Impact of selected teleconnection pattern on solar energy potential in different climatic zones of Nigeria

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Abstract: Meeting the energy demands and sustainable development goals in Nigeria requires investigation of potentials of alternative energy sources and possible challenges to their reliability. In this study, we investigated the impact of four (4) teleconnection patterns on the solar energy potential within different climatic zones of Nigeria. Our results indicate that there are weak and insignificant correlation between the studied teleconnection patterns and solar energy potential on the long run. However, monthly analysis suggests significant correlation values between all the teleconnection patterns studied and solar energy production within all the climatic regions of the country. Therefore, it is important to consider the role of teleconnection pattern in energy planning and forecasting within the region.

1. Introduction
Teleconnections are spatial patterns in the atmosphere that link weather and climate anomalies over large distances across the globe [1]. Large scale oscillations in the Atlantic Ocean include Tropical Northern Atlantic (TNA), North Atlantic Oscillation (NAO), and Tropical Southern Atlantic (TSA). The teleconnection patterns in the Pacific oceans include El Nino Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). In the Indian Ocean, there is the Indian Ocean Dipole (IOD). A nonlinear relationship between different teleconnection patterns has been established [2]. It has long been recognized that the weather at one location on the Earth is linked to the weather at other very distant locations. ENSO has been found to affect drought in West Africa [3], locust outbreaks [4], fish population [5], and diseases in Africa [6]. However, the impact of teleconnection patterns on the energy sector has not been investigated.

There is an increasing demand for clean and affordable energy to mitigate the impact of climate change [7]. Solar energy is one of the most demanded renewable energies across the world. It has the advantages of being infinite and environmentally friendly. Recent technological advances have increased the efficiency of commercially available solar panels. Tropical countries, due to the higher insolation received, are adopting solar energy as the preferred renewable energy mode. However, there are several challenges to the deployment of solar energy, especially in tropical countries. These challenges include cloudiness [8], the initial cost of setting up, unclear national policy, and battery technology. Stoyanov et al [9] assessed the impact of such factors on the electricity generated from
operational grid connected photovoltaic system (PVS). One of the unexplored challenges to solar energy in sub-Saharan Africa is the impact of teleconnection patterns.

Solar energy is one of the cleanest and most readily available renewable energies all over the globe, and for the sake of this research, we would be deliberating more on the impact of teleconnection patterns on solar energy potentials in the Coastal, Sahel and Guinea regions. The effect of solar activity variations on climate is far from being correctly quantified, which leads to difficulties in distinguishing between various causes of climatic variations [10, 11]. Research over the past century has shown that teleconnection patterns fluctuate over a very broad range of time scales, from just beyond the period of synoptic-scale variability, to inter-annual and even inter-decadal time scales. Besides the fact that teleconnections connect weather and climate over a great distance, which is a fascinating observation in its own right, teleconnections generate much interest because they persist for a longer time than most other phenomena in the atmosphere. This implies that when teleconnections are active, the atmosphere may be in a state that is more amenable to useful weather forecasts over a time period that is much longer than a typical weather forecast. The features that cause teleconnections to be long lasting are their long wavelength and their slow growth and decay.

Understanding and quantifying the contributions of teleconnection patterns to solar energy potentials in the tropical region will help to plan better for maximum power output. In this study, we aim to investigate the impact of teleconnection patterns within the Atlantic and Pacific oceans on the solar energy potential within different climatic zones at different temporal scales. Four teleconnection patterns in the Pacific and Atlantic oceans were considered across three climatic zones of Nigeria. Results from this study will help the country plan for the achievement of the Sustainable Development Goals (SDGs) through strategic planning towards accessing sustainable energy.

2. Methodology

2.1. Data and study area
For this work, the monthly 2m temperature and surface solar radiation data used for the Sahel, Guinea, and Coastal regions of Nigeria, were obtained between January 1980 to November 2020 from ECMWF Reanalysis 5th Generation data of the European Centre for Medium-Range Weather Forecasts [11]. While the teleconnection data used are the Tropical Southern Atlantic (TSA) Index, Tropical Northern Atlantic (TNA) index, Pacific Decadal Oscillation (PDO), and El Nino Southern Oscillation (ENSO). These data were obtained from the NOAA (National Oceanic and Atmospheric Administration) database [13]. The different climatic zones considered within Nigeria is shown in figure 1.

Figure 1. Classification of Nigeria considered in this study.
2.2. Solar energy potential

The energy potential is estimated using equation (1) [14, 15]

\[ P = \eta_{\text{ref}} A G_T (1 - 0.0045(T_C - 298.15)) \]  

where \( \eta_{\text{ref}}, T_C, G_T, A \) are the cell electrical efficiency at reference temperature taken to be 0.14, air temperature in Kelvin, solar radiation flux on the module, and area taken as 0.5 square metres respectively. The estimated solar potential for the three regions under consideration is shown in figure 2 while the temporal evolution of the teleconnection patterns is shown in figure 3.

![Figure 2](image1.png)

**Figure 2.** Monthly time series of estimated solar energy potential in the various regions.

![Figure 3](image2.png)

**Figure 3.** Time series of teleconnection patterns considered in this study.
3. Results and Discussion
The linear relationship between teleconnection patterns and the solar energy potential in the different climatic zones of Nigeria is shown in figure 4 while the statistics is presented in table 1.

![Figure 4. Correlation between teleconnection patterns and solar energy potential for data between 1980 – 2020](image)

The correlations were found to be very weak and insignificant. In the coastal and Sahel regions, PDO showed negative and positive relationships respectively. All teleconnection patterns exhibit a positive correlation with the potential solar energy in all climatic region. The strongest correlation was observed between TSA and the solar energy potential in the coastal region while the weakest was with ENSO in the Sahel. Generally, ENSO and TSA showed a stronger correlation in the coastal region and weakest in the Sahel. Although, PDO and TNA exhibit the strongest correlation in the coastal region, their weakest correlation was in the Guinea region.

| Region | NINO | PDO | TNA | TSA |
|--------|------|-----|-----|-----|
| Coastal | -0.029 | 0.036 | -0.028 | -0.055 |
| Guinea | 0.024 | 0.020 | 0.025 | 0.024 |
| Sahel | 0.017 | -0.025 | 0.018 | 0.032 |

The monthly correlation values between solar energy potential and teleconnection pattern were studied and the results presented in figure 5. In the coastal region, strong negative significance was
observed between NINO and PDO, and solar energy potential. The two then exhibit a positive relationship in April, although not significant. This implies that the increasing strength of NINO will likely reduce the solar energy potential in the coastal region in all months of the year except February, April, and November.

![Figure 5. Monthly correlation between teleconnection pattern and solar energy potential in the different climatic zones of Nigeria](image)

TSA showed a similar pattern of significant negative correlation in April and non-significant positive correlation in May. Furthermore, TNA showed strong positive correlation with solar energy potential in the coastal region in the months of January and May while negative correlations were observed for the teleconnection pattern in the later part of the year (June - December). The correlation of the teleconnection patterns with solar energy potentials was found to weaken towards the end of the year. In the Guinea region, significant correlation was reported for PDO (positive), TNA (positive), and TNA (negative) in March, June, and October respectively. TNA showed negative correlations in only four months of the year in the coastal region, but four months of positive correlation in the Guinea region. A strong significant correlation was reported in the Sahel region for TNA (negative), PDO (negative), NINO (positive), and TSA (positive) in the months of May, June, July, and November respectively.

4. Conclusion
In this study, the plausible impact of selected teleconnection patterns on the solar energy potential of three climatic regions within Nigeria was considered. Power production within the region; usually hydroelectric or thermal plants have suffered many setbacks including limited production, environmental challenges, disruption of the gas supply network, and expensive maintenance cost of the plants.

Our results suggest that at the annual scale, the teleconnection patterns have little or no impact on solar energy potential in Nigeria. However, monthly analysis suggests the significant impact of teleconnection on solar energy potential which must be considered during the planning of energy systems within the country. It is proposed that further research into the mechanism for these monthly correlation patterns should be investigated.

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