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Estimation of Small Onshore Wind Power Development for Poverty Reduction in Jubek State, South Sudan, Africa

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Abstract: Energy security is one of the challenging issues hindering developmental progress in developing countries. Wind power as a renewable energy source can play a significant role in poverty reduction if adequate information is provided. In this study, multi-approach technics were applied for a better understanding of the wind energy potential in Jubek State, South Sudan. Geographic Information System (GIS), remote sensing, and mathematical equations were applied in identifying suitable locations, potential power per unit area, wind farm layout, design of appropriate turbine size, and utilization of wind energy in both agricultural and domestic sectors. Wind speed, land use land cover, and digital elevation maps of the study area were processed in ArcGIS, MATLAB (Weibull distribution), and Minitab software. The results show that 17,331.4 km$^2$ (94.64%) of the study area is appropriate for wind power generation, with wind density of about 3.65 W/m$^2$ and installation capacity about 19,757.79 MW, resulting in an annual energy production of about 7269.29 GWh. With the proposed wind turbine, one ton of various crops and animal products require 1–4 and 2–20 turbines, respectively. Therefore, the step-by-step procedures followed in this study will contribute to poverty reduction through improving agricultural productivity and food quality.

Keywords: Standalone Wind Turbine; ArcGIS; Weibull wind distribution; Agro-Processing Industries

1. Introduction

Energy security is considered to be one of the most challenging topics across the history of humankind. Industrialization, civilization, and the entire developmental process rely on the availability and sustainability of energy. Fossil fuel remains the most prominent means of energy supply, but the drawbacks of such energy, i.e., high cost, depletion, and environmental degradation, have forced scientists to develop alternative sources that are low-cost, sustainable, and friendly to the environment. Based on renewable energy reports in 2018, evidence strongly indicated that most of the countries worldwide generate almost 26% of their electricity from renewable energy, mostly solar and wind power; this makes an addition of about 181 GW in 2018 as compared to 2017, making a total of 2378 GW by the end 2018 [1]. It was predicted that the world energy requirement by 2030 would be 31,675 TWh, and in 2004 the global production of electricity was 17,450 TWh. As part of the United Nations General recommendation under the theme Sustainable Development Goal on Sustainable Energy for All (SDG 7), energy is one of the key elements that was considered [2–4].

1.1. Energy Use in Food Production

Exceptional values have been reported on energy consumption in agriculture, shreds of evidence from the Intergovernmental Panel on Climate Change in 1995 during their third assessment reported
indicated that 3% (9 EJ) of the global energy was spent on agriculture, and up to 20% of the greenhouse gas emissions worldwide. It was generally observed that agricultural yield improvements result in positive energy ratios; this can be justified by the gained in using fossil energy as an input for agricultural activities—the harvested crops contain more energy than the energy consumed in crop production [5].

A study was conducted by Cranfield University in the UK in order to review energy requirements for agricultural production from the field to the farm gate. They used the life cycle analysis (LCA) approach, which is a recommended method for estimating the cradle to grave, a product or process of environmental impacts. Selected materials were field crops (maize, wheat, sugarcane, beans, oilseed rape, and potatoes) and three animal products in the form of meat (lamb, poultry, beef, and pork), eggs, and milk [6–8]. Besides this, [9] reported a detailed work on the transport cost from farm to plate or distance from the production area to consumption zone. Such work is essential for understanding wasted energy and efficiency at an extent which is beyond the farm boundaries.

In the LCA, in order to capture all embodied energies, it is necessary to consider all inputs used in the production of a given product. Therefore, the authors included energy used in fertilizer, buildings, machinery, and pesticides together with diesel and other forms of fuel as direct energy. For estimating inputs for animal production, they included energy for producing feed crops. Breeding overhead was also included in their work. Therefore, the final values presented in Table 1 show the total energy used in producing each item. Their findings concluded that energy input to produce most of the crops based on UK standards is between 1–6 GJ t$^{-1}$. The variation is based on the properties of different crops or animals, as well as farming practices such as the use of organic or inorganic systems or performing integrated farming or conventional farming [10,11].

Table 1. Energy requirement for producing and processing 1 ton of crops and animal products (kW h$^{-1}$) [6].

| Product Type | Product | Required Energy kW h$^{-1}$ |
|--------------|---------|-----------------------------|
| Arable Crop  | Wheat   | 700.056 - 597.27            |
|              | Oilseed rape | 1477.896 - 1666.8          |
|              | Potatoes | 405.588 - 411.144          |
|              | Barley   | 630.606 - 733.392          |
|              | Field beans | 697.278 - 677.832         |
|              | Soya beans | 1019.526 - 897.294        |
|              | Sugarcane | 58.338 - 897.294          |
|              | Maize    | 669.498 - 597.27          |
| Animal Production | Poultry | 4722.6 -                 |
|                  | Pig meat | 6389.4 -                 |
|                  | Beef     | 8334 -                 |
|                  | Lamb meat | 6111.6 -                 |
|                  | Milk     | 750.06 -                 |
|                  | Eggs     | 3333.6 -                 |

1.2. Energy in South Sudan

Investigating and accessing energy, primarily through renewable sources, has become an exciting topic among scientists. South Sudan is one of the African countries with a considerable shortage in the energy sector. The whole of the country relies on a thermal system as the only source of energy in the country, with a total coverage of only 1%, and mostly within the capital city Juba, in which the area of this study is located [12]. Based on a report published by the South Sudan National Bureau of Statistics, the country’s electric power per capita is between 1 and 10 kWh [13]. Due to the current energy insecurity in South Sudan, the government moved to study alternative sources of energy, and currently, the most focus is on hydropower generation due to the availability of remarkable water bodies across the country. Significant efforts are already being made to develop the energy sector in the country, e.g.,
the assessment of potential locations for constructing sizeable hydropower stations, but all are still at the feasibility study level [13]. At the moment, about five locations have been identified and the constructions are expected to end from 2026 to 2040, depending on resource availability. Although other sources of renewable energy could be harvested to support some developmental activities, such as agriculture and small industries, so far, no precise information has been reported on the potential of wind, solar, and bioenergy in South Sudan.

1.3. About Wind Energy Potentials

The distribution of wind power density parameter was used to classify onshore wind energy at the global, continental, and national level. This work was conducted at the NREL (National Renewable Energy Laboratory), and it was found that wind power density can be classified into seven classes, i.e., poor class, with energy density of 0 to 200 W/m², marginal class (200 to 300 W/m²), fair class (300 to 400 W/m²), good class (400 to 500 W/m²), excellent class (500 to 600 W/m²), outstanding class (600 to 800 W/m²), and finally superb class (<800 W/m²) [14]. Results of research conducted to investigate the best height for installing wind energy in Iran showed that 40 m height was the best of all locations, with an annual power density of 265 W/m² [14]. For better understanding and planning for sustainable wind energy behavior in a given location, it is crucial to gather an extensive range of data in the form of temporal and particular distribution of wind and some other factors, such as the land use land cover map and location coordinates. Remote sensing and GIS are the most widely used tools for gathering such information for a long time series and comprehensive area coverage in a cost-effective manner. In Afghanistan, a combined solar and wind research work was conducted to estimate potential production, applying Modelling with Multi-Criteria Decision-Making (MCDM) method together with GIS approaches. It was found that there was an annual production of 342,521 GWh, 140,982 GWh, and about 6000 GWh from wind energy, solar photovoltaic (PV), and concentrating solar power, respectively [15]. In Malaysia, a study was conducted by [16] to study the spatial–temporal status of wind power density. The study tackled two aspects—the first was to simulate a spatial wind map through spatial wind modeling, and secondly spatiotemporal analysis to determine wind energy density. Their results indicate that Malaysia has a potential capacity of 1.5232 MW/m² of wind energy.

It is crucial to establish an accurate model for forecasting wind energy modeling to manage the uncertainty changes in wind speed. These will work together, along with spatial and temporal wind analysis, for better wind energy production in the future. In this regard, various research works have been conducted in many countries in order to estimate wind energy using Probability Distribution Functions (PDFs) [16]. The results of these studies recognize the significance of the PDFs method in the study of wind energy.

The aim of this study is to strengthen the effort of previous work in the literature by applying multi-approach technics for a better understanding of wind energy potential for a given location. The targeted sector to benefit from the results of this study is the agricultural sector, in order to improve agricultural productivity, processing, and marking. Also, this work is unique in terms of identifying a suitable location for both agricultural area and wind energy farms in order to efficiently supply the farmers with adequate electric power to run small agro-processing industries.

2. Materials and Methods

In this study, the potential of wind energy, most appropriate locations, and suitable wind turbine designs were determined using a multidimensional approach (remote sensing, GIS, mathematical models, and utilization). The combinations of the selected approaches can be considered as an additional method to previous findings in the literature. The step-to-step procedure of this research work is detailed in Figure 1. It consisted of six sections: suitable locations in terms of topography and land use land cover (LULC) (Section 3.1) in order to identify the most appropriate locations; wind speed data (Section 3.2) in order to extract wind speed data from the world map and then collect data for each selected point based on the locations identified in Section 3.1; statistical analysis (Section 3.3)
in order to identify the relationship between wind speed and wind power density at the three selected levels of elevations in the study area, Minitab software was used to perform ANOVA; study and model the most suitable wind behaviour, i.e., based on topography and monthly variation (Section 3.4); design a model wind power turbine with standard technical specifications that will suit the wind regime of the study area (Section 3.5); and finally, estimation of the energy requirement for small agro-processing units to improve agricultural productivity and upgrade food quality in order to eliminate poverty in the study area (Section 3.6).

![Figure 1. Conceptual framework of wind power generation.](image)

### 2.1. Datasets

In this study, three datasets from open access sources were used. Wind speed data were obtained from global metrological data, the LULC map from Africa LULC map, and the Digital Elevation Model (DEM) from Shuttle Radar Topography Mission (STRM).

#### 2.1.1. Wind Speed Data

Wind Speed data were obtained from TerraClimate data, which provides monthly time step information of both water balance and meteorological variables since the year 1958 to date. It was a temporal metadata ID in form of Network Common Data Form (netCDF) [17,18], validated TerraClimate dataset of monthly high resolution (1/240, 4-km) data of climate water balance for global land surfaces from 1958–2015. The concept of TerraClimate is based on the application of climatically supported interpolation, associating high-spatial-resolution climatological normals driven from the WorldClim dataset with monthly time series coarser resolution data. Data were obtained from the Climate Research Unit (CRU) and the Japanese 55-year Reanalysis (JRA-55) in order to generate a monthly dataset of wind speed, vapor pressure, precipitation, maximum and minimum temperature, and solar radiation. The authors validated the spatiotemporal outputs of TerraClimate by applying annual temperature, precipitation, and estimated reference evapotranspiration from ground stations, in addition to annual runoff data from flow stream gauges. Their findings revealed that TerraClimate datasets indicated significant improvement in overall temperature and precipitation mean of subpar correlations about \( p = 0.8 \) and \( 0.90 \) respectively. Therefore, the authors highly recommended the application of TerraClimate
dataset as inputs for ecological and hydrological research at global levels that need high spatial resolution and time series climate and water balance data.

2.1.2. Land Use Land Cover

Land cover refers to any physical material (Natural or man-made) that is available on the earth’s surface, and it can affect various process on the globe, e.g., energy and carbon budget, as well as water availability [19]. Various developed models used in the earth system and land surface value LC as an essential parameter [20,21]. Many researchers from different disciplines retrieve physical characteristics of the earth’s surface, and land cover depends on both anthropogenic effects and environmental variables that lead to specific land use [21–23]. In this study, we used a land use land cover map, which was developed by the Climate Change initiative (CCI) Land Cover team for Africa, with high resolution at 20 m based on Sentinel-2A observations for the duration from December 2015 to December 2016. The coordinate reference system used was WGS84 reference ellipsoid. The LC was divided into ten categories (cropland, tree-cover areas, grassland, shrub-cover areas, built-up areas, vegetation aquatic or regularly flooded, bare areas, open water, lichen and mosses/sparse vegetation, and snow and ice) [24].

2.1.3. Digital Elevation Model

The DEM was obtained from STRM; it refers to the elevation data of a given location with 30 m as a high-resolution digital topographic database. The STRM contains a particularly improved radar system that flew onboard the space shuttle Endeavour. It is an international project managed by the National Geospatial-Intelligence Agency NGA and NASA [25].

2.2. Case Study Description

The study area was located in the Southern part of South Sudan Figure 2B; it was one out of 32 states of the country, which hosts the capital city of the country. Jubek state covers about 18,313.7 km² with surface elevation ranges between (432–1289 m) Figure 2C and is surrounded by four states, i.e., Terekeka, Torit, Yei, and Amadi, in the North, East, South, and West, respectively Figure 2A. It lies between the longitude of 31°25′55.021″ E and latitude of 4°42′42.444″ N and compromises fourteen counties: Dollo, LyriaRokon, Oponi, Lobonok, Rejaf, Gondokoro, Mangala, Ganji Bungu, (Ganzi), Lodu, Wonduruba, and Luri. Based on the 2014 census report, the population of Jubek State is about 492,970, and thus represents 40% of the entire population of South Sudan. The monthly rainfall is 100 mm/month from April to October and dries during December to February. The sunshine from September to February is almost 8 to 9 h in a day, and from March to August is about 6–7 h, as seen in Figure 2.
2.3. Scope

Based on the specific method mentioned in this study, the following steps were applied to study the potential capacity of wind energy, most appropriate locations, and suitable wind turbine design, and proposed utilization of the output power in small agro-processing industries:

- Identification of the most appropriate locations based on DEM and LULC maps;
- Extraction of wind speed data from the world map and data collection of each selected point;
- Analysis and modelling of the most suitable wind behaviour based on different topographies and LULC classes;
- Design of a model wind power turbine with standard specifications to suit the wind regime of the study area for sustainable access to power generation throughout the year;
- Utilization of the produced wind power to supply small agro-processing industries.

2.4. Identification of a Suitable Location for Wind Turbin

Firstly, wind speed data were obtained from TerraClimate high-resolution data; remote sensed data in the form of a netCDF raster file for global data (1958–2018); for the purpose of this study, we extracted wind speed data for 19 years (2000–2018). Secondly, a LULC map of the study area was extracted from the Africa map developed by the CCI Land Cover team. This was a high-resolution image at 20 m based on Sentinel-2A observations for the duration from December 2015 to December 2016. The third input data were DEM, which was extracted from the global map of STRM. Extractions of these datasets were achieved with the help of the Spatial Analyst Tool (SAT)—extracted by the mask tool in ArcGIS 10.7.1. In order to collect wind speed sample data, the study area was divided into three classes based on the surface slope. The classes were named as High (H), Medium (M) and Low (L) and were carefully identified using extracted DEM, Figure 3. Besides this, the extracted LULC was
used to locate appropriate sites based on land class types (Figure 4), and the size of each class was also determined using an area calculator tool in ArcGIS.

Figure 3. Wind speed collecting locations in Jubek state.

Figure 4. Land use land cover map of Jubek state 2016.

2.5. Wind Speed Data Collection

In this part, the collection of wind speed data was based on the points identified in Section 2.4. After extraction of the wind speed data of the study area from the global map, the next step was to
collect wind speed data at the pixel level. SAT local-cell statistics in ArcGIS was applied to calculate the mean monthly wind speed in order to generate annual data. Finally, the SAT-extraction multi-point extraction tool in ArcGIS was used to collect per pixel wind speed data, which were based on the selected locations (Figure 3).

2.6. Statistical Analysis

To identify the relationship between wind speed and wind power density with the three selected levels of elevations in the study area, we used Minitab software to perform ANOVA with $\alpha = 0.05$.

2.7. Analysis of Wind Speed Behaviors

This section aims to determine and evaluate average wind speeds, wind densities, wind speed with high probability, and wind speed with maximum energy at the three selected locations. Weibull statistics were applied using Weibull distribution through the maximum likelihood method.

Weibull is most commonly used to fit the statistical wind data for representing the wind regime. The probability density function $f(v)$ indicates the fraction of probability for which the wind is at a given velocity $v$, as shown in Equation (1). To obtain a better fit of Weibull function, a huge amount of wind speed data is recommended in order to identify the most dominant wind speed for a given time series, which is an important input in wind turbine design [26,27]. Comparative plots of Weibull wind speed were generated with the help of density and cumulative probability in Weibull distribution.

$$f(v) = \left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}}$$  \hspace{1cm} (1)

In the literature, various methods have been used in determining Weibull parameter shape and scale factors. The most well-known methods are moment, standard deviation, curve fitting, and power density, maximum likelihood. All the above methods were proven to have almost similar results [28], but for long time-series data, maximum likelihood is mostly recommended [21,22]. Therefore, in this study, maximum likelihood was chosen to determine $k$ and $c$ parameters using Equations (2) and (3), respectively.

$$k = \left(\frac{\delta V}{V_m}\right)^{-1.090}$$  \hspace{1cm} (2)

$$c = \frac{V_m}{\Gamma(1 + \frac{1}{k})}$$  \hspace{1cm} (3)

Wind density at each point was calculated in order to estimate and evaluate the potential of wind for power generation, using Equation (4) [29–31]:

$$p = \frac{1}{2} \rho v^3 (W/m^2),$$  \hspace{1cm} (4)

where $\rho$ is the density of air at the sea level with mean temperature and pressure; in this study 1.225 kg/m$^3$ was applied.

2.8. Design of Suitable Wind Turbine

This section proposes a model design of a wind power turbine with the standard technical specification that suits the wind regime of the study area. In the fourth step, mathematical equations were used in the design of an appropriate size of a wind turbine for the study area based on standard recommendations (Appendix A); layout for the designed turbine was also discussed in this section. Based on the LULC map, suitable locations for small wind power turbines were found to be farmland, grassland, forestland, and barren land. Out of the ten LULC classes, seven were identified as suitable for installing a wind turbine, and in this study, we considered it as one of the critical factors to estimate wind power potential in Jubek State. To install a wind turbine at a given area size, the recommended
distance between any two turbines should be 3-15 multiply the turbine diameter \([30,32,33]\). In the current work, \(3 \times \) the rotor diameter was selected, i.e., \(3 \times D\), where \(D\) is the diameter of the designed turbine. Therefore, to calculate the optimum capacity potential of Jubek state, the rated power divided by \(3D\), the result would be around 1.14 MW per km\(^2\). For a proper layout of the farmland, as proposed in this study, we considered a circle shape, based on the fact that a turbine forms a circle shape during operation; the center of the circle represents the turbine position, and from the center of one turbine to the next turbine is the distance between any two turbines.

2.9. Estimation of Energy Requirement for Small Agro-Processing Units

Finally, in order to make use of the generated information about the wind speed and the equivalent power generated, the final step was the estimation of energy requirement for small agro-processing units to improve agricultural productivity and upgrade food quality in order to eliminate poverty in the study area. This was achieved by collecting information from the literature on the required energy to produce some selected agricultural products, starting from field cultivation up to processing and packaging. Therefore, data used in this regard were obtained from \([6,7]\), who conducted research using LCA, which is a recommended approach for estimating the cradle to grave, a product or process of the environmental impacts of a given area/event. They studied six field crops (maize, wheat, sugarcane, beans, oilseed rape, and potatoes), the meat of four animals (lamb, poultry, beef, and pork), and eggs and milk. Their findings resulted in the estimated energy required to produce a quantity of one ton of each of the mentioned agricultural products. Therefore, in this study, we estimated the energy produced by one wind turbine in order to identify the total number of turbines that would produce one ton of the selected agricultural products. This will assist decision-makers and technicians in establishing an appropriate wind energy policy that will help to improve agricultural productivity and food quality to eradicate poverty in the country.

3. Results

3.1. Identification of a Suitable Location for Wind Turbine

Figure 3 shows the three identified locations, i.e., H 1117–839 m, M 796–616 m, and L 588–458 m. A total of 21 wind speed collection points were divided as 7, 7, and 6 for H, M, and L, respectively. Coordinates of each location with elevation are given in Table 2. For each location, monthly wind speed data were collected for 19 years (2000–2018), making a total of 4560 wind speed data points (1596, 1596, and 1368 for high, medium, and low elevations).

Figure 4 illustrates suitable locations for a wind turbine in the study area. It was found that tree-cover (5628.939 km\(^2\)), shrubs (2687.876 km\(^2\)), grassland (8656.458 km\(^2\)), cropland (352.155 km\(^2\)), vegetation aquatic or regularly flooded (5.292 km\(^2\)), lichens and mosses/sparse vegetation (0.007 km\(^2\)), and bare areas (0.678 km\(^2\)) made the total appropriate location for installing wind power turbine to be 17,331.4 km\(^2\), which represents about 94.64% of Jubek State (Table 3).
Table 2. Sample collection coordinates, elevation, average annual wind speed and density of Jubek state, South Sudan.

| Elevation | S/N | Longitude | Latitude | Elevation | Wind Speed m/s | Wind Power Density W/m² |
|-----------|-----|-----------|----------|-----------|----------------|------------------------|
| High      | 1   | 32.0604   | 4.67185  | 852       | 1.89           | 4.20                   |
|           | 2   | 32.0128   | 4.41725  | 885       | 1.94           | 4.58                   |
|           | 3   | 31.8272   | 4.07223  | 938       | 1.92           | 4.42                   |
|           | 4   | 31.1134   | 4.1912   | 893       | 1.86           | 4.03                   |
|           | 5   | 31.2823   | 4.5624   | 936       | 1.88           | 4.13                   |
|           | 6   | 31.0634   | 4.76941  | 922       | 1.84           | 3.88                   |
|           | 7   | 30.8755   | 4.70279  | 1117      | 1.87           | 4.09                   |
|           | 8   | 31.5893   | 5.10253  | 839       | 1.89           | 4.19                   |
| Medium    | 9   | 32.0699   | 4.64806  | 774       | 1.91           | 4.33                   |
|           | 10  | 31.9058   | 4.6314   | 733       | 1.90           | 4.32                   |
|           | 11  | 31.4346   | 4.85745  | 796       | 1.87           | 4.11                   |
|           | 12  | 31.6131   | 4.47436  | 647       | 1.80           | 3.67                   |
|           | 13  | 31.7844   | 4.44818  | 616       | 1.88           | 4.16                   |
|           | 14  | 31.6631   | 4.25307  | 620       | 1.85           | 3.94                   |
|           | 15  | 30.9968   | 4.93597  | 634       | 1.87           | 4.06                   |
|           | 16  | 30.9516   | 4.77893  | 660       | 1.86           | 4.04                   |
| Low       | 17  | 31.8606   | 5.1644   | 499       | 1.91           | 4.35                   |
|           | 18  | 31.9557   | 4.94311  | 483       | 1.86           | 4.03                   |
|           | 19  | 31.7202   | 4.9788   | 458       | 1.90           | 4.31                   |
|           | 20  | 31.3514   | 4.9907   | 526       | 1.89           | 4.21                   |
|           | 21  | 31.0111   | 5.22865  | 588       | 1.82           | 3.77                   |

Table 3. Land use land cover classes of Jubek state 2016.

| Class Code | Land Cover Class                      | Area Km² |
|------------|--------------------------------------|----------|
| 0          | No data                              | 0        |
| 1          | Tree cover areas                     | 5628.939 |
| 2          | Shrubs cover areas                   | 2687.876 |
| 3          | Grassland                            | 8656.458 |
| 4          | Cropland                             | 352.155  |
| 5          | Vegetation aquatic or regularly flooded | 5.292    |
| 6          | Lichens and mosses/sparse vegetation | 0.007    |
| 7          | Bare areas                           | 0.678    |
| 8          | Built-up areas                       | 41.116   |
| 9          | Snow and ice                         | 0        |
| 10         | Open water                           | 40.542   |

3.2. Dominant Wind speed

Figure 5 shows the monthly wind speed behaviour of Jubek state for 19 years (2000–2018). During the study period, wind speed trends show that during the study period, maximum wind speeds were mostly captured between December and March and remained low from April to November (Table 4).
3.3. Statistical Analysis

The results of the statistical analysis show $p$ values = 0.00 and $R^2 = 1$ for both speed and power density versus elevation (Tables 4–7 and Figure 6); this reveals that there is a significant variation between values of speed and wind density at different locations based on the topographic situation and monthly variation in the study area Figure 6a,b respectively. Therefore, the wind turbine design can perform adequately at any location within the study area.

Table 4. Analysis of Variance wind power density versus elevation.

| Source        | DF  | Adj SS  | Adj MS   | F-Value | $p$-Value |
|---------------|-----|---------|----------|---------|-----------|
| Elevation (m) | 20  | 0.9337  | 0.04669  | *       | *         |
| Error         | 0   | *       | *        |         |           |
| Total         | 20  | 0.9337  |          | *       |           |

* $p$ value = 0 and $R^2 = 1$.

Table 5. Model summary wind speed versus elevations.

| S     | $R^2$ | $R^2$(adj) | $R^2$(pred) |
|-------|-------|------------|-------------|
|       | 100.00% | *          | *           |

* $p$ value = 0 and $R^2 = 1$.

Table 6. Analysis of Variance wind speed versus elevations.

| Source        | DF  | Adj SS  | Adj MS   | F-Value | $p$-Value |
|---------------|-----|---------|----------|---------|-----------|
| Elevation (m) | 20  | 0.02187 | 0.001093 | *       | *         |
| Error         | 0   | *       | *        |         |           |
| Total         | 20  | 0.02187 |          | *       |           |

* $p$ value = 0 and $R^2 = 1$. 

Figure 5. Monthly Wind speed variation at of the study area for 2000-2018.
Table 7. Model summary of wind power density versus elevation.

| S | R² | R²(adj) | R²(pred) |
|---|----|---------|----------|
| * | 100.00% | * | * |

*p value = 0 and R² = 1.

Figure 6. (a) Wind speed (m/s) versus elevation. (b) Wind power density W/m² versus elevation.
3.4. Analysis of Wind Speed Behaviours

Table 8 describes the Weibull parameters and properties of monthly wind speed. The obtained results illustrate that the monthly shape parameter ranges from 1.58 to 2.36, and scale ranges from 5.45 to 16.66. The average monthly shape parameter was found to be 1.95, 1.96, and 1.97 at H, M, and L elevation, respectively. The scale parameter was found to be 10.51, 10.55, and 9.65 at H, M, and L elevation, respectively. The most dominant wind speed with high probability was approximately 1.87 m/s at H, 1.85 m/s at both M and L elevation for the study period.

Table 8. Monthly and average wind data analysis for high, medium, and low elevations.

| Elevation | Month  | Std.  | k     | c     | Wind Speed | Power Density W/m² | k(opt) | c(opt) |
|-----------|--------|-------|-------|-------|------------|---------------------|--------|--------|
| High      | January| 0.348 | 2.269 | 6.454 | 2.121      | 5.96                |        |        |
|           | February| 0.358 | 2.027 | 5.538 | 2.238      | 7.009               |        |        |
|           | March   | 0.248 | 2.069 | 8.845 | 1.964      | 4.736               |        |        |
|           | April   | 0.218 | 2.186 | 9.087 | 2.085      | 5.662               |        |        |
|           | May     | 0.159 | 2.003 | 13.652| 1.932      | 4.505               |        |        |
|           | June    | 0.141 | 1.843 | 14.386| 1.78       | 3.526               |        |        |
|           | July    | 0.115 | 1.787 | 16.066| 1.734      | 3.256               |        |        |
|           | August  | 0.097 | 1.714 | 16.353| 1.667      | 2.894               |        |        |
|           | September| 0.14 | 1.762 | 10.683| 1.694      | 3.039               |        |        |
|           | October | 0.161 | 1.909 | 12.414| 1.835      | 3.864               |        |        |
|           | November| 0.256 | 1.808 | 7.04  | 1.698      | 3.058               |        |        |
|           | December| 0.358 | 2.027 | 5.538 | 1.698      | 3.058               |        |        |
|           | Mean    | 1.95  | 10.505| 1.87  | 4.214      | 5.23                | 2.11   |        |
| Medium    | January | 0.356 | 2.246 | 6.192 | 2.095      | 5.745               |        |        |
|           | February| 0.331 | 2.312 | 7.519 | 2.172      | 6.402               |        |        |
|           | March   | 0.251 | 1.974 | 8.17  | 1.868      | 4.074               |        |        |
|           | April   | 0.228 | 2.171 | 8.685 | 2.066      | 5.513               |        |        |
|           | May     | 0.162 | 1.963 | 13.18 | 1.89       | 4.222               |        |        |
|           | June    | 0.139 | 1.928 | 15.14 | 1.865      | 4.057               |        |        |
|           | July    | 0.117 | 1.811 | 16.25 | 1.757      | 3.389               |        |        |
|           | August  | 0.096 | 1.696 | 16.657| 1.65       | 2.807               |        |        |
|           | September| 0.145| 1.754 | 10.362| 1.685      | 2.989               |        |        |
|           | October | 0.166 | 1.907 | 12.133| 1.831      | 3.834               |        |        |
|           | November| 0.261 | 1.773 | 6.8   | 1.662      | 2.872               |        |        |
|           | December| 0.364 | 2.023 | 5.464 | 1.662      | 2.872               |        |        |
|           | Mean    | 1.963 | 10.546| 1.85  | 4.065      | 5.08                | 2.14   |        |
| Low       | January | 0.355 | 2.287 | 6.342 | 2.136      | 6.088               |        |        |
|           | February| 0.368 | 2.358 | 6.623 | 2.204      | 6.688               |        |        |
|           | March   | 0.278 | 1.995 | 7.535 | 1.88       | 4.156               |        |        |
|           | April   | 0.251 | 2.26  | 8.299 | 2.146      | 6.173               |        |        |
|           | May     | 0.179 | 1.958 | 11.785| 1.878      | 4.141               |        |        |
|           | June    | 0.138 | 1.929 | 15.218| 1.867      | 4.068               |        |        |
|           | July    | 0.126 | 1.791 | 14.568| 1.732      | 3.248               |        |        |
|           | August  | 0.103 | 1.579 | 14.217| 1.531      | 2.242               |        |        |
|           | September| 0.174| 1.738 | 8.358 | 1.656      | 2.837               |        |        |
|           | October | 0.194 | 1.908 | 10.49 | 1.821      | 3.777               |        |        |
|           | November| 0.265 | 1.773 | 6.902 | 1.662      | 2.867               |        |        |
|           | December| 0.364 | 2.035 | 5.453 | 1.662      | 2.867               |        |        |
|           | Mean    | 1.968 | 9.649 | 1.848 | 4.096      | 5.16                | 1.94   |        |

To find the optimum values of \( k \) and \( c \) parameters that correctly fit the wind speed and wind density data, the calculated average wind energy density by Weibull function was solved as an objective function to suit the actual energy. Table 9 and Figures 7 and 8 show the wind speed data observed (represented by bars) and predicted (represented by line) properly fit in the Weibull distribution, the highest annual wind speed was found in H (1.87 m/s), and the same value was recorded in both M and L (1.85 m/s). Also Table 10 and Figures 9 and 10, illustrate the PDF and CDF fitted to the Weibull distribution show the highest value of annual mean power density to be 4.6, 4.5, and 4.5 W/m² at H, M,
and L, respectively. The optimum values of $k$ and $c$ parameters were determined for the three selected types of locations.

Table 9. Summary statistics for average annual wind speed density, Weibull fit using maximum likelihood.

| Site Elevation | Data | High   | Medium | Low   |
|----------------|------|--------|--------|-------|
| $k$            |      | 2.03009| 2.01066| 2.02168|
| $c$            |      | 6.32352| 6.40924| 5.81653|
| Mean           |      | 1.88879| 1.87207| 1.87232|
| Variance       |      | 0.121581| 0.116502| 0.139376|
| Log likelihood |      | −55.4042| −50.2096| −71.7944|

Figure 7. Comparative plot of Weibull wind speed for H, M, and L.

Figure 8. Comparative plot of Weibull wind speed for H, M, and L.
Table 10. Summary statistics for average annual wind power density Weibull fit using maximum likelihood.

| Site Elevation | Data | High   | Medium | Low   |
|----------------|------|--------|--------|-------|
|                | k    | 5.22908| 5.08035| 5.1644|
|                | c    | 2.10784| 2.13641| 1.93884|
|                | Mean | 4.63126| 4.49926| 4.57999|
|                | Variance | 5.33251| 4.91265| 6.06135|
|                | Log likelihood | −451.252| −442.673| −462.678|

Figure 9. Comparative plot of Weibull power density over H, M, and L.

Figure 10. Comparative plot of Weibull power density over H, M, and L.

3.5. Design Layout of Suitable Wind Turbine

In this study, the blade length is 10 m resulting in a swept area of about 314 m$^2$. The size of the land covered by each turbine was found to be 28.5 m$^2$. Based on the fact that 3 × D (30 m) is the distance between two turbines, and a turbine always rotates to form a circle, then the area covered by this circle (3 m diameter) will be 28.5 m$^2$. This means the proposed layout of the designed system as a swept area of the turbine intersects to about 1.5 m (Figure 11).
Equation (5) \[14,30\]. From the LULC of Jubek state, the suitable land size for installing wind power turbines was found to be 17,331.4 km\(^2\).

Installation capacity (IC) = \( \text{Area (km}^2) \times \text{Area Factor} \left( \frac{\text{MW}}{\text{km}^2} \right) \) \[5\]

\[
= 17,331.4 \times 1.14 = 19,757.79 \text{ MW}.
\]

Based on the capacity factor of Jubek State (0.042\%), the annual energy production was estimated by Equation (6) \[14,34\].

\[
\text{GWh} = (\text{IC} \times 8760 \times \text{Capacity Factor})
\]

\[
= 7269.29 \text{ GWh}.
\]

The designed specifications proposed for installing a wind turbine in Jubek state based on the data provided in this study are shown in Table 11. This shows that Jubek state has a capacity potential of installing a wind turbine in the range of about 19,757.79 MW.

### Table 11. Estimated parameters of the designed wind turbine suitable for Jubek state.

| S/N | Parameter                        | Value           |
|-----|----------------------------------|-----------------|
| 1   | Estimated wind power/area        | 3.645 W/m\(^2\) |
| 2   | Power/turbine                    | 3.645           |
| 3   | Annual output capacity           | 417.75345 kw/h/yr |
| 4   | Size land/per turbine            | 28.5 m\(^2\)   |
| 5   | Swept area (m\(^2\))            | 314 m\(^2\)    |
| 6   | Power output from the wind       | 1.14 MW/km\(^2\) |
| 7   | Capacity factor                  | 0.042           |
| 8   | Rotor diameter                   | 10              |
| 9   | Hub height                       | 40 m            |
| 10  | Cut in speed                     | 1.8 m/s         |
| 11  | Rated speed                      | 7 m/s           |
| 12  | Cut out speed                    | 10 m/s          |

**3.6. Estimated Energy Requirement for Small Agro-Processing Units**

Finally, in the fifth step, the energy requirement for processing agricultural products was obtained from the literature, and then the expected available power matched with the energy requirement data to estimate how the farmers will make use of wind energy to improve agricultural productivity and quality. Table 1 shows the energy required to produce 1 ton of some selected field crops and...
animal products [6,7]. For domestic utilization, with regard to electricity consumption in South Sudan, one person was estimated to reach 140 kW by 2030 [35]. Based on the specification shown in this paper, one turbine can supply electricity to a family of three family members. The results obtained in this study were used to estimate the number of turbines required to produce 1 ton of the mentioned crops and animal products in Table 12.

Table 12. Estimated numbers of turbines and area size for producing and processing 1 ton of agricultural product.

| Type          | Product     | Farming System | RE (kW•h⁻¹) | TR | TOE (kW/h) | Required Area (m²) |
|---------------|-------------|----------------|-------------|----|------------|--------------------|
| Crop          | Wheat       | Non-Organic    | 700.056     | 2  | 700        | 525.88             |
|               | Oilseed rape| Non-Organic    | 1477.896    | 4  | 1478       | 1110.19            |
|               | Potatoes    | Non-Organic    | 405.588     | 1  | 406        | 304.68             |
|               | Barley      | Non Organic    | 630.606     | 2  | 631        | 473.71             |
|               | Field beans | Non-Organic    | 697.278     | 2  | 697        | 523.79             |
|               | Soya beans  | Non-Organic    | 1019.526    | 2  | 1020       | 765.86             |
|               | Sugarcane   | Non-Organic    | 58.338      | 0  | 58.3       | 43.82              |
|               | Maize       | Non-Organic    | 669.498     | 2  | 669        | 502.92             |
|               | Wheat       | Organic        | 597.27      | 1  | 597        | 448.67             |
|               | Oil seed rape| Organic       | 1666.8      | 4  | 1667       | 1252.09            |
|               | Potatoes    | Organic        | 411.144     | 1  | 411        | 308.85             |
|               | Barley      | Organic        | 733.392     | 2  | 733        | 550.92             |
|               | Field beans | Organic        | 677.832     | 2  | 678        | 509.18             |
|               | Soya beans  | Organic        | 897.294     | 2  | 897        | 674.04             |

| Animal Production | Poultry     | 4722.6         | 11 | 4723 | 3547.6 |
|                   | Pig meat    | 6389.4         | 15 | 6389 | 4799.69 |
|                   | Beef        | 8334           | 20 | 8334 | 6260.47 |
|                   | Lamb meat   | 6111.6         | 15 | 6112 | 4591.01 |
|                   | Milk        | 750.06         | 2  | 750  | 563.44  |
|                   | Eggs        | 3333.6         | 8  | 3334 | 2504.19 |

RE = required energy; TR = required turbine; TOE = turbine output energy

4. Discussions

This study came with a broad aim in order to fulfill the UN recommendations for 2030 agenda, which stated, “leave no one behind” [4], during the seventieth session of the general assembly, whereby all the head of states governments agreed to end poverty in all forms and dimensions in 2030. We selected South Sudan because we believe that it is one of the most affected nations in terms of food and energy security, which are considered to be major contributors to promoting poverty [36,37], and evidence is reported mostly in developing countries [38,39].

Food security deterioration in South Sudan affects more than 41.7% of the population, and it was projected that the situation will continue to increase if no serious action is taken [40]. In South Sudan, Jubek state was selected as the area of study because it accommodates about 40% of the current population of the country, which indicates that it is the most appropriate location in which the outcome of this study can be implemented than other parts of South Sudan or any other country facing the same situation across the globe. Furthermore, it is easy to access more information on poverty, especially in urban areas, due to its attraction to rural people [41]. In this study, we focused on improving and promoting the agricultural sector through the establishment of a sustainable energy source, which can play a great role in operating agro-processing industries as well as reducing poverty among the people, through high food quality and job creation. Unfortunately, the country is now in poor shape in terms of energy source, as it relies totally on the thermal energy system, covering only 1% of South Sudan [11]. Reports indicate that the current per capita electricity requirement is about 1–10 kWh [12], and this is projected to reach 5 kW to 140 kW per person per year by 2025 [35]. The current government effort
to promote the energy sector in the county is the establishment of large hydropower [11], which we consider a long-term plan, which will not rescue the ongoing energy shortage situation. Besides this, the financial limitation may affect the process due to the large required budget.

For the development of a wind-energy turbine, wind speed is the most important input. Essential information on the status of wind speed for a given location can be determined by a monthly mean of wind speed data collected for a specific time period [28,32,42]. Figure 5 describes the dynamics means of wind speed in Jubek state from 2000 to 2018. Land and topographical condition influence the potential of wind energy potential. Therefore, it is important to investigate the nature of a given location for sustainable access to wind energy [43]. Our findings revealed that the study area has enough land cover for installing wind energy, covering about 94.64% of the total area. This indicates the suitability of Jubek state for wind energy production, in line with previous work in the literature [44–46], which stated that land cover type affects the potential of wind energy. Figure 3 illustrates that there is no significant difference in wind behaviour at a surface slope within the range of 1117–458m. Therefore, the fluctuation shown in this figure justifies the some factors related to land cover type must have influenced the wind speed, and therefore additional care should be taken regarding the type of land cover while installing wind turbines.

Design of an appropriate wind turbine mostly relays on accurate data on wind speed across the year for sustainable power supply. We applied Weibull distribution to estimate the most dominant wind speed in the study area. It was found that 1.85 m/s is the most sustained wind speed in the study area, and this falls under the poor wind category [13]; therefore, it is best to used a standalone turbine, which mostly suits remote locations rather than grid connection [47]. Therefore, we consider it to be suitable for agricultural utilization and to support the domestic needs of farmers with no access to electricity from the grid lines [48]. The wind turbine proposed in this paper relies on this value, which was obtained through a well-recognized method and recommended by various experts [26,30,49–51]. Area coverage per each turbine was also determined in order to assist decision-makers and the farmers in allocating a given part of land for wind energy. Fortunately, wind turbines can be installed in most of the land cover types [52], and this will play a great role in transport cost reduction between farm and small agro-processing industries owned by individual farmers. The proposed turbine in this study requires 28.5 m² of land with the layout shown in Figure 11. Table 3 shows that Jubek state has vast land which can accommodate enough wind turbine plants to support various developmental activities, such as agricultural practices, but small factors regarding site screening and financial cost should be taken into consideration [27,51].

As our goal in this study was to reduce the poverty level in South Sudan through upgrading the agricultural sector, we estimated the energy requirement for agricultural production and matched it with the available wind power. It was found that Jubek state has a wind density of about 3.65 W/m² and installation capacity of about 19,757.79 MW, which is equivalent to annual energy production of about 7269.29 GWh. For the situation of Jubek State, the results revealed that most of the energy required in producing 1 ton of crops ranges between (38.34–1666.6 kWt⁻¹) and requires one to four turbines and an area size 43.82–1252.09 km² for turbine installation, whereas for animal production the energy required in producing 1 ton of animal products ranges between 750.06 and 8334 kWt⁻¹ and requires 2–20 turbines and an area size 563.44–6260.47 km² for turbine installation. The calculation was based on results introduced by [6,8]. Besides this, based on the proposed design discussed in this paper, one wind turbine has the potential to supply a family of three people in the country. The statistical analysis based on ANOVA with $\alpha = 0.05$ showed $p$-value = 0.00 and $R^2 = 1$, which prove that there is a significant variation between values of speed and wind density at different locations based on the topographic and monthly data in the study area. The findings introduced in this paper show the possibility to reduce poverty in South Sudan through the application of wind energy in agricultural production. Thus, they can support future research on other renewable energy sources, such as hydropower, solar energy, and bioenergy, which can support wind energy for better and more sustainable energy supply.
5. Conclusions

The current status of the study area as a hosting state for the capital city of South Sudan makes it the most significant state among the other 31 states in the country. It accommodates about 40% of the total population of the country. The unfortunate situation of the entire country, with only 1% electricity coverage, hinders almost all developmental activities, including agriculture. Various local, regional, and international agencies frequently report on the food insecurity in South Sudan; this represents a threat to the country, as well as some neighbouring countries. The findings of this paper show practical input in upgrading policies that could positively assist decision-makers, charity organizations, academics, and private sectors to improve agricultural productivity and food quality. Our results show that the study area has potential for the establishment of wind power. The suitable land is about 1731.4 km², which represents 94.64% of its total area, wind density about 3.65 W/m², and installation capacity about 19,757.79 MW, resulting in annual energy production of about 7269.29 GWh. For the situation of Jubek State, the energy required in producing one ton of crops ranges between 38.34 and 1666.6 kWt⁻¹ and requires one to four turbines and an area size of 43.82–1252.09 km², whereas for animal production, the energy required in producing one ton of animal products ranges between 750.06 and 8334 kWt⁻¹ and requires 2–20 turbines and an area size of 563.44–6260.47 km². Finally, the paper showed a step-by-step routine to improve energy and food security in order to reduce poverty in South Sudan, as well as other countries across the globe facing similar situations. The main findings of this study can be summarized as follows:

- Based on DEM and LULC maps, 94.64% of Jubek state is suitable for wind energy production;
- Based on the remotely-sensed data, the Weibull distribution indicated that the most dominant wind speed in the study was found to be 1.85 m/s;
- Based on the design specification, the proposed turbine for Jubek state requires an area size of about 28.5 m²;
- Jubek state has a wind density of about 3.65 W/m² and installation capacity about 19,757.79 MW, which is equivalent to annual energy production of about 7269.29 GWh;
- For the situation of Jubek State, the energy required for producing one ton of crops ranges between 38.34 and 1666.6 kWt⁻¹ and requires one to four turbines and an area size of 43.82–1252.09 km² for turbine installation, whereas for animal production, the energy required in producing one ton of animal products ranges between 750.06 and 8334 kWt⁻¹ and requires 2–20 turbines and an area size of 563.44–6260.47 km² for turbine installation;
- With the proposed wind turbine design addressed in this study, one turbine is sufficient to meet the domestic demands of three people.

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Appendix A

| Nomenclature | Description |
|--------------|-------------|
| ANOVA        | Analysis of Variance |
| ArcGIS       | Aeronautical Reconnaissance Coverage Geographic Information System |
| c            | Weibull scale factor |
| CRU          | Climate Research Unit |
| DEM          | Digital Elevation Model |
| GIS          | Geographic Information System |
| GJ<sup>−1</sup> | Giga Joulé per ton |
| GW           | Giga Watts |
| H            | High Elevation |
| JRA-55       | Japanese 55-year Reanalysis |
| k            | Weibull shape factor |
| kW<sup>−1</sup> | kilowatts per ton |
| kWh          | kilowatts per hour |
| L            | Low Elevation |
| LC           | Land Classes |
| LCA          | Life Cycle Analysis |
| LULC         | Land Use Land Cover |
| M            | Medium Elevation |
| m<sup>2</sup> | Meter Square |
| MATLAB       | Matrix Laboratory |
| MW           | Megawatts |
| NASA         | National Aeronautics and Space Administration |
| NGA          | National Geospatial-Intelligence Agency |
| PDFs         | Probability Distribution Functions |
| SAT          | Spatial Analyst Tool |
| STRM         | Shuttle Radar Topography Mission |
| TWh          | Terawatts per hour |
| UK           | United Kingdom |
| UN           | United Nations |
| W            | Watt |
| WGS84        | World Geodetic System 1984 |

References

1. REN 21 Renewables Now Renewables Global Status Report 2019; REN 21: Paris, France, 2019; ISBN 9783981891140. Available online: https://www.ren21.net/gs (accessed on 15 May 2019).
2. Yan, B.; Li, Q. Coupled on-site measurement/CFD based approach for high-resolution wind resource assessment over complex terrains. *Energy Convers. Manag.* 2016, 117, 351–366. [CrossRef]
3. Spröte, W. ECOSOC – Economic And Social Council. *A Concise Encycl. USA* 2010, 147–152.
4. Johnston, R. Arsenic and the 2030 Agenda for Sustainable Development. In *Proceedings of the Arsenic in the Environment—Proceedings*; Informa UK Limited: Colchester, UK, 2016; pp. 12–14.
5. Samson, R.; Mani, S.; Boddey, R.; Sokhansanj, S.; Quesada, D.; Urquiaga, S.; Reis, V.; Lem, C.H. The Potential of C4Perennial Grasses for Developing a Global BIOHEAT Industry. *Crit. Rev. Plant Sci.* 2005, 24, 461–495. [CrossRef]
6. Williams, A.G.; Audsley, E.; Sandars, D.L. Determining the Environmental Burdens and Resource Use in the Production of Agricultural and Horticultural Commodities; Main Report. Defra Res. Proj. IS0205; Cranfield University: Bedford, UK; Available online: www.silsoe.cranfield.ac.uk (accessed on 15 August 2006).
7. Woods, J.; Williams, A.; Hughes, J.K.; Black, M.; Murphy, R. Energy and the food system. *Philos. Trans. R. Soc. B Biol. Sci.* 2010, 365, 2991–3006. [CrossRef] [PubMed]
8. Pretty, J.; Ball, A.; Lang, T.; Morison, J. Farm costs and food miles: An assessment of the full cost of the UK weekly food basket. *Food Policy* 2005, 30, 1–19. [CrossRef]

9. Luetzow, M. Appendix 1.18: Food and Agriculture Organization of the United Nations. *Encycl. Toxicol.* 2005, 511–516.

10. Bailey, A.; Basford, W.; Penlington, N.; Park, J.; Keatinge, J.; Rehman, T.; Tranter, R.; Yates, C. A comparison of energy use in conventional and integrated arable farming systems in the UK. *Agric. Ecosyst. Environ.* 2003, 97, 241–253. [CrossRef]

11. Deng, J. Regional Motivation to Develop South Sudan’s Hydro Power Capacity. Available online: https://www.esi-africa.com/industry-sectors/generation/regional-motivation-to-develop-south-sudans-hydro-power-capacity/ (accessed on 14 February 2020).

12. NBHS National Baseline Household Survey 2009. 2009, pp. 1–175. Available online: https://catalog.ihsn.org/index.php/catalog (accessed on 29 March 2019).

13. Bandoc, G.; Prăvălie, R.; Patriche, C.; Degeratu, M. Spatial assessment of wind power potential at global scale. A geographical approach. *J. Clean. Prod.* 2018, 200, 1065–1086. [CrossRef]

14. Anwarzai, M.A.; Nagasaka, K. Utility-scale implementable potential of wind and solar energies for Afghanistan using GIS multi-criteria decision analysis. *Renew. Sustain. Energy Rev.* 2017, 71, 150–160. [CrossRef]

15. Ibrahim, M.Z.; Yong, K.H.; Ismail, M.; Albani, A. Spatial analysis of wind potential for Malaysia. *Int. J. Renew. Energy Res.* 2015, 5, 201–209. [CrossRef]

16. Commins, T. Maejo International Potential of Wind Power for Thailand: An Assessment. 2014. Available online: www.mijst.mju.ac.th/vol2/255-266.pdf (accessed on 31 March 2008).

17. TERRA Climate Data. Available online: file:///D:/Wind_power/Onshore_Wind1/Paper/WindPowerReference/TERRAClimateData.pdf (accessed on 5 December 2019).

18. Abatzoglou, J.T.; Dobrowski, S.Z.; Parks, S.A.; Hegewisch, K.C. TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958–2015. *Sci. Data* 2018, 5, 170191. [CrossRef] [PubMed]

19. Zhu, Z.; Woodcock, C.E. Continuous change detection and classification of land cover using all available Landsat data. *Remote. Sens. Environ.* 2014, 144, 152–171. [CrossRef]

20. Radke, R.J.; Andra, S.; Al-Kofahi, O.; Roysam, B. Image change detection algorithms: A systematic survey. *IEEE Trans. Image Process.* 2005, 14, 294–307. [CrossRef]

21. Wang, X.; Zheng, D.; Shen, Y. Land use change and its driving forces on the Tibetan Plateau during 1990–2000. *Catena* 2008, 72, 56–66. [CrossRef]

22. Wan, Z.; Zhang, Y.; Zhang, Q.; Li, Z.-L. Quality assessment and validation of the MODIS global land surface temperature. *Int. J. Remote. Sens.* 2004, 25, 261–274. [CrossRef]

23. lambin, E.F.; Turner, B.L.; Geist, H.J.; Agbola, S.B.; Angelsen, A.; Folke, C.; Bruce, J.W.; Coomes, O.T.; Dirzo, R.; George, P.S.; et al. The causes of land-use and land-cover change: Moving beyond the myths. *Glob. Environ. Chang.* 2001, 11, 261–269. [CrossRef]

24. Africa Land Used Land Cover 2016. Available online: www.2016africalandcover20m.esrin.esa.int/download.php (accessed on 2 December 2019).

25. NASA; NGA; Agencies, I. Shuttle Radar Topography Mission—Global 30m. Open Topogr. 2000. Available online: www.opentopo.sdsc.edu/raster/opentopoID=OTSRTM.082015.4326.1 (accessed on 14 December 2019).

26. Seguro, J.; Lambert, T. Modern estimation of the parameters of the Weibull wind speed distribution for wind energy analysis. *J. Wind. Eng. Ind. Aerodyn.* 2000, 85, 75–84. [CrossRef]

27. U.S. IEA. *Annual Energy Outlook 2011*; IEA: Paris, France, 2011; Volume 2011, ISBN 2025869592.

28. Li, Y.; Wu, X.-P.; Li, Q.-S.; Tee, K.F.; Yi, L.; Xiao-Peng, W.; Qiu-Sheng, L.; Fah, T.K. Assessment of onshore wind energy potential under different geographical climate conditions in China. *Energy* 2018, 152, 498–511. [CrossRef]

29. Mostafaeipour, A.; Abarghooei, H. Harnessing wind energy at Manjil area located in north of Iran. *Renew. Sustain. Energy Rev.* 2008, 12, 1758–1766. [CrossRef]

30. Bina, S.M.; Jalilinasrabady, S.; Fujii, H.; Farabi-Asl, H. A comprehensive approach for wind power plant potential assessment, application to northwestern Iran. *Energy* 2018, 164, 344–358. [CrossRef]

31. Mostafaeipour, A.; Jadidi, M.; Mohammadi, K.; Sedaghat, A. An analysis of wind energy potential and economic evaluation in Zahedan, Iran. *Renew. Sustain. Energy Rev.* 2014, 30, 641–650. [CrossRef]

32. U.S. Environmental Protection Agency Screening Sites for Wind Energy Potential. 2014. Available online: http://www.epa.gov/renewableenergyland/docs/wind_decision_tree.pdf (accessed on 14 February 2020).
33. Tan, Y.; Tan, Y.; Zhu, Y. Fireworks Algorithm for Optimization. In *Advances in Swarm Intelligence*; Springer: Berlin/Heidelberg, 2015; pp. 355–364.
34. Waewsak, J.; Kongruang, C.; Gagnon, Y. Assessment of wind power plants with limited wind resources in developing countries: Application to Ko Yai in southern Thailand. *Sustain. Energy Technol. Assess.* 2017, 19, 79–93. [CrossRef]
35. African Development Bank South Sudan: An Infrastructure Action Plan South Sudan. A Program for Sustained Economic Growth. 2013, pp. 1–321. Available online: https://www.afdb.org/fileadmin/uploads/afdb/Documents/GenericDocuments/SouthSudan (accessed on 14 February 2020).
36. Clapp, J. *The Global Food Crisis: Governance Challenges and Opportunities*; Wilfrid Laurier University Press: Waterloo, ON, Canada, 2009; ISBN 1554581923. Available online: https://www.academia.edu/21307291/The_Global_food (accessed on 14 February 2020).
37. FAO Food and Agriculture Organization in the 21st Century: Ensuring Food Security in a Changing World. 2011. Available online: www.fao.org/3/i2390e/i2390e00.pdf (accessed on 14 February 2020).
38. FAO Energy-Smart Food for People and Climate. Issue Paper. RomeFood Agric. Organ. United Nations 2011. p. 66. Available online: www.fao.org/3/i2454e/i2454e00.pdf (accessed on 14 February 2020).
39. State, T.; Insecurity, F. The State of Food Insecurity in the World 2010 Technical Notes. 2020, p. 6. Available online: http://www.fao.org/fileadmin/templates/publications/pdf/SOFI-2010_Technical_Notes_en.pdf (accessed on 14 February 2020).
40. IPC Integrated Food Security Phase Classification the Republic of South Sudan May 2017 Projection Period for Most Likely Scenarios: June–July 2017. 2017, pp. 1–5. Available online: https://reliefweb.int/sites/reliefweb.int/files/resources/IPC_SouthSudan_AcuteFI_Jan (accessed on 14 February 2020).
41. Programme, W.F. FAO/WFP Crop and Food Security Assessment – Sierra Leone; FAO: Rome, Italy, 2014; ISBN 9789251091616. Available online: www.fao.org/3/a-i7450e.pdf (accessed on 14 February 2020).
42. Feng, J.; Feng, L.; Wang, J.; King, C.W. Evaluation of the onshore wind energy potential in mainland China—Based on GIS modeling and EROI analysis. *Resour. Conserv. Recyc.* 2020, 152, 104484. [CrossRef]
43. Diffendorfer, J.E.; Compton, R.W. Land Cover and Topography Affect the Land Transformation Caused by Wind Facilities. *PLoS ONE* 2014, 9, e88914. [CrossRef] [PubMed]
44. Traiteur, J.J.; Callicutt, D.J.; Smith, M.; Roy, S.B. A Short-Term Ensemble Wind Speed Forecasting System for Wind Power Applications. *J. Appl. Meteorol. Clim.* 2012, 51, 1763–1774. [CrossRef]
45. McDonald, R.I.; Fargione, J.; Kiesecker, J.; Miller, W.M.; Powell, J. Energy Sprawl or Energy Efficiency: Climate Policy Impacts on Natural Habitat for the United States of America. *PLoS ONE* 2009, 4, e6802. [CrossRef]
46. Kiesecker, J.M.; Evans, J.S.; Fargione, J.; Doherty, K.; Foresman, K.R.; Kunz, T.H.; Naugle, D.; Nibbelink, N.P.; Niemuth, N.D. Win-Win for Wind and Wildlife: A Vision to Facilitate Sustainable Development. *PLOS ONE* 2011, 6, e17566. [CrossRef]
47. Fazelpour, F.; Markarian, E.; Soltani, N. Wind energy potential and economic assessment of four locations in Sistan and Balouchestan province in Iran. *Renew. Energy* 2017, 109, 646–667. [CrossRef]
48. Size, W.; Turbine, W.; Need, D.I.; Do, W.; Systems, W.; Can, W.; Installation, I.F.; Off-grid, C.I.G. Small Wind Guidebook. 2019; pp. 1–22. Available online: https://windexchange.energy.gov/small-wind-guidebook (accessed on 14 February 2020).
49. Dabbaghiyan, A.; Fazelpour, F.; Abnavi, M.D.; Rosen, M.A. Evaluation of wind energy potential in province of Bushehr, Iran. *Renew. Energy* 2016, 55, 455–466. [CrossRef]
50. Arreyndip, N.A.; Joseph, E. Small 500 kW onshore wind farm project in Kribi, Cameroon: Sizing and checkers layout optimization model. *Energy Rep.* 2018, 4, 528–535. [CrossRef]
51. International Energy Agency [IEA] World Energy Outlook 2010 Edition. 2010, pp. 1–735. Available online: http://www.worldenergylayoutoutlook.org/media/weo2010.pdf (accessed on 14 February 2020).
52. Enevoldsen, P.; Permien, F.-H.; Bakhtaoui, I.; Von Krauland, A.-K.; Jacobson, M.Z.; Xydis, G.; Sovacool, B.K.; Valentine, S.V.; Luecht, D.; Oxley, G. How much wind power potential does europe have? Examining european wind power potential with an enhanced socio-technical atlas. *Energy Policy* 2019, 132, 1092–1100. [CrossRef]