INDEX OF COMPLEMENTARITY BETWEEN WIND AND SOLAR ENERGY IN VLORA, ALBANIA

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Abstract

The study aims to determine the complementarity index for renewable energy in Vlora, Albania. The city's electricity supply is primarily based on hydroelectric energy. With the increasing load demand in recent years, there is a growing need to exploit renewable energy sources, driven by Albania's favorable geographic location. Analyzing wind and solar energy data at different temporal and spatial scales is essential for optimizing electricity production from these sources. The complementarity between these two energy sources can reduce the need for energy storage in hybrid systems. Identifying the best complementarity ensures continuous energy supply while preventing overproduction. By examining the monthly average wind speed and solar radiation data, we can predict the monthly electricity production using a photovoltaic system and turbine suitable for the area. Based on the forecast graphs for solar and wind energy production, we determine the complementarity index in time, energy, and amplitude. The results show a moderate level of synchronization in their production over time, although they do not always fully complement each other.

***Keywords**: complementarity index; wind energy; solar energy; renewable energy; hybrid system.*

Përmbledhje

Studimi ka për qëllim përcaktimin e indeksit të komplementaritetit për energjinë e rinovueshme në Vlorë, Shqipëri. Furnizimi me energji elektrike në këtë qytet bazohet kryesisht tek energjia hidrike. Me rritjen e kërkesës nga ana e konsumatorit vitet e fundit po del si nevojë shfrytëzimi i energjive të rinovueshme, nisur edhe nga pozicioni gjeografik i favorshëm që ka Shqipëria.

Analizimi i të dhënave të energjisë së erës dhe diellit në shkallë të ndryshme kohore dhe hapësinore është thelbësore për optimizimin e prodhimit të energjisë elektrike prej tyre. Komplementariteti midis këtyre dy burimeve mund të zvogëlojë nevojën për ruajtjen e energjisë në sistemet hibride. Identifikimi i komplementaritetit më të mirë siguron furnizim të vazhdueshëm me energji duke parandaluar mbiprodhimin. Duke ekzaminuar shpejtësinë mesatare mujore të erës dhe të dhënat e rrezatimit diellor, ne mund të parashikojmë prodhimin mujor të energjisë elektrike duke përdorur një sistem fotovoltaik dhe turbinë të përshtatshme për zonën. Bazuar në grafikët e parashikimit të prodhimit të energjisë diellore dhe të erës, përcaktojmë indeksin e komplementaritetit në kohë, energji dhe amplitudë. Produkti i rezultateve të marra është indeksi i komplementaritetit i cili tregon një nivel të moderuar të sinkronizimit në prodhimin e tyre me kalimin e kohës, megjithëse jo gjithmonë ato plotësojnë njëra-tjetrën.

***Fjalë kyçe**: Indeksi i komplementaritetit;energjia e erës; energjia e diellit; energji e rinovueshme; sistem hibrid.*

Introduction

In this study, Vlora was selected as the site to assess the complementarity between solar and wind energy sources over time using the complementarity index proposed by Beluco. (Beluco.et.al, 2019)

Vlora receives electricity primarily from the country's main hydroelectric power plant via the transmission network, while the city's 96 MW combined-cycle power plant remains inactive. In recent years, the population in this region has grown significantly, mainly due to tourism, which has led to a sharp increase in energy consumption. This surge in demand has placed additional strain on the existing energy infrastructure, highlighting the need for alternative, renewable energy sources.

Solar and wind energy are promising solutions to meet the region's growing energy needs. Solar power peaks during daylight hours, while wind energy can complement it when the sun is not shining, providing a reliable and consistent energy supply. This combination would not only help address the rising demand but also enhance the region's energy security and sustainability, especially considering climate change and the increased pressure on traditional power sources.

Vlora benefits from high annual solar radiation, with a maximum value of 7.2 kWh/m² in July and a minimum of 1.8 kWh/m² in December. The city also enjoys over 2,700 sunny hours annually, AKBN; (Agjensia Kombetare e Burimeve Natyrore, n.d.). Additionally, the area's geographical location supports moderate to fast winds, making it well-suited for wind energy generation, (Ministria Infrastruktures dhe Energjitikes , n.d.)(MIE 2021).

Since both solar and wind energy are intermittent and have distinct production patterns, it is crucial to study their complementarity. The complementarity index proposed by Beluco (Beluco.et.al, 2008)) provides a way to assess how well these two renewable energy sources work together over time. This index measures the extent to which the energy production from one source can compensate for or enhance the production of the other, considering factors like timing, energy output, and amplitude. By evaluating the complementarity index, we can determine how effectively solar, and wind energy can be integrated into a system, ensuring a more reliable and continuous energy supply, even when one of the sources is unavailable or fluctuating. This helps to optimize the use of renewable energy, reduce reliance on backup systems, and improve the overall stability of the energy grid.

I. Methodology

Vlora is situated in southern Albania at geographical coordinates 40.47076° N, 19.491272° E. The electricity production forecast from renewable energy sources is based on data collected for wind speed and solar radiation throughout the calendar year 2021. The daily wind speed data at a height of 50 meters were obtained from DAV (Data Access Viewer), NASA POWER, while the solar radiation and solar hours for each month of the 2021 calendar year are based on data from the GSA (Global Solar Atlas).

Figure 1. Location of Vlora district on the map of Albania.

To determine the electricity that can be produced from wind energy, we refer to a study conducted in one of the areas with high wind potential in Vlora, specifically in Karaburun, at a height of 50 meters. The most efficient wind turbine, the E48, has a rotor diameter of 48 meters, a hub height of 50 meters, and an output power of 600 kW (Serdari & Berberi, July 2017). Referring to GSA, the photovoltaic system with a power capacity of 1000 kWp has been selected and the average electricity produced for each month was extracted.
To fully harness the potential of wind and solar energy, it is crucial to study their temporal complementarity in the selected area.

Time complementarity can exist when the energy availability of two or more sources has periods that align them in time in the same region (Bagatini, 2017). The method used in the article determines the Complementarity Index between solar and wind energy. It helps to understand how the two sources complement each other in terms of their availability. If one energy source is low, the other might be higher, helping to balance the overall energy production. This index was calculated by multiplying three component indices: time, energy, and amplitude complementarity.
The Time Complementarity Index, k_t, consists of determining the month with the lowest value of the energy produced by the first source and that of the second source according to :

$$k_t = \frac{|m_1 - m_2 \ + 12|}{6}$$

or

$$k_t = \frac{|m_1 - m_2|}{6}$$

m_1- month with the lowest value of the source energy ≠1

m_2- month with the lowest value of the source energy ≠2. This value is a number ranging from 1 to 12

The energy Complementarity Index, ke , evaluates the relationship between the average values of energy sources according to the given function.

$$k_e = 1 - \frac{|e_1 - e_2|}{e_1 + e_2}$$

e_1-average value for the first source;

e_2-average value for the second source

The Amplitude Complementarity Index, k_a, evaluates the difference in the maximal and minimal values of the energy sources and is calculated according to the following formula:

$$\begin{cases} 1-\left(\frac{\delta_1-\delta_2}{1-\delta_2}\right)^2 & if \quad \delta_1 \leq \delta_2 \\ \frac{(1-\delta_2)^2}{(1-\delta_2)^2+(\delta_1-\delta_2)^2} & if \quad \delta_1 \geq \delta_2 \end{cases}$$

Where,

$$\delta_1 = 1 - \frac{d_1}{e_1}$$

$$\delta_2 = 1 - \frac{d_2}{e_2}$$

d_1- amplitude of the difference from the mean of the first source.

d_2 amplitude of the difference from the mean of the second source.

The value of the Index of Complementarity

$$k = k_t k_e k_a$$

II. Data processing

The data on the daily wind speed at the height of 50 m, obtained at DAV in Fig.2 shows the daily wind speed graph, which notes that the highest value is in November (13.3 m/s), while the lowest value is in March (1.78 m/s). The month with the highest average wind speed is January, 6.99 m/s, and the lowest average value is June, 3.2 m/s. November, December, January, and February are the months with the highest average daily wind speed throughout the year.

Based on the data obtained from the GSA for solar radiation and solar hours for Vlora for each month of the calendar year, the graph shown in Fig. 3. The highest value of solar radiation is reached in July, 7.2kWh/m2, while the smallest value in terms of the peak is in December, approximately 3.9kWh/m2.

December has the weakest solar radiation and fewer solar hours, while June, July, and August have high solar radiation and more solar hours than the other months.

The electricity planned to be produced by the turbine (U.S. Department of Energy, n.d.)is given in Table 1. The graph built with the obtained data for each month is shown in Fig.4. In January, we see the highest wind speed parameters, which means the highest value of electricity that could be produced. The electrical energy production through wind energy is much higher in winter than in the rest of the year. Meanwhile, during summer, the electrical energy production through wind energy is at its lowest.

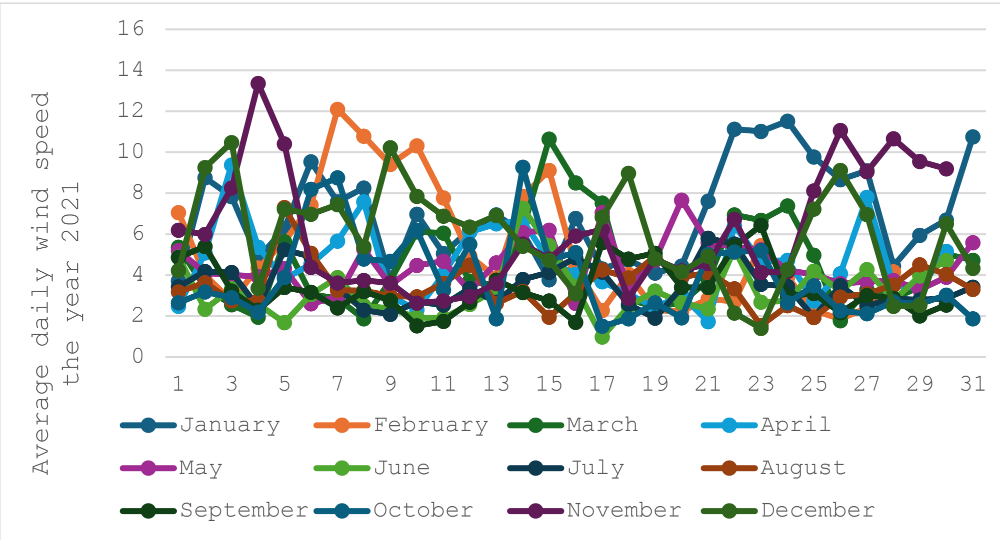

Figure 2. Average daily wind speed for a month throughout the Year 2021, Vlora, Albania

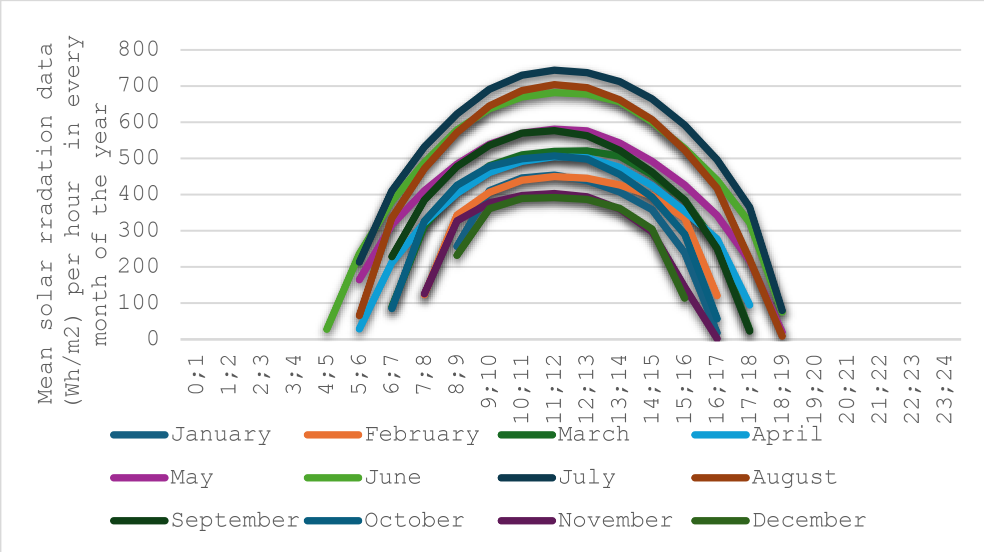

Figure 3. Solar radiation data during solar hours in a calendar year in Vlora, Albania

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Table 1. Mean monthly wind energy values predicted for the average wind speeds throughout the year 2021

Month	Speed (m/sek)	Power Mwh
January	7	281
February	5.3	164
March	4.6	105
April	4.6	105
May	4.48	99.7
June	3.3	38.6
July	3.4	44.8
August	3.48	46.8
September	3.36	42.2
October	3.8	66.3

November	6.1	252
December	5.9	226

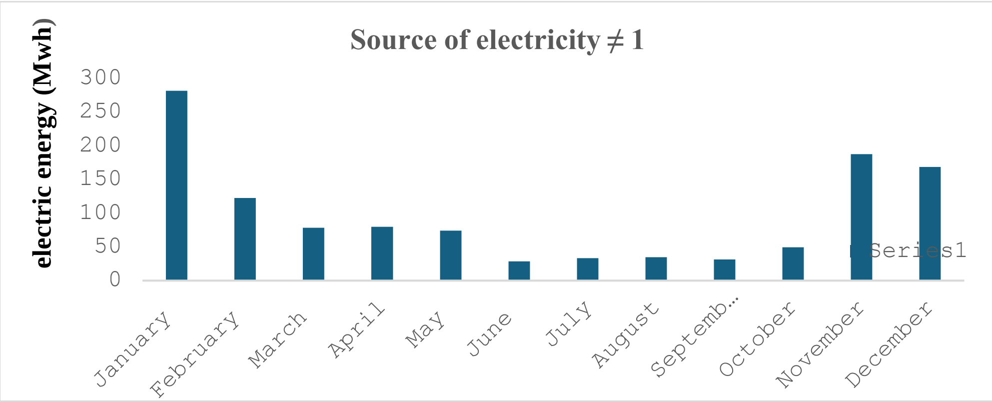

Figure 4. Electricity that would be produced by wind energy for the calendar year 2021, Vlora, Albania

For the photovoltaic system with a power of 1000kWp, the average monthly value of the electricity produced by it is shown in Table 2. The high values of solar radiation and the solar hours in the summer months reflect the high production of electricity, while the months of winter are the ones with the lowest production, fig.5

Table 2. Mean monthly solar energy values predicted throughout the year 2021 by Pv 1000kWp

Month	Power Mwh
January	88
February	96
March	135
April	138
May	156
June	164

July	174
August	168
September	139
October	120
November	85
December	75

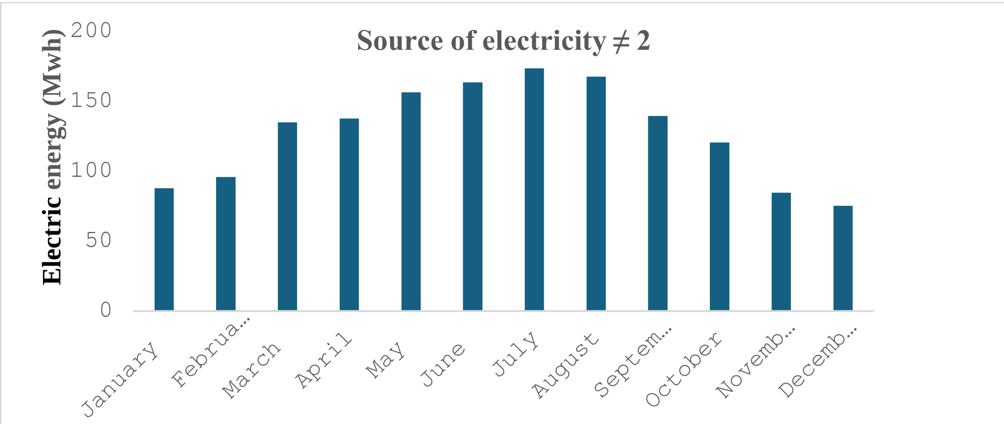

Figure 5. Electricity predicted by solar energy for the calendar year 2021, Vlora, Albania.

Results

The data collected in the graphs of electricity production during the 12 months of the year can be used to determine the complementarity indices in time, energy, and amplitude.

The month with the lowest energy value of "source ≠1" is the sixth, while "source ≠2" is the twelfth.

The Complementarity Index over Time is $k_t = 1$. That means full complementarity.

The average energy value of "source ≠1", $e_1 = 128.175$ MWh while the average energy value of "source ≠2" is $e_2 = 97.48446$ 97 MWh, The estimated $k_e = 0.864$. So, the Complementarity Index in Energy is relatively high.

Since, $d_1 = 98.4$ Mwh ; $d_2 = 252.685$ Mwh; δ1= 0.24: δ2 = - 1,59 we have used

$$\frac{(1-\delta_2)^2}{(1-\delta_2)^2 + (\delta_1 - \delta_2)^2}$$

Because $\delta_1 \geq \delta_2$

The Complementarity Index in Amplitude is $k_a = 0.79374$, indicating a relatively high level of complementarity between the energy production from the two sources
The value of the index of complementarity in Vlora Albania is :
$k_t = 0.686$

Conclusions

If two or more renewable energy sources are available in the same region, their complementarity can result in a combined hybrid energy system.

The complementarity index in time, energy, and amplitude have been determined based on the estimated values of electricity production in the Vlora district from the two sources, solar and wind. Referring to the data of solar radiation and wind speed taken into consideration during one year estimated, the index k of complementarity results in k=0.686.

Therefore, we have a moderate temporal complementarity index in time during a calendar year. This means that, over time, wind and solar energy in Vlora work reasonably well together, but not perfectly. They don't always align to fully complement each other, but there is still a notable overlap in their production periods.

The results show that wind-solar hybrid energy systems can be more effective than photovoltaic or separate wind turbine systems. These systems can also be studied spatially in key regions where wind energy has high potential, and turbine systems can be installed.

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