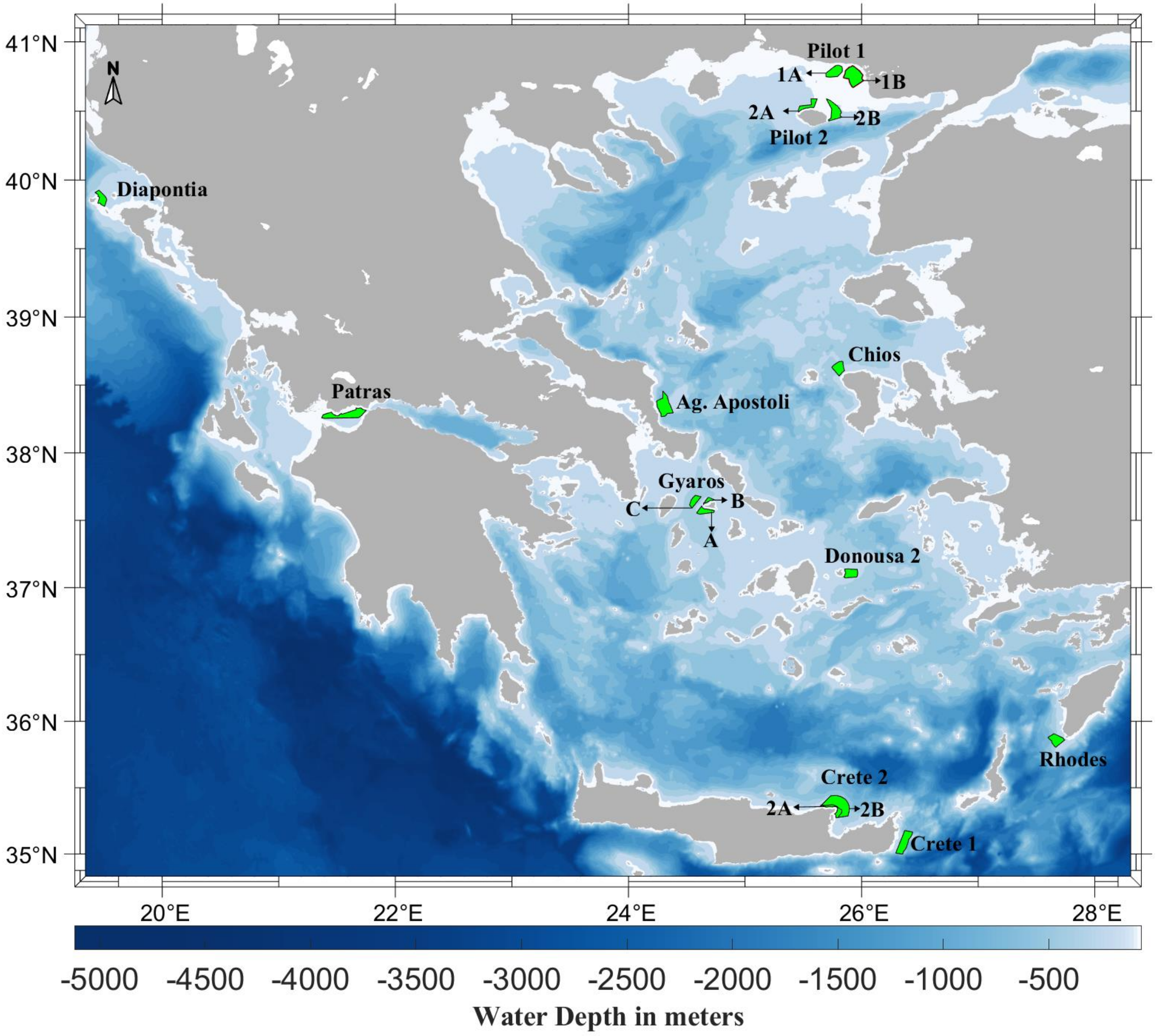

Figure 1. The medium-term potential OWFODA according to the NDP-OWF.

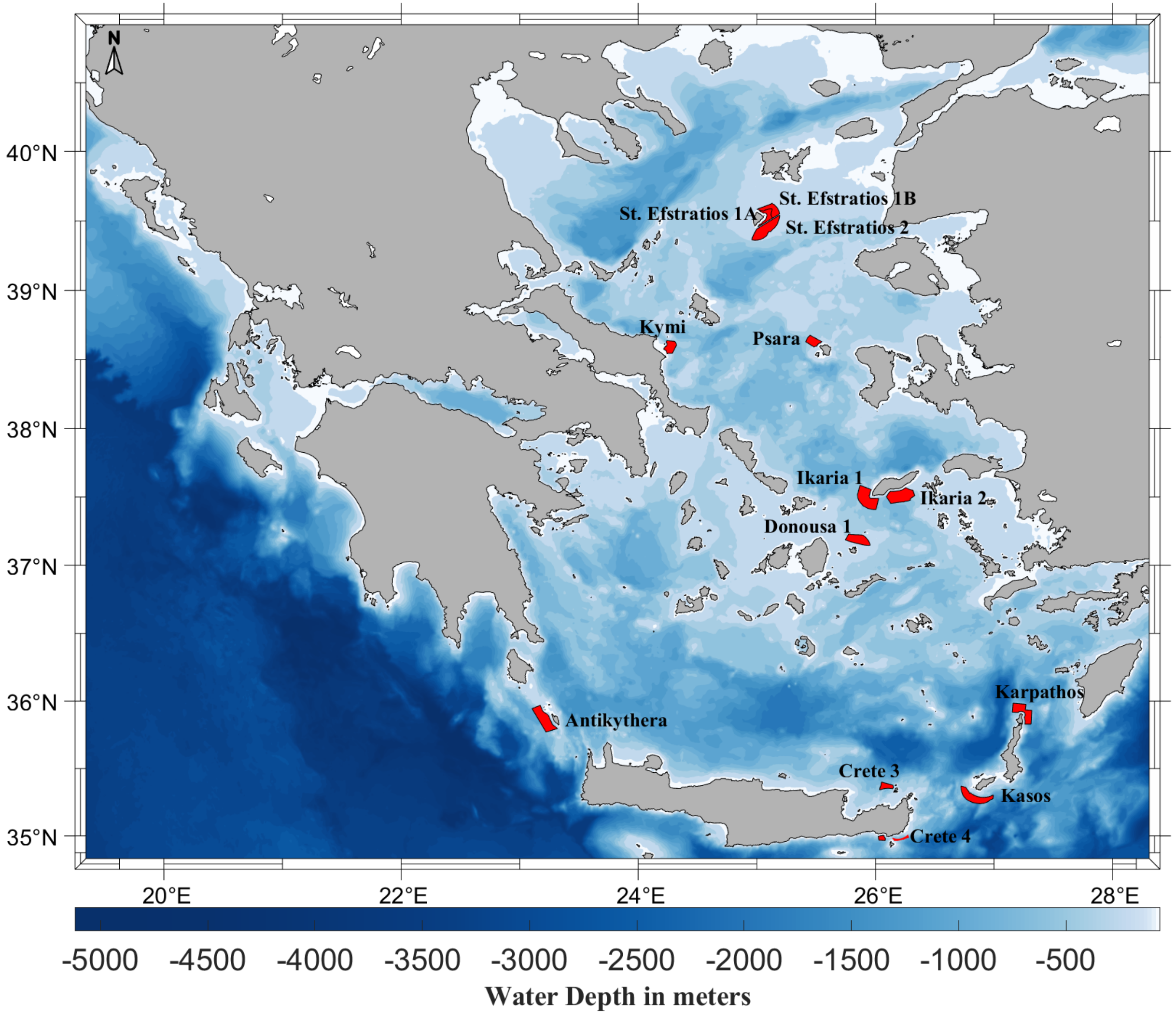

Figure 2. The long-term potential OWFODA according to the NDP-OWF.

Wind data sources– In situ wind data

- Wind speed time series (5 to 16 years);
- Locations very close to the shore;
- The wind measurements have a recording interval of 3 hours.

Data from six buoys are analysed:

- 2 buoys (68422-Pylos and 61277-Crete) Copernicus Marine Service - ocean in situ data
- 4 buoys (Athos (ATH), Lesvos (LES), Mykonos (MYK), and Santorini (SAN) - POSEIDON network (HCMR)

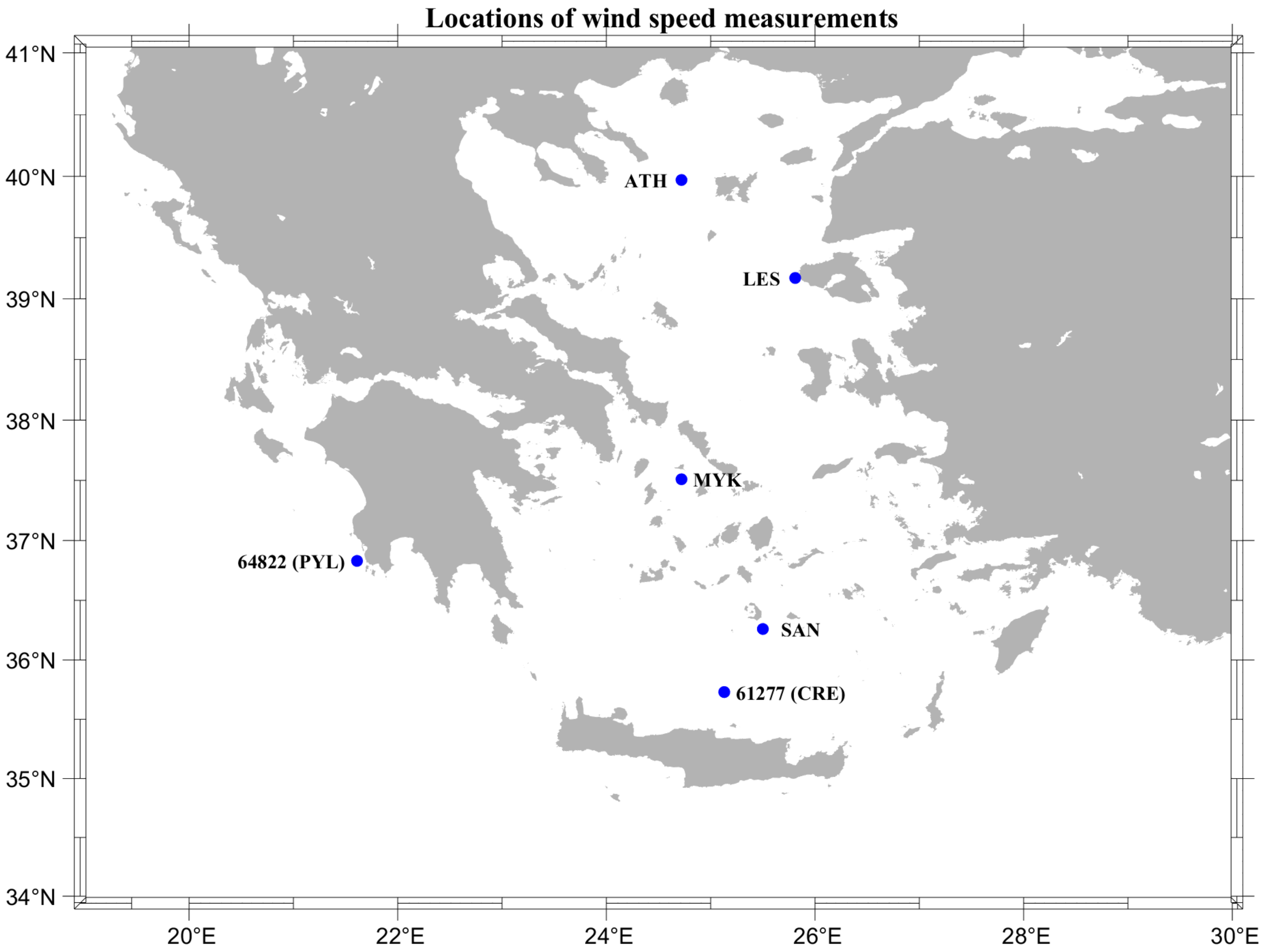

Figure 3. Locations of the examined oceanographic buoys.

Wind data sources– CERRA reanalysis system

- Copernicus European Regional Reanalysis (CERRA) (https://cds.climate.copernicus.eu/)
- HARMONIE – ALADIN (NWP) model & an improved DA system
- Spatial resolution: 5.5 km x 5.5 km
- Temporal span and resolution: 1985 – 2020, 3-h time step with monthly upgrades
- 11 height levels (15 – 500 m)

Methodology - Statistical analysis: Wind speed and power density

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- Statistical analysis at 2 temporal scales:

Annual

For every year j and for the 36 years, $j = 1,2,\ldots J = 36$

Seasonal

For a specific season s and every year j, and for a specific season s and the 36 years, $j = 1,2,\ldots J = 36$

Basic statistical parameters

- Mean
- Median
- Standard deviation
- Mean annual variability (MAV)
- Interannual variability (IAV)

WIND SPEED

Also includes:

- Theil – Sen estimator & Man – Kendall test – the linear slopes of annual mean WS, 95th and 99th percentiles of WS.
- GEV distribution – wind speed return levels

WIND POWER DENSITY

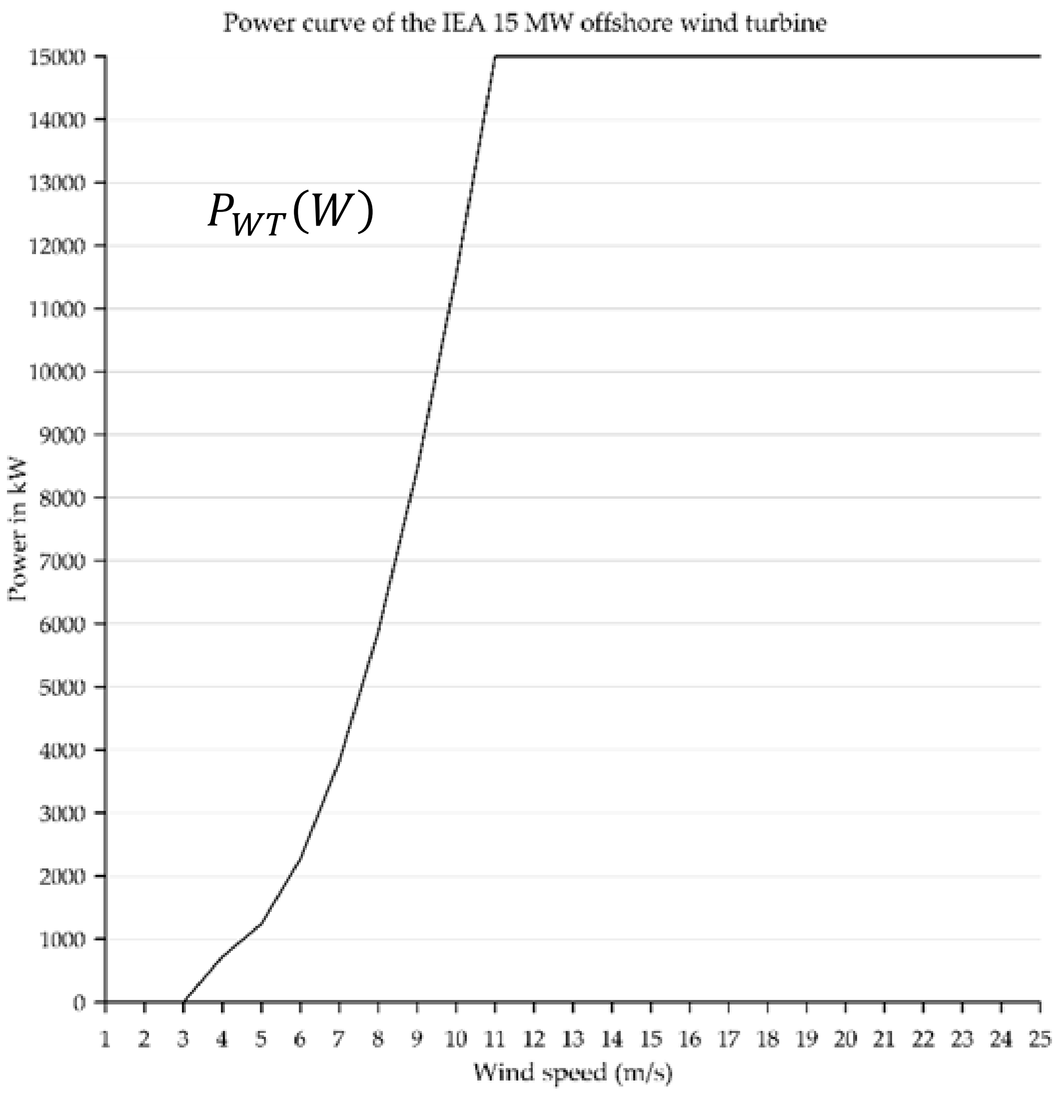
$$WPD = \frac{1}{2}\rho u^3$$

where ρ is the air density 1.2258 kg/m^3

Methodology – OWT and annual energy production

- IEA 15-MW upwind offshore wind turbine
- Renewable Energy Laboratory (NREL)
- IEC Class 1B
- Direct drive wind turbine
- 3 blades

Table 1: Main characteristics of the IEA 15-MW wind turbine	
Power rating	15 MW
Specific rating	332 W/m^2
Cut-in wind speed	3 m/s
Rated wind speed	10.59 m/s
Cut-out wind speed	25 m/s
Rotor diameter	240 m
Hub height	150 m



Methodology – OWT and annual energy production

Energy output

$$E_{WT} = T_r \int_{u_{cut-in}}^{u_{cut-out}} P_{WT}(W) f_W(W) dW \,,$$

where

$f_W(W)$ is the probability density function of wind speed, and T_r is the time period considered.

Annual Energy Production of an OWF

From a start-year 1, to an end-year N:

$$AEP_{OWF} = \frac{1}{N}\left[\alpha \times \eta \times \sum_{j=1}^{j=N} E_j\right],$$

where:

- $\boldsymbol{E_j}$ is the energy generated from all wind turbines of the OWF at year j;
- $\boldsymbol{\alpha}$ (94%) is the farm availability depending on the duration of the maintenance operations-downtime;
- $\boldsymbol{\eta}$ (90.5%) is the overall energy efficiency of the OWF, depending on the electrical and aerodynamic (farm wake effect) losses.

Methodology – Accuracy of the CERRA dataset

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Evaluation statistics

Wind Speed:

- (mean) $bias$
- mean absolute error (MAE)
- mean relative absolute error ($MRAE$)
- root mean squared error ($RMSE$)
- normalized root mean squared error ($NRMSE$)
- Pearson correlation coefficient ($\hat{\rho}_{BC}$)

Wind Direction:

- root mean squared error ($RMSE$)
- (mean) $bias$
- circular-circular correlation coefficient ($r_{D_B D_C}$)

In-situ measurements from six oceanographic buoys

↓

Collocation of datasets in space and time

Common reference height above the sea surface:

10 m asl for both wind data sources

Methodology – Collocation of datasets in space and time

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Evaluation of CERRA / Estimation of the wind speed time series at the centroid of the OWFODA.

Inverse squared distance weighting interpolation function – 4 nearest points

$$u_{i,L} = \frac{\sum_{j=1}^{4} \frac{u_{i,j}}{d_j^2}}{\sum_{j=1}^{4} \frac{1}{d_j^2}}, v_{i,L} = \frac{\sum_{j=1}^{4} \frac{v_{i,j}}{d_j^2}}{\sum_{j=1}^{4} \frac{1}{d_j^2}}, i = 1,2, \dots, n,$$

where,

- d_1, d_2, d_3, d_4, the corresponding distances from the location of interest;
- the u and v components of wind speed:

$$u_{i,j} = -\left|W_{S_{i,j}}\right| \sin\left(W_{D_{i,j}}\right), v_{i,j} = -\left|W_{S_{i,j}}\right| \cos\left(W_{D_{i,j}}\right),$$
$$i = 1,2, \dots, n, j = 1,2,3,4,$$

W_S and W_D are the wind speed and direction (CERRA - 4 nearest points);

$j = 1,2,3,4$ the location around the point of interest;

$i = 1,2, \dots, n$, the particular point (observation) of the time series;

Timeseries at location of interest/centroid

Wind Speed

$$W_{S_{i,L}} = \sqrt{{u_{i,L}}^2 + {v_{i,L}}^2}, i = 1,2, \dots, n,$$

Wind Direction

$$W_{D_{i,L}} = \mathrm{mod}\left(180 + \frac{180}{\pi} \mathrm{atan2}(u_{i,L}, v_{i,L}), 360\right), i = 1,2, \dots, n,$$

Numerical Results – Evaluation of the CERRA

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Wind Speed

Table 2: Evaluation parameters of CERRA wind speed performance against collocated measured wind speed (at 10 m asl) at the examined locations.

Buoy name	*bias*	*MAE*	*RMSE*	*NRMSE* (%)	$\hat{\rho}_{BC}$
PYL	−0.108	1.373	1.843	8.921	0.824
CRE	0.122	1.319	1.821	8.699	0.824
ATH	0.463	1.494	1.951	9.338	0.880
LES	−0.506	1.553	2.163	8.820	0.840
MYK	0.456	1.803	2.381	7.968	0.788
SAN	0.176	1.515	1.986	9.347	0.813

Wind Direction

Table 3: Evaluation parameters of CERRA wind direction performance against collocated measured wind speed (at 10 m asl) at the examined locations.

Buoy name	*bias* (°)	*RMSE* (°)	$r_{U_B U_C}$
PYL	−3.226	45.240	0.655
CRE	−5.684	43.576	0.758
ATH	−8.547	37.859	0.730
LES	−5.433	61.468	0.399
MYK	−4.847	41.307	0.723
SAN	−6.911	39.327	0.772

Conclusions

Evaluation of the CERRA

Wind Speed:

- In good agreement with measured wind speeds provided from oceanographic buoys
- Mean *bias* varies between **–0.506 m/s and 0.463 m/s**
- MAE varies between **1.319 m/s and 1.803 m/s**
- $RMSE$ values fluctuate between **1.82 m/s and 2.38 m/s**
- $NRMSE$ takes values **smaller than 9.35%** for all locations
- Correlation coefficient $\hat{\rho}_{BC}$ is always **greater than 0.78**

Wind direction:

- *bias* varies within **[–8.547°, –3.226°]**
- $RMSE$ between **37.86° and 61.47°**
- Circular-circular correlation coefficient was **greater than 0.655** (except for LES)

Numerical results – OWFODA

Statistics of the 3-hourly wind speed (at the centroid of the OWFODA)

- Centroid of each polygon
- Pilot 1 (600MW)
- Pilot 2 neglected

Table 4: Wind speed statistics for the medium-term OWFODA

Short-name (1)	Polygon name	Parameter						
		m_{Ws} m/s	$Ws_{0.5}$ m/s	s_{W_Y} m/s	Ws_{max} m/s	CV %	$Ws_{0.95}$ m/s	$Ws_{0.99}$ m/s
O1	Ag. Apostoli	7.58	7.48	4.06	29.61	53.60	14.38	17.42
O2	Chios	7.89	7.56	4.21	29.52	53.32	15.30	19.38
O3	Crete1	**9.12**	8.83	5.04	29.03	55.21	17.56	19.86
O4	Crete2A	7.82	7.93	3.89	25.96	49.75	13.88	16.20
O5	Crete2B	8.01	8.16	3.86	26.01	48.15	14.01	16.59
O6	Diapontia	6.60	5.94	4.09	29.30	62.03	14.07	17.39
O7	Donousa2	8.84	**8.94**	4.16	28.79	47.09	15.44	17.93
O8	Patras	**6.00**	**5.31**	4.12	30.18	**68.66**	13.54	18.28
O9	GyarosA	8.32	8.09	4.58	28.63	55.08	15.81	18.21
O10	GyarosB	8.36	8.13	4.65	29.54	55.64	16.05	18.65
O11	GyarosC	8.49	8.06	4.85	28.65	57.15	16.76	19.28
O12	Pilot1A	6.17	5.69	3.73	28.55	60.39	12.88	17.20
O13	Pilot1B	6.97	6.59	4.06	28.59	58.26	14.16	18.64
O14	Rhodes	8.28	8.24	3.90	29.61	**47.08**	14.82	17.60

([1]) Occasionally, for large tables, the short names of the OWFODA will be used

Numerical results – OWFODA

Statistics of the annual wind speed

- Centroid of each polygon
- Pilot 1 (600MW)
- Pilot 2 neglected

Table 5: Annual wind speed statistics for the medium-term OWFODA

Polygon name	Parameter							
	$m_{W_{SY}}$ m/s	$W_{SY\,0.5}$ m/s	$s_{W_{SY}}$ m/s	$W_{SY\,max}$ m/s	MAV %	IAV %	$W_{SY\,0.95}$ m/s	$W_{SY\,0.99}$ m/s
Ag. Apostoli	7.58	7.68	0.33	8.16	53.39	4.35	8.00	8.16
Chios	7.89	7.89	0.24	8.37	53.19	**3.01**	8.28	8.37
Crete1	**9.12**	**9.13**	0.40	9.96	55.04	4.39	9.85	9.96
Crete2A	7.82	7.79	0.32	8.64	49.62	4.13	8.37	8.64
Crete2B	8.01	8.00	0.32	8.87	48.02	3.99	8.54	8.87
Diapontia	6.60	6.59	0.29	7.25	61.92	4.40	7.07	7.25
Donousa2	8.84	8.87	0.37	9.82	46.94	4.21	9.33	9.82
Patras	**6.00**	**5.96**	0.31	6.74	**68.41**	5.15	6.57	6.74
GyarosA	8.32	8.37	0.41	9.00	54.90	4.91	8.93	9.00
GyarosB	8.36	8.43	0.42	9.08	55.44	5.06	9.00	9.08
GyarosC	8.49	8.58	0.44	9.27	56.93	**5.19**	9.15	9.27
Pilot1A	6.17	6.16	0.25	6.66	60.25	4.02	6.63	6.66
Pilot1B	6.97	7.00	0.27	7.53	58.12	3.86	7.44	7.53
Rhodes	8.28	8.30	0.37	9.20	**46.91**	4.42	8.92	9.20

Numerical results – OWFODA

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Statistics of trends

- Centroid of each polygon
- Pilot 1 (600MW)
- Pilot 2 neglected

Table 6: Slopes of mean annual wind speeds and extreme percentiles for the medium-term OWFODA

Polygon name	Parameter					
	$b(m_{W_S})$ m/s/y	p –value	$b(W_{S_{0.95}})$ m/s/y	p –value	$b(W_{S_{0.99}})$ m/s/y	p –value
Ag. Apostoli	–0.004	0.505	–0.012	0.215	–0.014	0.376
Chios	–0.001	0.902	**0.016**	**0.048**	**0.036**	**0.048**
Crete1	–0.011	0.051	**–0.022**	**0.016**	**–0.019**	**0.028**
Crete2A	–0.003	0.505	–0.006	0.334	0.000	0.967
Crete2B	–0.004	0.391	–0.006	0.470	0.003	0.775
Diapontia	0.005	0.294	0.012	0.178	0.014	0.307
Donousa2	–0.004	0.540	–0.004	0.614	0.003	0.754
Patras	–0.007	0.138	**–0.030**	**0.037**	–0.007	0.924
GyarosA	–0.002	0.634	–0.006	0.438	0.003	0.859
GyarosB	–0.003	0.673	–0.010	0.307	–0.003	0.634
GyarosC	–0.006	0.247	–0.015	0.215	–0.002	0.859
Pilot1A	0.004	0.307	0.004	0.754	0.021	0.186
Pilot1B	0.002	0.796	–0.003	0.838	0.013	0.470
Rhodes	**–0.018**	**0.002**	**–0.027**	**0.001**	0.000	0.946

Numerical results – OWFODA

Statistics of extreme wind speeds

- Centroid of each polygon
- Pilot 1 (600MW)
- Pilot 2 neglected

Table 7: Return levels of wind speed for the medium-term OWFODA

Polygon name	Return levels and 95% confidence intervals								
	RL_{20}	$CI-RL_{20}$		RL_{30}	$CI-RL_{30}$		RL_{50}	$CI-RL_{50}$	
Ag. Apostoli	26.954	25.439	28.468	27.510	25.773	29.248	28.159	26.096	30.222
Chios	28.444	27.430	29.458	28.794	28.008	31.217	29.177	27.854	30.500
Crete1	27.525	26.213	28.837	27.982	26.409	29.554	28.530	26.574	30.485
Crete2A	**24.741**	23.704	25.778	**25.118**	23.961	26.276	**25.542**	24.208	26.876
Crete2B	25.195	24.200	26.191	25.545	24.433	26.657	25.930	24.646	27.214
Diapontia	26.693	25.402	27.983	27.174	25.670	28.678	27.749	25.932	29.565
Donousa2	26.569	25.472	27.667	26.990	25.767	28.214	27.476	26.071	28.881
Patras	**30.296**	26.751	33.841	**31.435**	26.796	36.073	**32.927**	26.588	39.267
GyarosA	26.679	24.986	28.373	27.289	25.234	29.343	28.045	25.455	30.635
GyarosB	26.725	24.952	28.498	27.383	25.215	29.551	28.218	25.461	30.976
GyarosC	27.501	25.361	29.64	28.196	25.464	30.928	29.078	25.444	32.712
Pilot1A	26.919	25.728	28.109	27.338	25.975	28.7	27.812	26.195	29.429
Pilot1B	27.175	26.273	28.077	27.508	26.511	28.505	27.879	26.741	29.016
Rhodes	27.451	25.597	29.304	28.100	25.883	30.317	28.884	26.134	31.634

Numerical results – OWFODA

Wind Power Density

- Centroid of each polygon
- Pilot 1 (600MW)
- Pilot 2 neglected

Table 8: Annual wind power density statistics for the medium-term OWFODAs

Polygon name	Parameter				
	m_{WPD}, W/m^2	$WPD_{0.5}$, W/m^2	s_{WPD}, W/m^2	MAV %	IAV %
Ag. Apostoli	509.75	522.36	61.31	136.03	12.03
Chios	584.26	578.75	58.07	151.90	9.94
Crete1	**908.60**	**918.99**	102.60	126.12	11.29
Crete2A	513.21	511.48	50.35	117.40	9.81
Crete2B	536.56	537.21	51.14	116.51	**9.53**
Diapontia	408.14	402.51	43.43	168.18	10.64
Donousa2	708.16	712.73	69.35	**114.27**	9.79
Patras	359.56	348.26	53.62	**208.20**	**14.91**
GyarosA	688.13	701.69	78.44	126.57	11.40
GyarosB	706.45	723.48	84.34	128.40	11.94
GyarosC	765.16	773.10	96.54	132.81	12.62
Pilot1A	**328.03**	**323.31**	36.01	188.80	10.98
Pilot1B	448.99	452.65	49.25	172.57	10.97
Rhodes	588.56	594.78	64.68	124.02	10.99

Numerical results – OWFODA

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Offshore wind energy production – Number of OWT and installed capacity

- IEA 15 – MW OWT
- Pilot 1 (600MW & 219.28km^2) → 40 OWT (Pilot 1A: 14, Pilot 1B: 26)

3 scenarios

1. **Scenario S3:** This scenario considers a capacity density of 3 MW/km^2 (roughly corresponding to the capacity density of the Pilot-1 area) – the conservative
2. **Scenario S5.0:** This scenario considers a capacity density of 5.0 MW/km^2 – the balanced
3. **Scenario S7.0:** This scenario considers a capacity density of 7.0 MW/km^2 – the optimistic

Table 9. Medium-term OWFODA, number and foundation type of wind turbines and corresponding capacity

			Scenarios					
			S3	S5.0	S7.0	S3	S5.0	S7.0
Polygon name	Surface [km^2]	Foundation	Number of wind turbines			Installed capacity (MW)		
Ag. Apostoli	133.9	FL	26	44	62	402	670	937
Chios	65.54	FL	13	21	24	197	328	360
Crete1	118.0	FL	23	39	55	354	590	826
Crete2A	40.06	FL	8	13	14	120	200	220
Crete2B	187.26	FL	37	62	87	562	936	1311
Diapontia	54.34	FB	10	18	19	163	272	299
Donousa 2	65.03	FL	13	21	30	195	325	455
Patras	138.83	FB	27	46	50	416	694	764
GyarosA	43.44	FL	8	14	20	130	217	304
GyarosB	14.90	FL	2	4	5	45	75	82
GyarosC	41.41	FL	8	13	19	124	207	290
Pilot1A	77.39	FB	14	14	14	210	210	210
Pilot1B	141.89	FB	26	26	26	390	390	390
Rhodes	74.86	FL	14	24	27	225	374	412
Total	**1196.85**		**229**	**365**	**452**	**3131**	**5488**	**6860**

Numerical Results – OWFODA

Offshore wind energy production – Annual energy production

- IEA 15 – MW OWT
- Pilot 1 (600MW & 219.28km^2) → 40 OWT (Pilot 1A: 14, Pilot 1B: 26)

Table 10: Annual energy production of the medium-term OWFODA

Polygon name	AEP (GWh)		
	Scenarios		
	S3	**S5.0**	**S7.0**
Ag. Apostoli	1260.70	2133.49	3006.29
Chios	645.48	1042.70	1191.65
Crete1	1384.36	2347.39	3310.43
Crete2A	418.02	679.28	731.53
Crete2B	1999.71	3350.86	4702.01
Diapontia	377.27	679.09	716.81
Donousa2	797.95	1288.99	1841.41
Patras	867.69	1478.29	1606.83
GyarosA	441.25	772.18	1103.12
GyarosB	110.73	221.45	276.82
GyarosC	441.04	716.69	1047.46
Pilot1A	452.41	452.41	452.41
Pilot1B	1058.54	1058.54	1058.54
Rhodes	773.79	1326.50	1492.31
Total	**11028.93**	**17547.86**	**22537.64**

Numerical results – OWFODA

Offshore wind energy production – AS, AN

- $AS = AEP/S$

- Annual energy production (AEP, in GWh)
- The surface (S, in km^2) of the OWFODA.

- $AN = AEP/N_{WT}$

-The number of the installed wind turbines N_{WT}.

Table 11: Medium-term OWFODA and corresponding *AS* and *AN* values

Polygon name	*AS*			*AN*
	Scenarios			
	S3	**S5.0**	**S7.0**	**All**
Ag. Apostoli	9.42	15.93	22.45	48.49
Chios	9.85	15.91	18.18	49.65
Crete1	**11.73**	**19.89**	**28.05**	**60.19**
Crete2A	10.43	16.96	18.26	52.25
Crete2B	10.68	17.89	25.11	54.05
Diapontia	6.94	12.50	13.19	37.73
Donousa2	**12.27**	**19.82**	**28.32**	**61.38**
Patras	6.25	10.65	11.57	32.14
GyarosA	10.16	17.78	25.40	55.16
GyarosB	7.43	14.86	18.57	55.36
GyarosC	10.65	17.31	25.29	55.13
Pilot1A	5.85	5.85	5.85	32.32
Pilot1B	7.46	7.46	7.46	40.71
Rhodes	10.34	17.72	19.93	55.27
Overall	9.21	14.66	18.83	

Numerical results – OWFODA

Offshore wind energy production – Mean monthly energy production

Maximum total energy

- August: 1897 GWh
- July: 1885 GWh

Minimum total energy

- May: 1178 GWh
- April: 1229 GWh

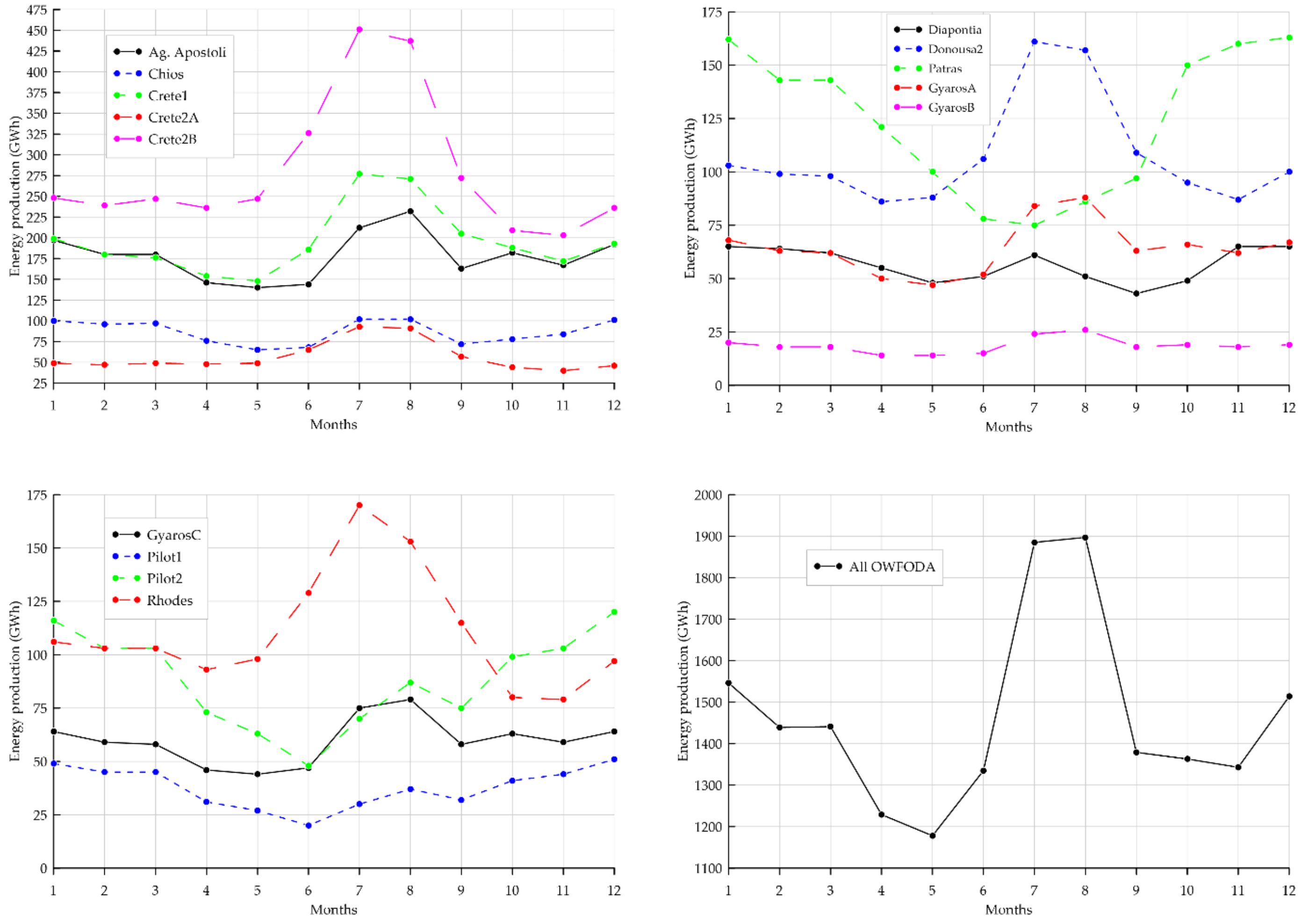

Figure 8. Mean monthly energy production at the medium – term OWFODA

- Etesians strongly affect the central and southern Aegean Sea
- The OWFODA of the central-southern Aegean play a major role to the 2030-2032 targets of Greece.

Numerical Results – OWFODA

Offshore wind energy production – daily energy production

Highest variability

Patras (101.34%); Pilot1A (100.00%); Diapontia (88.19%)

Lowest variability

Donousa2 (64.22%); Crete1 (67.15%); Rhodes (68.35%)

- Roughly increase from October – January;
- Decrease: February-end of May;
- Highest values during June-August;
- Autumn decreases

3 peaks: December, end of January and July,

2 troughs: April-May and September.

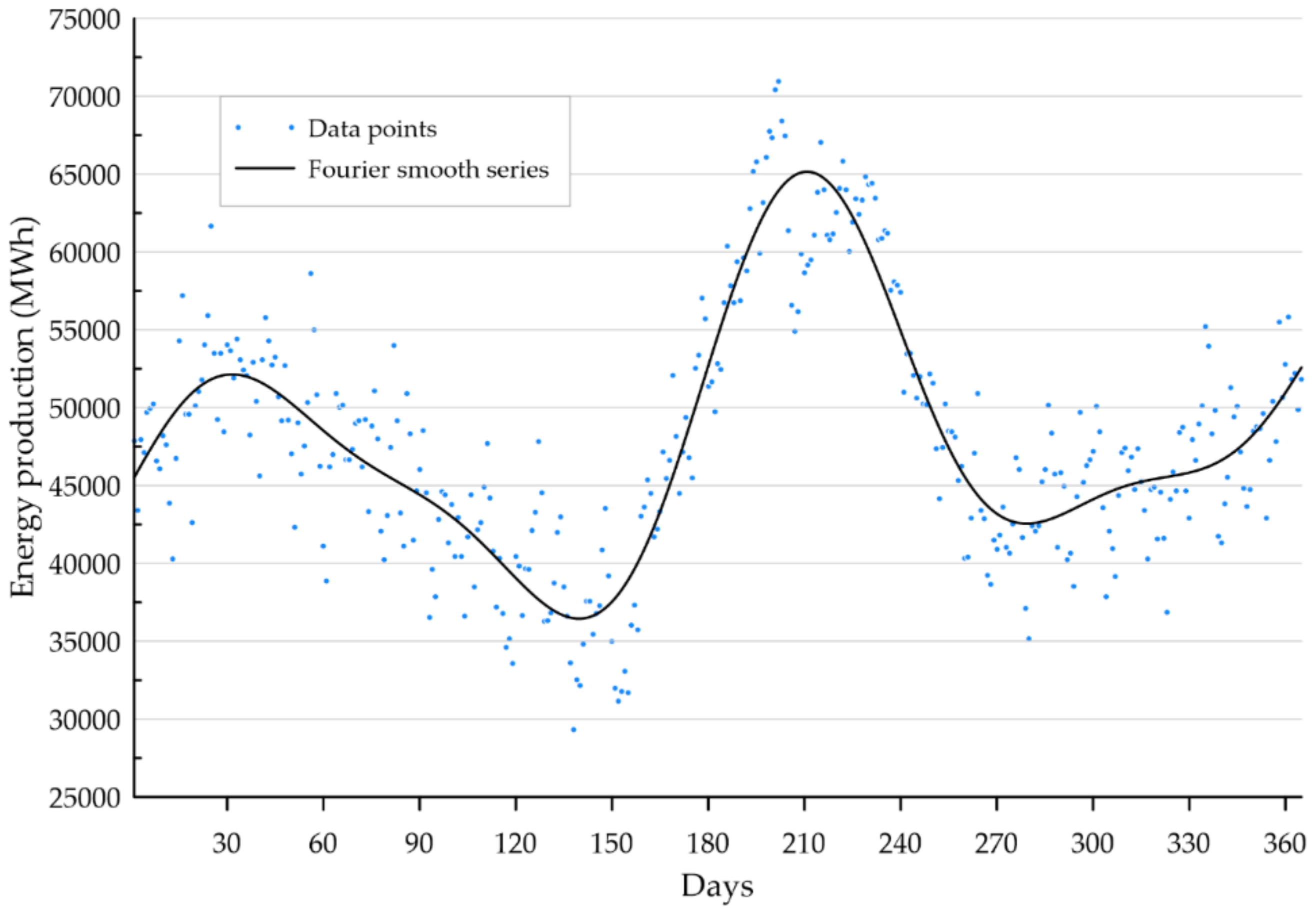

Figure 8. Mean monthly energy production at the medium – term OWFODA.

Numerical results – OWFODA

Offshore wind energy production – Hourly energy production

- **Donousa2** is the optimal location for the development of OWF:
  - the highest CF;
  - PoH;
  - the lowest variability;
  - the highest *AN*;
  - The second highest value of *AS*.

- **Most productive hours:**
  - 15:00-18:00 UTC (Donousa2, Patras, GyarosA, B, C and Rhodes);
  - 12:00-15:00 UTC (for Ag. Apostoli, Crete2A, and Crete2B);
  - 18:00-21:00 UTC (for Chios, and Diapontia);
  - 03:00-06:00 UTC (for Crete1 and Pilot1B);
  - 21:00-00:00 UTC for Pilot1A.

Table 12: Statistics of the hourly energy production for the medium-term OWFODA under scenario S5.0

Polygon name	Parameter					
	CF (%)	PoH (%)	m_{EP} MWh	s_{EP} MWh	CV %	EP_{peak} (hours in UTC)
Ag. Apostoli	43.35	76.9	243.38	220.32	90.52	12:00-15:00
Chios	44.39	79.9	118.95	104.79	88.09	18:00-21:00
Crete1	53.81	80.1	267.78	209.85	78.37	03:00-06:00
Crete2A	46.71	79.4	77.49	65.60	84.66	12:00-15:00
Crete2B	48.32	81.2	382.26	311.56	81.51	12:00-15:00
Diapontia	33.73	67.5	77.47	86.73	111.96	18:00-21:00
Donousa2	**54.87**	**85.1**	147.04	107.82	**73.33**	15:00-18:00
Patras	28.73	60.5	168.64	208.08	123.39	15:00-18:00
GyarosA	49.31	77.9	88.09	74.97	85.10	15:00-18:00
GyarosB	49.49	77.7	25.26	21.45	84.90	15:00-18:00
GyarosC	49.29	77.7	81.76	69.99	85.61	15:00-18:00
Pilot1A	28.89	66.3	51.61	60.71	117.64	21:00-00:00
Pilot1B	36.40	71.7	120.76	123.96	102.66	03:00-06:00
Rhodes	49.41	84.4	151.32	119.23	78.79	15:00-18:00

Conclusions

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OWFODA

Most wind energetic: Crete1 (with 9.12 m/s annual wind speed at 150 m asl); Donousa2 (8.84 m/s),

Highest values of wind power density: Crete1 (908.6 W/m^2), GyarosC (765.16 W/m^2);

Highest AS: Crete1 (19.9%) and Donousa2 (19.8%)

Highest AN: Donousa2 (61.4%) and Crete1 (60.2%)

Highest CF: Donousa2 (54.9%), and Crete1 (53.8%)

Highest PoH: Donousa2 (85.1%), and Rhodes (84.4%)

Highest MAV (WPD): Gulf of Patras (208.2%) and Pilot1A (188.8%)

Highest IAV (WPD): Gulf of Patras (14.9%) and GyarosC (12.6%).

Lowest wind speeds: Gulf of Patras and Pilot1

Highest MAV (WS): Gulf of Patras (68.4%), and Diapontia (61.92%);

Highest IAV (WS): at GyarosC (5.19%) and the Gulf of Patras (5.15%).

Highest 30-years return values: Gulf of Patras (31.4 m/s) and Chios (28.8 m/s).

OVERALL: Donousa2 seems to be the optimal location for the development of OWF, since it is characterized by the highest capacity factor and percentage of operating time, combined with the lowest variability, the highest value for *AN*, and the second maximum value of *AS*.

Numerical results – OWFODA

Correlation, synergies and complementarity of wind energy

O1	Ag. Apostoli
O2	Chios
O3	Crete1
O4	Crete2A
O5	Crete2B
O6	Diapontia
O7	Donousa2
O8	Patras
O9	GyarosA
O10	GyarosB
O11	GyarosC
O12	Pilot1A
O13	Pilot1B
O14	Rhodes

Table 13: Correlation coefficient of wind energy produced (per 3 hours) by each OWFODA (values of correlation coefficient above 0.6 are shown in boldface)

	Polygon name (short names)													
	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14
O1	1.000													
O2	0.581	1.000												
O3	0.350	0.398	1.000											
O4	0.371	0.347	**0.659**	1.000										
O5	0.368	0.356	**0.647**	**0.971**	1.000									
O6	0.019	0.108	–0.051	–0.028	–0.012	1.000								
O7	0.489	0.560	**0.706**	**0.651**	**0.628**	–0.012	1.000							
O8	0.352	0.239	0.087	0.044	0.032	0.050	0.158	1.000						
O9	**0.769**	**0.626**	0.521	0.498	0.485	–0.014	**0.689**	0.328	1.000					
O10	**0.776**	**0.613**	0.518	0.500	0.486	–0.015	**0.691**	0.323	**0.987**	1.000				
O11	**0.763**	**0.608**	0.488	0.454	0.440	–0.021	**0.637**	0.373	**0.958**	**0.946**	1.000			
O12	0.456	0.371	0.131	0.097	0.111	0.044	0.207	0.389	0.390	0.391	0.399	1.000		
O13	0.514	0.409	0.134	0.094	0.108	0.050	0.222	0.383	0.429	0.430	0.436	**0.888**	1.000	
O14	0.118	0.204	0.528	0.504	0.508	0.025	0.510	–0.040	0.230	0.234	0.203	0.018	–0.010	1.000

Numerical results – OWFODA

Correlation, synergies and complementarity of wind energy

O1	Ag. Apostoli
O2	Chios
O3	Crete1
O4	Crete2A
O5	Crete2B
O6	Diapontia
O7	Donousa2
O8	Patras
O9	GyarosA
O10	GyarosB
O11	GyarosC
O12	Pilot1A
O13	Pilot1B
O14	Rhodes

Table 14: Correlation coefficient of monthly wind energy produced by each OWFODA (values of correlation coefficient above 0.6 are shown in boldface)

	Polygon name (short names)													
	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14
O1	1													
O2	**0.753**	1												
O3	**0.684**	0.595	1											
O4	0.560	0.430	0.854	1										
O5	0.545	0.443	0.836	0.994	1									
O6	−0.108	0.231	−0.143	−0.146	−0.103	1								
O7	**0.720**	**0.615**	**0.923**	**0.898**	**0.884**	−0.139	1							
O8	0.272	0.251	−0.109	−0.358	−0.372	0.054	−0.161	1						
O9	**0.926**	**0.736**	**0.813**	**0.677**	**0.653**	−0.134	**0.848**	0.202	1					
O10	**0.924**	**0.718**	**0.816**	**0.685**	**0.660**	−0.148	**0.854**	0.189	**0.998**	1				
O11	**0.923**	**0.725**	**0.778**	**0.612**	0.585	−0.149	**0.798**	0.288	**0.989**	**0.986**	1			
O12	0.538	0.558	0.099	−0.127	−0.126	0.175	0.091	0.679	0.449	0.437	0.499	1		
O13	0.564	0.584	0.100	−0.143	−0.141	0.182	0.090	0.691	0.464	0.451	0.514	**0.978**	1	
O14	0.296	0.319	**0.735**	**0.811**	**0.825**	0.020	**0.755**	−0.392	0.416	0.424	0.353	−0.195	−0.219	1

Numerical Results – OWFODA

Correlation, synergies and complementarity of wind energy

O1	Ag. Apostoli
O2	Chios
O3	Crete1
O4	Crete2A
O5	Crete2B
O6	Diapontia
O7	Donousa2
O8	Patras
O9	GyarosA
O10	GyarosB
O11	GyarosC
O12	Pilot1A
O13	Pilot1B
O14	Rhodes

Table 15: Correlation coefficient of annual wind energy produced by each OWFODA (values of correlation coefficient above 0.6 are shown in boldface)

	Polygon name													
	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14
O1	1													
O2	**0.613**	1												
O3	**0.668**	**0.660**	1											
O4	0.596	**0.641**	0.818	1										
O5	0.537	**0.626**	0.796	0.990	1									
O6	-0.330	0.015	-0.073	0.047	0.106	1								
O7	**0.720**	**0.773**	**0.897**	**0.764**	**0.736**	-0.104	1							
O8	0.346	0.349	0.259	0.047	0.021	-0.355	0.344	1						
O9	**0.896**	**0.698**	**0.826**	**0.711**	**0.657**	-0.324	**0.881**	0.391	1					
O10	**0.903**	**0.683**	**0.814**	**0.697**	**0.642**	-0.334	**0.877**	0.407	**0.998**	1				
O11	**0.884**	**0.689**	**0.816**	**0.680**	**0.623**	-0.363	**0.867**	0.463	**0.990**	**0.988**	1			
O12	0.468	0.383	0.270	0.199	0.173	-0.032	0.431	0.454	0.453	0.474	0.452	1		
O13	0.575	0.427	0.350	0.297	0.262	-0.168	0.513	0.478	0.573	0.596	0.574	**0.948**	1	
O14	0.144	0.401	0.578	0.553	0.583	0.254	0.497	0.164	0.279	0.281	0.305	0.079	0.122	1

Conclusions 1

- For scenario S5.0, the maximum wind energy is produced during August and July (1897 GWh and 1885 GWh, respectively). The major energy contributors during July and August are the OWFODA of the central-southern Aegean Sea
- November, December and January are the major energy contributors in the Ionian and the North Aegean Seas OWFODA
- The OWFODA that are located at the central-southern Aegean Sea are of most importance as regards the achievement of the 2030-2032 energy targets of Greece
- At the daily and hourly energy production basis, the highest variabilities are observed for Patras (101.3% and 123.4%), and Pilot1A (100.0% and 117.64%), while the lowest variabilities are observed for Donousa2 (64.2% and 73.3%), and Crete1 (67.1% and 78.4%), respectively

Conclusions 2

- Synergy aspects of most of the examined OWFODA are very favourable at all time scales, especially for the neighbouring ones
- Lack of complementarity at the hourly and monthly scales, some signs of complementarity appear at the annual time scale. The lack of complementarity may be a future problem
- Gyaros and Donousa2: high synergetic features with most of the rest Aegean OWFODA at all time scales
- Rhodes OWFODA: relatively high degree of synergy with the rest areas of the central-southern Aegean Sea, in the monthly scale
- Diapontia OWFODA seem to be statistically isolated from the rest areas at all time scales
- Colocation of OWF with offshore solar might be an optimum solution

Thank you for your attention !

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Introduction

30.07.2022 → Hellenic Parliament → Law. 4964/2022

The OWF entity management: Hellenic Hydrocarbons & Energy Resources Management Company SA (HEREMA)

The development of offshore wind farms (OWF) consists an important national strategy.

31.10.2023 → HEREMA → draft NDP – OWF

Main pillars for:
- the design; development; siting; installation; exploitation of OWF;

Defines:
- the targets regarding the available estimated capacity at 2 temporal horizons;
- the preliminary potential OWFODA;
- a preliminary estimation of the available installed capacity of each polygon – area.

SEIA

Introduction

Considerations

- updated targets of the National Energy and Climate Plan (NECP);
- the environmental and biodiversity protection planning;
- suggestions and opinions from the competent public authorities and entities;
- the existing Special Spatial Framework for Renewable Energy Sources (SSF – RES);
- international best practices and approaches.

Spatial restrictions

- the minimum (1 nm) and the maximum (12 nm for the Ionian Sea, and 6 nm for the Aegean Sea) distance from the baseline.

20 exclusion criteria

- specific technical restrictions;
- environmental conditions (e.g. areas of absolute natural reserve, RAMSAR wetlands);
- cultural heritage sites (e.g. monuments registered in the World Heritage List);
- infrastructure networks (e.g. aviation infrastructure);
- rules and proposals from competent authorities (geoparks, shipwrecks, shipping lanes, submarine power cables)
- the applied minimum distance from the baseline (e.g. 1 nm) overcame the required minimum distance from the SSF-RES (e.g. protection zone A, urban and traditional agglomerations);
- Average annual wind speeds below 6.5 m/s and 8 m/s (at 100 m asl) were excluded for fixed-bottom and floating OWF
- Water depths greater than 1000 m were not included.

Numerical results – wind speed assessment

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Seasonal scale – mean seasonal WS

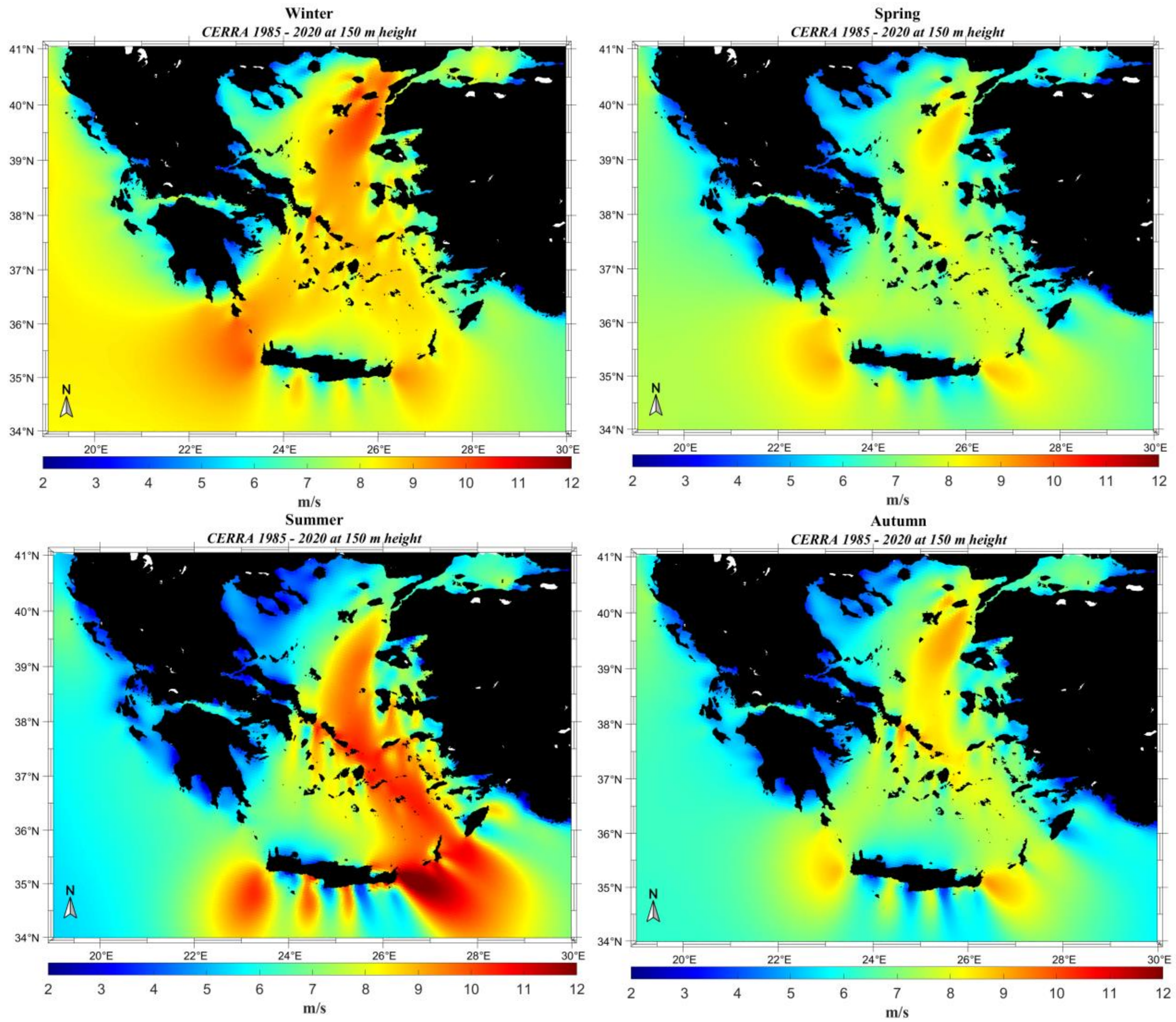

Figure 6. Mean seasonal wind speed at 150 m above sea level: winter (upper left), spring (upper right), summer (lower left), autumn (lower right).

Numerical results – wind speed assessment

Annual scale - mean annual WS, MAV, IAV

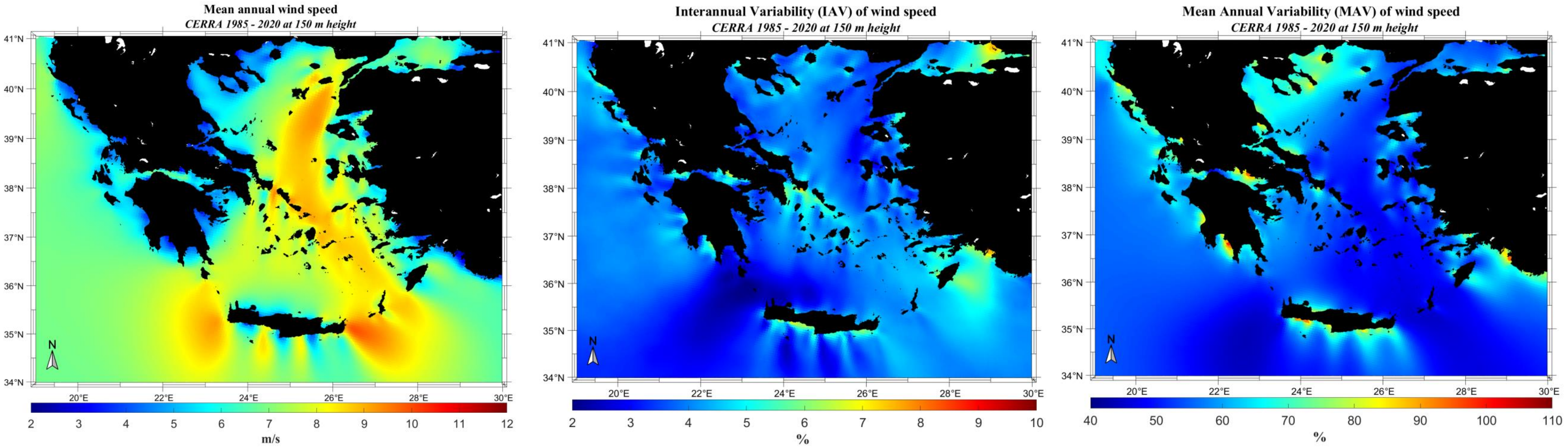

Figure 4. Mean annual wind speed (1st panel), interannual variability (2nd panel), and mean annual variability (3rd panel) at 150 m above sea level.

Numerical results – wind speed assessment

Annual scale – significant Theil – Sen slopes

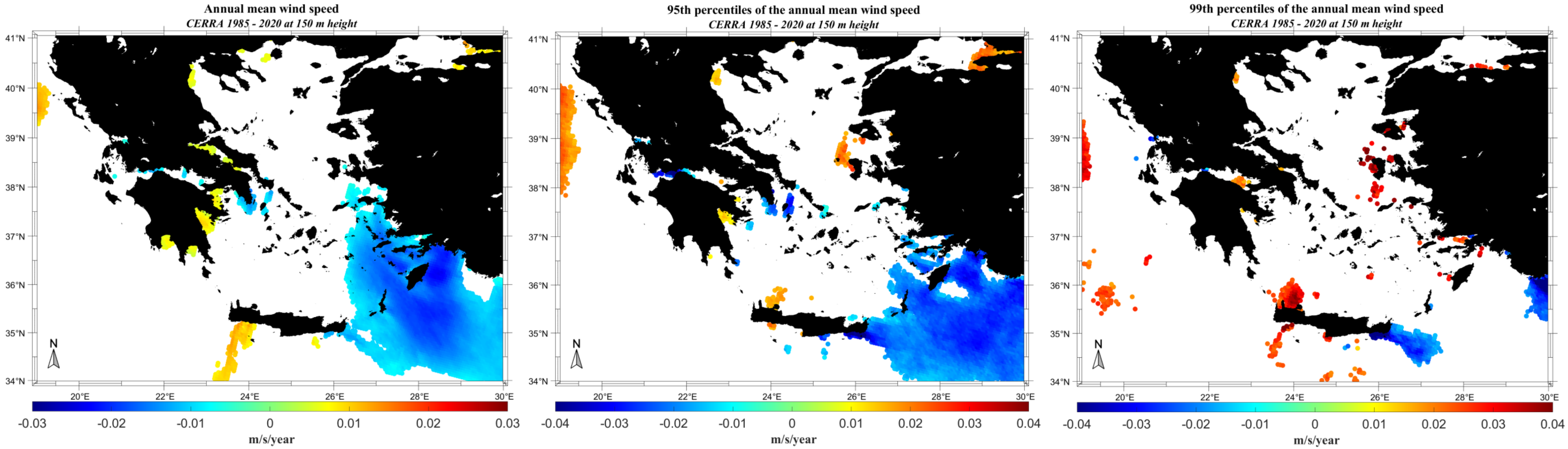

Figure 5. Statistically significant Theil-Sen slopes of the annual mean wind speed (1st panel), and of 95th (2nd panel), and 99th percentile points (3rd panel) of the annual mean wind speed at 150 m above sea level

Numerical results – wind speed assessment

n – years return levels (design values)

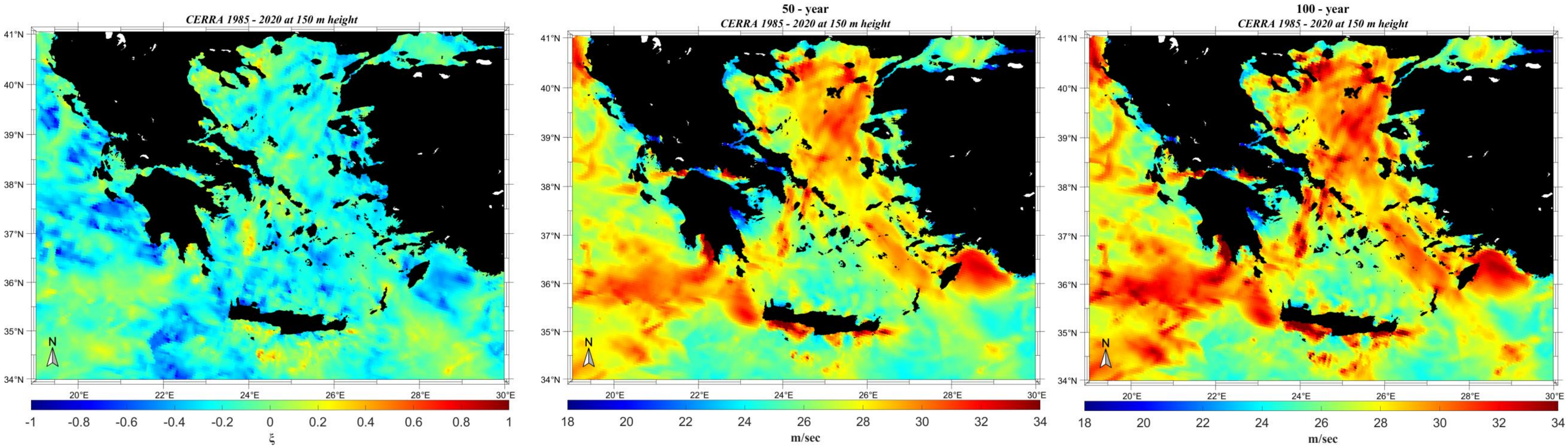

Figure 7. The spatial distribution of the shape parameter ξ for wind speed (1st panel), of the 50 (2nd panel) and 100-years (3rd panel) return levels of wind speed at 150 m above sea level