# THE COMPLEMENTARITY OF WIND AND SOLAR ENERGY IN KARABRUN, VLORA, ALBANIA

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**Abstract**: In Albania, only hydropower has a major role in meeting the electricity load. Due to recent economic development and the growth of year-round tourism in the region Vlora, Albania, there has been a surge in the electricity demand. Renewable energy, such as wind and solar sources appears to be a good solution to support the electrical system. Also, it is well known that wind and solar sources are cost-competitive and environment-friendly compared to other sources used to produce electricity. Renewable energies can be used combined to generate electricity. The advantages in this case have been related to decreased electricity storage and increased production´s electric load. Many studies have observed the variable nature of renewable sources and how they can complement each other making the total electricity production more sustainable than each source independently. Complementarity of renewable sources specifically solar and wind can be determined through statistical methods. The correlation as the measurement between two randomly distributed variables helps us estimate how linearly they are related.

This study evaluates the complementarity between renewable energy sources, solar and wind based on the correlation coefficients calculated according to Pearson and Spearmen in the peninsula of Karabrun, the largest peninsula of Albania, located near the city of Vlora, southwestern Albania, where the Adriatic Sea meets the Ionian Sea. Pearson's product-moment coefficient (r) is the simple correlation coefficient. This metric quantifies the association strength between two bivariate variables. Spearman's rank correlation coefficient (ρS) known as Spearman's Rho, its simple definition can be stated as the Pearson correlation utilizes the ranks instead of the real values, allowing us to assess the relationship between variables even if this is non-linear. Through the analysis of monthly average wind speed and solar radiation data, a prediction of electricity production for each month of a calendar year was made. The forecast electricity from wind sources is based on the operation of the wind turbine rated as the most efficient for this area. The solar radiation data provided by the Global Solar Atlas served to select the adequate photovoltaic system. The interpretation of the results was done through the statistical program from IBM SPSS statistics. The analysis shows that both energy sources have a high negative value in complementarity. Correlation values represent that if one of the sources has low generation potential, the other complements the electric energy. It is going to increase the overall reliability of the system.

**Keywords:** complementary; wind energy; solar energy; correlation coefficient, IBM SPSS statistics software.

## 1. INTRODUCTION

The increased electricity load in recent years is linked to the development of a country's economy, especially in industry and tourism. In Albania, the primary manner of producing power is using conventional water sources. Utilizing renewable energy to sustain the electrical grid has gained significant attention recently. However, although a lot of solar energy-related initiatives have been put into action, wind energy consumption isn't moving forward very quickly.

The main issue with renewable energy sources is their sporadic nature. An interruption denotes a load that is unpredictable and variable or an unavailable source (Elaine K. Hart, 2012). To ensure a continuous supply of electricity, renewable sources such as wind and sun, it is good to operate in the hybrid mode because they will increase the system's reliability, avoid using plants based on combustible material, and reduce the energy requirement stored. Therefore, studies on the variable nature of renewable energy sources are needed to be carried out.

This paper examines the complementarity between solar and wind-predicted electricity during a calendar year (2021) in Karaburun peninsula, Vlorë, Albania. This has required the conversion of the meteorological data (https://globalsolaratlas, n.d.), (https://power.larc.nasa.gov/data-access-viewer/ , n.d.), for a calendar year into electric power. A Pearson and Spearman correlation analysis is the tool used to examine the temporal complementarity of these two sources (Muñoz-Pincheira JL, april 2024).

The concept of complementarity is: "a relationship or situation in which two or more different things improve or emphasize each other's qualities" (J. Jurasz, 2020). Referring to energy sources complementarity should then be understood as the ability to work in a complementary way. Numerous studies have examined the complementary nature of various intermittent renewable energy sources and how combining two or more of these sources produces a smoother total power production than if each source were used alone (Widen. J, April 2015), (da Luz, 2023). Metrics and indices can be used to measure the complementarity between alternative renewable energy sources in location and time. Correlation coefficients are the most widely utilized metrics in research on energy complementarity. The methodology and input data are presented in Section 2. In Section 3,4 the results are presented and discussed. Finally, Section 5 summarizes the paper and highlights its main conclusions.

## 2. DATA AND METHODOLOGY

Climate data recorded at a height of 50 meters, were used to calculate the monthly average wind speed for the selected region from January to December 2021. A wind turbine's capacity to produce electricity is determined by its air density, normally about 1.2 kg/m3, wind speed, and the swept area of its turbine blades, (Hassan, 2020).

$$P_w = \frac{1}{2}\rho.A.V^3$$

Where: Pw = Power (Watts), ρ (rho, a Greek letter) = density of the air in kg/m3, A = cross-sectional area of the wind in m2, v = velocity of the wind in m/s

When choosing an appropriate wind turbine, the Weibull distribution and capacity factor (CF), are important parameters to be evaluated. (Darwish, January 2019,), (Npower, n.d.)

Based on the study done for the Karaburun Penisola, (Serdari, 2017), two parameters of the Weibull distribution calculated using the Maximum Likelihood Method varied between $1.56 \leq k \leq 1.77$ and $6.26 \leq c \leq 7.84$ m/s. The maximum capacity factor the turbine can achieve was between 21.71 and 33.44%. The most suitable wind turbine was the E48. The average wind power output ranged between 218.33 and 668.95 kW. The turbine has a diameter of 48 m, a height of 50 m, and an output power of 600 kW (Mitrushi, 2020)

Global Solar Atlas (GSA) offers access to data (Bień, 2024)needed for the preliminary assessment of solar energy projects. Referring to Solar radiation and solar hours for Vlora for each month of the calendar year was selected PV system with a configuration; ground-mounted large scale, Azimuth of PV panels 180º, Tilt of PV panels 34º (https://globalsolaratlas, n.d.)

To examine the correlation between solar and wind power at Karaburun Peninsula for every month of the year, the following equations are used:

Pearson's correlation coefficient. Correlation analysis attempts to measure the strength of such relationships between two variables utilizing a single number called a correlation coefficient (I. Walpole, 2012), (Gallardo, 2020).

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

where n is the sample size, $xi$, and $yi$ are the individual sample points of each variable, $\bar{x}$ and $\bar{y}$ are the sample means for each variable. Pearson correlation coefficient is the simplest and most used method to detect linear relationships between two data sets and indicates the strength of the dependence by its magnitude. If r=1 the two data sets correlate perfectly, if r= -1 there is a perfect anti-correlation, and when r=0 there is no linear relationship. Hypothesis tests are used to test the null hypothesis of no correlation.

a. Spearman's rank correlation coefficient, (Spearman's rho – $\rho_s$ (x, y)) which can be described as simply the Pearson correlation applied to ranks.

$$\rho_s = \frac{covariance\ (rank\ x, rank\ y)}{\sigma_{rank\ x}.\sigma_{rank\ y}}$$

The electrical values predicted by the photovoltaic system, source_1, and those calculated for the average monthly wind speed, source_2 were used to determine the correlation using IBM SPSS Statistics software.

**3. RESULTS**

The estimated mean monthly wind speeds and the E48 wind turbine's corresponding power output are explained in Table 1.

***Table 1: Estimated mean monthly wind speed and E48 wind turbine's corresponding power output.***

| **Month** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **wind speed (m/s)** | 7 | 5.3 | 4.6 | 4.6 | 4.48 | 3.3 | 3.4 | 3.48 | 3.36 | 3.8 | 6.1 | 5.9 |
| **Power output (kW)** | 281 | 164 | 105. | 107. | 99.7 | 38.6 | 44.8 | 46.8 | 42.2 | 66.3 | 252 | 226 |

**Source:** The authors

Meanwhile, the PV system with a selected configuration can produce electric energy presented in Table 2.

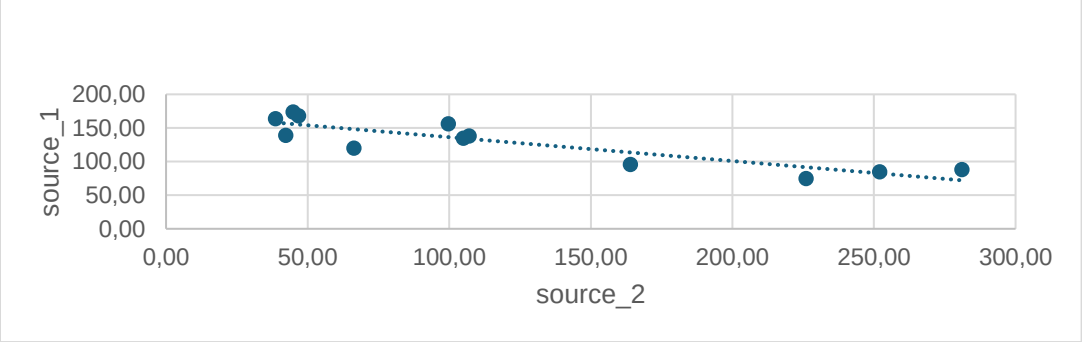
***Table 2: Mean monthly solar energy values predicted throughout the year.***

| **Month** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Power output (kWp)** | 88 | 96 | 135 | 138 | 156 | 164 | 174 | 168 | 139 | 120 | 85 | 75 |

**Source:** The authors

The graph shows the correlation between two sources, solar and wind energy based on the mean value of electricity forecasted to be produced by them in the Karabrun peninsula, using IBM SPSS Statistics software

***Fig 1: Correlation between source _1 and source_2***




**Source:** The authors, IBM SPSS Statistics software (Version 29)

***Fig 2: Pearson Correlation***

**Correlations**

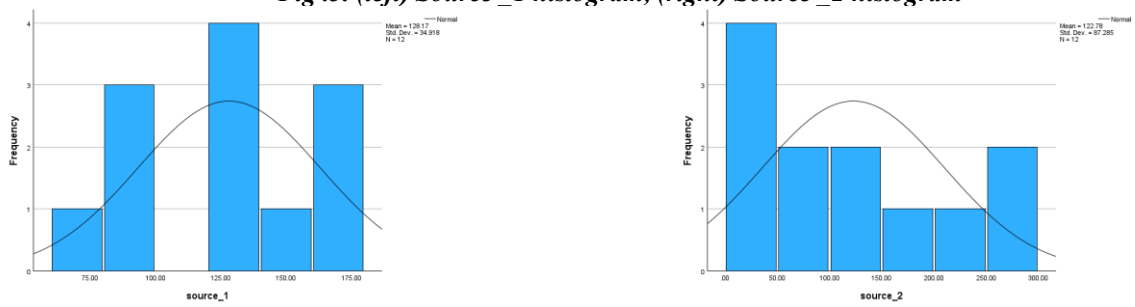
| | | source_1 | source_2 |
|---|---|---|---|
| source_1 | Pearson Correlation | 1 | -.886** |
| | Sig. (2-tailed) | | <.001 |
| | N | 12 | 12 |
| source_2 | Pearson Correlation | -.886** | 1 |
| | Sig. (2-tailed) | <.001 | |
| | N | 12 | 12 |

**Source:** The authors, IBM SPSS Statistics software (Version 29)

As in Fig. 2 the *p*-value is <0.01 which means that there is less than a 5% level we reject the null hypothesis, so there is a significant relation between source_ 1 (solar source) and source_2(wind source). Moreover, the Pearson Correlation is -0.886, suggesting a strong negative relationship between electric power produced by renewable energy sources

The histogram displays that, the data deviate from the normal distribution, which means that the number of measurements does not ensure that the correlation according to Pearson is sufficient to conclude the study of complementarity.

***Fig .3. (left) Source _1 histogram, (right) Source _2 histogram***




**Source:** The authors, IBM SPSS Statistics software (Version 29)

The remedy to this situation is the use of Spearman's correlation coefficient because it is a non-parametric estimator of the intensity of the relationship, perhaps non-linear, of two variables:

***Fig.4. Spearman's rho Correlation.***

**Correlations**

| | | | source_1 | source_2 |
|---|---|---|---|---|
| Spearman's rho | source_1 | Correlation Coefficient | 1.000 | -.839** |
| | | Sig. (2-tailed) | . | <.001 |
| | | N | 12 | 12 |
| | source_2 | Correlation Coefficient | -.839** | 1.000 |
| | | Sig. (2-tailed) | <.001 | . |
| | | N | 12 | 12 |

**Source:** The authors, IBM SPSS Statistics software (Version 29)

During the measuring, it is noted a high value of rank correlation coefficient, rho (-0.839), and *p*-value less than 5%. The negative correlation coefficient shows about the same parameter in both methods. So, the complementarity between solar and wind energy in the Karaburun peninsula, Vlora, Albania has high value.

## 4. DISCUSSIONS

In the carried-out analysis, the electricity estimates are based on photovoltaic systems that are deemed suitable for the chosen site, and the established values match the sun hours without accounting for elements that could lower the system's efficiency. Additionally, the wind turbine has been selected as the most appropriate option based on a study that was conducted, without considering the variables that could influence the energy output in this instance. The annual energy production, and, thus, the complementarity values are not realistically specified in this study and are simply forecasted. We haven't included any energy storage to balance energy flow by both sources.

## 5. CONCLUSIONS

The present study aimed to forecast how much electricity the Karaburuni Peninsula in Vlora, Albania, could produce from solar and wind power. These monthly data from a calendar year were used to assess how well the two renewable energy sources complement one another.

Using IBM SPSS software, correlation analysis was done to establish complementarity. When Pearson's correlation coefficient was applied as the initial technique, the result was a negative value, r (-0.886), indicating a strong

negative complementarity between the amount of electricity produced by renewable sources, solar, and wind. Since the histogram did not follow a normal distribution, Spearman's correlation coefficient was utilized as a backup approach. The result of the correlation coefficient was rho (-0.839).

For the largest peninsula in Albania, Karaburuni, both approaches provide a high value of the complementing characteristic of the two sources, the sun and the wind.

A future study should also include energy storage to balance energy flow by both sources.

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