Wind energy potential in Greece using a small wind turbine

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Abstract: The aim of this study is to outline the wind speed distribution in Greece and examine the potential of using this resource for generation of wind power in the country. Long-term wind speed data from 69 stations are analyzed in order to calculate the energy output for a small 2.5 kW installed wind turbine at each site in Greece. The Homer software was used to predict the energy production, the cost of energy and the green house gas emissions reductions.

Key-words: - Renewable energy, Homer software, Wind power, Cost Of Energy, GHG Emissions

1. Introduction

Energy has played a vital role in the development of human being since the industrial revolution of the 18th century. The significance of energy in economic development has been recognized almost universally and energy consumption is an index of prosperity and standard of living of people in a country. Basic life requirements such as water and food are also obtained and transported by the energy. Hence, supplying high quality and uninterruptible energy with the lowest costs is an essential requirement. Due to climate effects, air quality issues, rapid depletion of fossil fuel resources and increasing of fuel prices national decision makers increasingly emphasize deployment of less carbon-intensive and more sustainable electricity sources [1-2].

The idea of using wind to produce work is not a new concept. Wind power was used, inter alia, by windmills and sailing ships, for water pumping and irrigation and for grinding grain [3]. Wind energy is clean, inexhaustible, environmentally friendly, and sustainable source of energy. Technology of the extraction of power from wind with modern turbines is a well established industry, at present. According to Resch et al. the global theoretical potential of wind energy was estimated at 6000 EJ however the technical potential of wind energy is 600 EJ [4]. The installed capacity in wind energy increased approximately 67 times in the last 18 years (from 2900 MW in 1996 to 194527 MW in 2010) [3, 5].

The main objective of the present work was to investigate the wind energy resources and the potential for wind energy generation for each of the 69 considered sites in Greece. This paper utilizes average monthly wind speed data of 69 locations in Greece. The annual energy production, the economic analysis and the environmental considerations calculated using Homer software. HOMER (Hybrid Optimization Model for Electric Renewables) is a modelling tool that facilitates design of electric power systems [6-7]. The assessment criterion of the analysis is the electricity production. The project takes for granted a small-micro wind turbine of 2.5 kW, at each of the 69 locations to calculate the electricity production, the Cost Of Energy (COE), the Capacity Factor (CF) and potential emission reduction due to the wind turbine.

2. Global trends of wind energy

Wind energy technology has developed very fast during the last 20 years and wind is rapidly becoming a practical source of energy for electric utilities around the world (Figure 1). The recently data of wind energy development on various continents indicate that the growth rates is high not only in the European Union and in the USA but also on developing countries. In 2010 China installed almost half the global market (16.5 GW) and is the new leader of wind power in the world (Table 1) [5]. According to the forecasts of the Global Wind Energy Council [8] wind energy will supply approximately the 16% of the worldwide electricity demand.

![Figure 1. Global installed wind power capacity](image)

Table 1 Wind power capacity installed world wide (in MW) in the last 5 years.
Europe has the highest total installed capacity mainly in the countries of the European Union (Table 1). The European Union has set a binding target of a 20% renewable energy contribution by 2020 [9]. Around 180 GW of onshore and offshore wind power could be installed in the European Union (estimates from the European Commission [10] and the European Wind Energy Association [11]); meaning between 10 and 15% of the total EU electricity demand. Leader of wind power in Europe is Germany followed by Spain, Italy, France and the UK (Figure 2). However, if population numbers are considered Denmark is the pioneer in front of Spain, Portugal and Germany, France and the UK are low in the country rankings (Figure 3).

Greece from 1995 to 2010 is shown in Fig. 4. In terms of installed capacity Greece is in the 11th position while, if population numbers are considered is in the 10th position. Despite the financial crisis, 121 MW of wind power installed in Greece in 2010 [5].

Figure 4. Wind energy in Greece from 1995 to 2010.

3. Wind resource

In order to calculate the power output from a wind turbine it is necessary to collect accurate meteorological data about the wind data in a targeted location. In this study the CRES [12] and the TECG [13] are the source for these data. CRES (Centre for Renewable Energy Sources and Saving) is the Greek national entity for the promotion of renewable energy sources, rational use of energy and energy conservation. TCG (Technical Chamber of Greece) is a public legal entity, with elected administration. It aims at developing Science and Technology in sectors related to the disciplines of its members, for the economic, social, and cultural development of the country, in accordance with the principles of sustainability and environmental protection.

In the present work 69 representative locations covering all areas of Greece have been identified for wind potential resource assessment. The average monthly and yearly wind speeds at these locations are given in Table 2. The geography in terms of latitude and longitude are also presented in the same table. In the present study, wind turbine of 2.5 kW from Wind Energy Solution is used. The wind power curve of the WES 5 Tulipo wind machine is shown in Fig. 5. WES 5 Tulipo, has 5 m rotor diameter and 10 m of tower [14].

Table 2. Long-term mean values of wind speed for 69 locations in Greece.

<table>
<thead>
<tr>
<th>N.</th>
<th>City</th>
<th>Latitude N</th>
<th>Longitude E</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Agchialos</td>
<td>39° 13’</td>
<td>22° 48’</td>
<td>2.650</td>
</tr>
<tr>
<td>2</td>
<td>Agridia</td>
<td>39° 30’</td>
<td>23° 00’</td>
<td>4.389</td>
</tr>
<tr>
<td>3</td>
<td>Agros</td>
<td>38° 37’</td>
<td>21° 23’</td>
<td>1.917</td>
</tr>
<tr>
<td>4</td>
<td>Alexandroupolis</td>
<td>40° 51’</td>
<td>25° 56’</td>
<td>3.642</td>
</tr>
<tr>
<td>5</td>
<td>Aliartos</td>
<td>30° 23’</td>
<td>23° 06’</td>
<td>4.564</td>
</tr>
<tr>
<td>6</td>
<td>Andravida</td>
<td>37° 55’</td>
<td>21° 17’</td>
<td>2.533</td>
</tr>
<tr>
<td>7</td>
<td>Araxos</td>
<td>38° 09’</td>
<td>21° 25’</td>
<td>2.683</td>
</tr>
<tr>
<td>8</td>
<td>Argos/Pirgela</td>
<td>37° 36’</td>
<td>22° 47’</td>
<td>3.963</td>
</tr>
<tr>
<td>9</td>
<td>Argostoli</td>
<td>38° 11’</td>
<td>20° 29’</td>
<td>3.292</td>
</tr>
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</table>
In order to characterize the wind regimes HOMER uses the two-parameter Weibull distribution. The probability density function is given by the equation:

\[ f(v) = \frac{k}{c} \left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^k} \quad (1) \]

where: \( v \) is the wind speed (m/s), \( k \) is the Weibull shape factor (unitless) and \( c \) is the Weibull scale parameter (m/s). The cumulative distribution function is given by the following equation:

\[ F(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^k\right] \quad (2) \]

The following equation relates the two Weibull parameters and the average wind speed:

\[ \overline{v} = c \Gamma\left(1 + \frac{1}{k}\right) \quad (3) \]

where: \( \Gamma \) is the gamma function.

Finally, HOMER calculates the yearly energy production (YEP) using the following equation:

\[ YEP(v_m) = \sum_{v=Vc}^{V_{max}} f(v) \times P(v) \times 8760 \quad (4) \]

where \( v_m \) is the average wind speed, \( V_{in} \) is the Cut-in speed of the wind turbine, \( V_{out} \) is the Cut-out speed of the wind turbine, \( P(v) \) is the turbine power at wind speed \( v \), \( f(v) \) is the Weibull probability function for wind speed \( v \), calculated for the average wind speed \( v_m \) [15].
4. Economic analysis of hybrid energy systems

HOMER defines the levelized COE as the average cost/kWh of useful electrical energy produced by the system. In order to calculate the COE, HOMER divides the annualized cost of producing electricity by the total useful electric energy production. The equation for the COE is as follows:

$$COE = \frac{C_{ann,tot}}{E_{prim,AC} + E_{prim,DC} + E_{grid,sales}}$$  \hspace{1cm} (5)$$

where $C_{ann,tot}$ is the total annualized cost (€/yr), $E_{prim,AC}$ is AC primary load served (kWh/year), $E_{prim,DC}$ is DC primary load served (kWh/year), $E_{grid,sales}$ is total grid sales (kWh/year). The initial capital cost, replacement cost, maintenance cost and lifetime of wind turbine is given in Table 3 [16]. The project life time has been considered to be 15 yr and the annual real interest rate has been taken as 5%.
The long-term seasonal variation of wind speed at 69 locations is examined in Table 2. As it can be seen from the Table 2, wind speeds are generally higher during the months November to March as compared to other months. This indicates that a wind generator produces more energy during winter. Notably, the data also shows that there is a considerable variation of the monthly average wind speed during summer. According to the data the Aegean Archipelago islands, especially Cyclades and Dodecanese, which are island complexes belonging in the South Aegean Prefecture and located in the south-eastern region of Greece and the European Union possesses excellent wind potential. Is very interesting the fact that in most of these islands the electricity production cost is extremely high (e.g. 0.5 €/kWh) [17].

The electricity from the wind turbine, the number of hours of the year during which the wind turbine output was greater than zero, and the CF for the 69 locations are given in Fig. 6, Fig. 7 and Fig. 8 respectively. According to the results Crete, Cyclades and Dodecanese prefectures are the more attractive areas. The lowest energy and CFs values are obtained in the North and Central Greece (Thrace, Macedonia, Thessalia and Epirus).

The COE is an important parameter in every power system. As depicted in Fig. 9, the results show that the Aegean Archipelago islands (Crete, Cyclades and Dodecanese) have the lowest production cost of about 0.06 €/kWh while the areas in the North Greece have the higher cost (Kastoria 3.237 €/kWh). For the comparison the electricity price for the domestic users in all Greece is approximately 0.1 €/kWh [18]. From 69 investigated areas the 32 has COE lower than 0.1 €/kWh so in these areas the installation of small turbine is financially sound. Replacing energy generated by conventional methods with small wind turbines could provide further benefits to Greece in the form of reduced emissions of priority air pollutants and greenhouse gas (GHG) as the wind turbines has zero GHG emissions. The Homer is capable of estimating the amount of GHG which could be avoided as a result of usage of wind generators [19] [20]. Calculation of the annual reduction in GHG emissions-estimated to occur if the proposed WES 5 Tulipo wind turbine is implemented -was performed. The amount of GHG reduction for the 69 locations is presented in Fig. 10. Based on Fig. 10 the highest GHG emissions mitigation of 11.22 tons/year was observed at Skiros.

### Table 3 Costs in connection with the WES 5 Tulipo wind turbine.

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## 5. Results and discussion

Given the wind speed data at a certain site, the Homer calculates the net energy output of the wind turbine. The long-term seasonal variation of wind speed at 69 locations is examined in Table 2. As it can be seen from the Table 2, wind speeds are generally higher during the months November to March as compared to other months. This indicates that a wind generator produces more energy during winter. Notably, the data also shows that there is a considerable variation of the monthly average wind speed during summer. According to the data the Aegean Archipelago islands, especially Cyclades and Dodecanese, which are island complexes belonging in the South Aegean Prefecture and located in the south-eastern region of Greece and the European Union possesses excellent wind potential. Is very interesting the fact that in most of these islands the electricity production cost is extremely high (e.g. 0.5 €/kWh) [17].

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## 6. Conclusion

Greece has high energy production potential for wind turbine power plants. This paper presented an extended study for placement a small 2.5 kW wind turbine in Greece. The long-term meteorological parameters for each of the 69 considered sites in Greece from CRES and TEE-TCG are analyzed and the results corroborate that Greece has a high content of wind power potential all over the year.
The trend shows that wind speeds are relatively low in the north Greece and increases to relatively high speeds in the south.

The results of energy production analysis show that the Agean Archipelago Islands have the maximum values of renewable energy production and CF. Based on economical indicators, although the small wind turbines are not that competitive as the bigger generators, 32 areas have COE lower than the electricity price for the domestic users. From environmental point of view, it was calculated the quantity of green house gases can be avoided entering into the local atmosphere each year.

References: