ESTIMATION OF THE WIND POTENTIAL IN GREECE

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ABSTRACT

It is widely known that energy consumption since 1950 has considerably increased. Given the decrease in oil deposits worldwide, the exploitation of alternative energy sources has been thoroughly considered. An important issue is the consideration of renewable energy sources, consistent with the policy model of green development.

In the present work, a wind atlas (spatial distribution of wind velocities and directions) is created by the application of GIS technology, using 59 reference points at the Hellenic mainland and islands for the time period 1999-2000. Wind data from 48 meteorological stations of the Hellenic Center of Renewable Energy Sources (CRES) and 11 meteorological stations of the Hellenic National Meteorological Service, were analyzed.

The findings of this work showed that, the prevailing wind on seasonal basis over the Hellenic territory was of north and north-east directions at 58-78% of the measuring stations. The wind speed increases from north to south, with local maxima at South Aegean Sea, and diminishes again by reaching the north Cretan coast. The largest possible wind potential occurs at central Aegean Sea, while the wind potential increases at the south and east Hellenic coasts.

1. INTRODUCTION

In the past few years, subjects related to the production and management of energy as well as its correlation with the modern environmental issues, such as the imminent exhaustion of conventional energy resources, are of great scientific interest. Consequently, nowadays, there is an intense need of objective, organized and also scientifically certified data and information about the environmental friendly energy investments, such as the Renewable Energy Sources (RES). Wind energy is a renewable - inexhaustible source of energy, as the sun will always cause temperature changes between the various regions of earth resulted in the formation of winds, but also clean, “friendly” to the environment as the transformation in electric power does not overload the environment.

Greece is one of the windiest areas of Europe. This is due to the centres of atmospheric activity, that is to say dynamic factors that shape the weather of the Hellenic region, in combination with the geographic position of the country and its complicated horizontal and vertical dismemberment. The main factors that configure the wind tracks are mainly the seasonal prevailing barometric systems (anticyclones, depressions) (Nastos et al., 2002), and the local winds. Many of these systems coexist or interchange and combined with the complex bedrock of mainland, create various systems of winds with rapid changes of direction and strength in the cold period of the year (Karapiperis, 1968). Regarding the frequency of air masses, the polar air masses dominate over the wider Greek area (Maheras, 1983; Papagianakis, 1973).

Regions with important wind speed are detected after map study and collection of historic meteorological data. Thus, maps of wind potential are created, in order to provide information for the estimation of wind potential on various regions. In 1989, for better
comprehension of the possibility of wind energy development in Europe, the Institute Riso of Denmark created the European Atlas of Wind Potential (Figure 1), which features the possibilities of development of each region.

According to extensive wind potential studies (Centre for Renewable Energy Sources, 2002; Kaldellis and Kavadias, 2000), Greece possesses one of the best wind potential in Europe, since the local average wind speeds (at hub height) may overpass the 8–11 m/s, especially in the Aegean Archipelago and the mainland coasts. At the same time, the electricity production cost for the majority of the remote Greek islands is extremely high, approaching the value of 0.25 Euro/kWh, while the fuel cost is responsible for almost 50% of the abovementioned value (Kaldellis et al., 2001). The wind potential of Greece was firstly assessed from the Aerodynamic Laboratory of NTUA, wherein the annual wind potential map was created (Bergeles, 1980).

![Figure 1. European Wind Atlas (adopted by Riso National Laboratory, Roskilde, Denmark).](image)

**2. DATA ANALYSIS**

The objective of this paper is the exploitation of development of wind energy in Greece, along with the study and investigation of the spatial distribution of wind speed and wind direction via a Geographical Information System (GIS). The research that is attempted includes the analysis of wind data from 59 meteorological stations in Greece, aiming to the creation of wind maps, by the application of Kriging method.

Wind data from 48 meteorological stations of the Hellenic Center of Renewable Energy Sources (CRES) and from 11 meteorological stations of the Hellenic National Meteorological Service (HNMS) were used. Wind data from the meteorological stations of the Hellenic CRES refer to wind speed of 48 stations and wind direction of 45 stations, whereas those of the HNMS refer only to wind speed.
The meteorological stations were digitized according to their coordinates over the digitized bedrock of Greek districts and Greek coastline (biogeo.berkeley.edu). The projection system used is the World Geodetic System 1984 (WGS '84).

Figure 2. Geographical distribution of the meteorological stations used in the analysis.

Taking into consideration the aforementioned information, a data base was created. This data base and the file of the digitized bedrock of the meteorological stations were processed with ArcGIS 9.2, using the Kriging method (Nastos, 1993).

3. RESULTS AND DISCUSSION

Kriging technique was applied in order to build the spatial distribution of wind speed and wind direction over Greek area. Five different maps of wind speed distribution and wind direction were made.

Figure 3. Annual map of wind speed distribution and wind direction.
As it is depicted in Figure 3, higher wind speeds predominate in marine regions than in mainland, with mean annual speeds between 1-5.5 m/sec while maxima appear in central Aegean Sea from north-west to south-east direction. Ionian Sea presents a different wind pattern, with low speeds in the north regions (1-2 m/sec), which specifically reach 3-4 m/sec in the south coasts of Peloponnesus. North and central continental Greece appears lower mean annual speeds (1.5-2.5 m/sec), which slightly build up in the south mainland and especially in the region of Peloponnesus, reaching 3.5-4 m/sec.

Figure 4. Map of wind speed distribution and wind direction during winter.

The dominant winds over Greece during the year is of north, north-east and north-west directions at 78% of the stations, whereas at the rest stations the observed winds are of different directions, due to the relief of the region or the existence of local winds.

Figure 5. Map of wind speed distribution and wind direction during spring.
Figure 4, presents the spatial distribution of wind speed during winter, which is considered to be the windiest season of the year. The mean wind speed varies between 1-6 m/sec, with maxima (5.5-6 m/sec) appearing in central Aegean Sea. Wind speeds of 5-5.5 m/sec are observed in south Aegean, between eastern Cyclades islands, Ikaria and northern Dodecanese islands. The fact that the region of Dodecanese is not so windy during winter is due to the number of the calms (Katsoulis, 1970). A decrease in wind speed is shown in the north Aegean Sea. In the west and east of the central Aegean Sea, the mean speeds are decreasing and are lower in the east regions of the Hellenic peninsula than. Ionian Sea depicts very low mean wind speeds, with minima (1-2 m/sec) appearing in the north regions, while increased wind speeds (3.5-5 m/sec) appear in the south coasts of Peloponnesus.

Figure 6. Map of wind speed distribution and wind direction during summer.

Figure 7. Map of wind speed distribution and wind direction during autumn.
The dominant wind over the Hellenic territory during winter is of north, north-east and north-west directions at 69% of the measuring stations, with small deviations for the 31% of the stations, because of the region relief (Mytilene, Kavala).

The wind speed distribution during spring is shown in Figure 5. The mean wind speed varies between 1-5.5 m/sec. Spring is considered to be the less windy season of the year due to the calms (Katsoulis, 1970). Maxima (5-5.5 m/sec) are observed in central Aegean Sea (Naxos isle). In south Aegean Sea the values are significantly decreased up to the region of Crete (2.5-3.5 m/sec). On the contrary, the arc of eastern Sporades, south Evia, Kithira, Methoni and Dodecanese displays low values (3.5 to 4 m/sec). In north central regions and Ionian Sea, wind speeds are low and increase southwards and eastwards. The wind direction pattern seems to be partly different of the winter, but the prevailing directions are north, north-east and north-west at 62% of the measuring stations.

The Figure 6 shows the spatial distribution of wind speed during summer, which appears different pattern from the other seasons. The mean wind speed varies between 0.5-6 m/sec, with maxima (5.5-6 m/sec) appearing in eastern and south-eastern Aegean Sea, especially in Dodecanese isles. Generally, Aegean Sea presents high wind speeds, which increase from north-west to south-east and decrease northwards and near the mainland. Because of the Etesian wind system, which dominates in the open sea with very high values, the highest Etesian winds occur when the thermal minimum of India extends and reaches the region of Dodecanese and the Asia Minor coasts. In this way, wind speeds are decreasing in northern Aegean Sea and in the eastern coasts of mainland, in contrast to the western coasts of Asia Minor. During summer, Aegean Sea is a really windy area, due to the minimum number of calms. Almost in all the islands of Aegean Sea, the formation of sea breeze is not favored (because of the small extent of their land) and in this way the Etesian flow is not blocked, even if the sea breeze has a totally different direction (Katsoulis, 1970). The prevailing wind over the Hellenic territory during summer is of north, northeast and north-west directions at 76% of the measuring stations, whereas at the rest of the stations winds of different directions are observed due to the fact that the Etesian winds blow in various directions. Winds of south direction are not observed because of the absolute absence of depressions (Nastos et al., 2002).

Finally, as it is shown in Figure 7, the mean wind speeds during autumn vary between 1-5 m/sec with maxima (4.5-5 m/sec) appearing in central Aegean Sea. The region of Dodecanese isles is not very windy during autumn; a fact that occurs, because of the number of calms with is highly increased (Katsoulis, 1970). In northern Aegean Sea, decreasing wind speed values, reaches the coasts of Thrace and Western Macedonia. Receding from the central Aegean Sea to westerlies and easterlies, the mean speeds are decreasing towards the east coasts of Hellenic mainland (2-3 m/sec) while they are slightly increasing in the west coasts of Asia Minor (3.5-4 m/sec). Ionian Sea presents very low wind speeds than the Aegean. In north Ionian Sea, low wind speeds appear (1-2 m/sec), which slightly increase towards the south coasts of Peloponnese (3.5-4 m/sec) (Methoni, Kithira). The general significant increase of wind speed values against summer comes from the increasing cyclonic and anticyclonic activity. During this season, the prevailing winds are of north, north-east and north-west directions at 78% of the measuring stations, whereas at the rest of the stations, winds of different directions are observed, due to the relief of the region or the existence of local winds.

Wind power in Greece is about to expand by 352% by 2010 to meet the European target of 20% coverage of energy needs from renewable sources. Currently
there are 1,028 wind turbines installed throughout Greece and the number is set to reach 2,587 wind turbines before the end of 2010.

**Conclusions**
The analysis performed, gave evidence that Greece is one of the windiest areas of Europe and that wind power stations can fulfill the energy requirements for almost all islands of the Aegean Sea. This conclusion is derived by the findings of the present study, which revealed that the mean wind speed is stronger in the open Aegean Sea and flat country. The wind speed increases from north to south, with local maxima at South Aegean Sea, and diminishes again by reaching the North Cretan Coast. The largest possible wind potential occurs at Central Aegean Sea.

**References**
http://www.biogeo.berkeley.edu