energies

Article

Spatio-Temporal Analysis of Solar Energy Potential for Domestic and Agricultural Utilization to Diminish Poverty in Jubek State, South Sudan, Africa

Adam Juma Abdallah Gudo, Marye Belete, Ghali Abdullahi Abubakar and Jinsong Deng *

College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310058, China; 11714072@zju.edu.cn (A.J.A.G.); maryre_belete@zju.edu.cn (M.B.); ghaliaa@zju.edu.cn (G.A.A.)

* Correspondence: Jsong_deng@zju.edu.cn; Tel.: +86-571-8898-2623

Received: 29 January 2020; Accepted: 12 March 2020; Published: 17 March 2020

Abstract: The study aimed to generate informative data on solar radiation in order to establish sustainable solar energy that will support domestic needs and agricultural production and processing industries in Jubek State, South Sudan. Solar radiation intensity, timely data variation, site landscape, and environment were considered. Input data used was remotely sensed data, digital elevation model, land used land cover (LULC) processed with Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS). The spatio-temporal distribution analysis results show that (62%) 11,356.7 km^2 of the study area is suitable for solar energy farm with an annual potential of about 6.05 × 109 GWh/year out of which only 69.0158 GW h/year is required to meet the local demand of 492,970 people residing in the study area, i.e., 0.11% (1249.2 km^2) of Jubek State. Solar energy required for producing and processing 1 ton of different crop ranges between 58.39 × 10^{-6} and 1477.9 × 10^{-6} GWh and area size between 10.7 and 306.3 km^2, whereas 1 ton of animal production requires solar energy ranging between 750.1 × 10^{-6} and 8334 × 10^{-6} GWh and area of about 137.8 to 1531.5 km^2. These findings will assist in the establishment of agro-processing industries which will eventually lead to poverty reduction through job creation and improvement of food quantity and quality. The simple approach applied in this study is unique, especially for the study area, thus it can be applied to some other locations following the same steps.

Keywords: solar energy; spatio-temporal analysis; DEM; LULC; GIS; agro-processing industries; poverty

1. Introduction

The most driving elements of energy demand can be estimated by population size, industrial activities, and geographical variation, whereas as energy users can be categorized based on their ability to pay energy cost, and energy production efficiency [1]. The most dominant source of energy throughout history is fossil fuels, thus; over-dependence on these sources of energy is responsible for upgrading and promoting most environmental degradation through carbon dioxide emissions which is harmful to human health as well as to most living things [2]. These drawbacks of high consumption of fossil fuel motivate much research in the field of renewable energy [3].

Several researchers predicted that the growth in the renewable energy sector will promote global energy production due to the abundance of solar energy across the world and eventually will minimize the negative human impact on the environment [3]. Recently serious attention was given to photovoltaic (PV) energy due to a drastic expansion as one of the promising alternative potential renewable energy sources with a broad sense of advantages mostly for areas with a high electrical cost from the grid connection or remote locations [4]. Although solar energy contains a huge amount of energy to supply and support the world's energy demand, still it contributes less than it could [5]. Evidence from the global energy market revealed that solar energy has the potential to generate enough power to compete in the large scale market [6]. The U.S. solar market has shown a great drop in the cost of solar energy production due to remarkable practices shown in advanced methods in manufacturing solar panels [7]. The growth of PV markets will lead to standardizing designs by the manufacture and methods of system installation and publishing efficient practices in order to minimize the cost of PV energy production [8]. Besides the dropping cost of PV technology and hardware, the achievement of PV utility power production has the ability to harvest a significant part of the energy market. Currently, PV supplies the global energy market with about 3%, however, countries whereby most of their energy systems are supported by renewable energy sources rely on up to 30% of electricity from wind and solar energy [9].

Software tools make it easier to understand the geographical nature of a given location through raster (grid-based) map, thus, it is possible to display visual information on habitats, risk development, fire potential, and potential solar energy sites. Such information is useful for decision-makers in sustainable planning and developmental practices [3]. Major infrastructure policy decision can be made through advanced methods of data processing and availability of geospatial data [10]. These types of tools assist in the case of management of large scale data that balance the potential of energy production and estimate potential cost consideration and conflicts [11]. In fact, evidence from the literature proved that the GIS approach has gained positive attention from the inappropriate analysis of renewable energy resources across the world [12,13]. Remarkable efforts were injected by several researchers in this regard; study on identification of suitable land for the installation of a large PV project was conducted in Oman through the GIS approach [14]. In order to determine the available rooftop area for PV installation, especially in buildup areas, the authors of [13] introduced an approach to integrate the capability of GIS and an object-specific image. In Dhaka Quickbird high-resolution optical satellite imagery was used to locate and determine bright rooftops in order to estimate the potential of solar energy generation [15]. In Jiangsu province, the authors of [16] determined the existing solar panels placed at the roof taking into consideration both social and natural limitations. Research on the geographical, technical, and economic potential of renewable energies was conducted at various levels across the globe [17]. In Western Australia, a high-resolution grid was used to merge environmental factors and electricity sites in order to access the potential solar system for power generation [18]. In Fujian province, a high-resolution grid map was applied to study the comprehensive potential analysis of solar PV [19].

Locating suitable sites for solar energy establishment influenced purchase cost, the efficiency of solar power, environmental impacts, and local community view [20]. The most parameters contributing to the achievement of solar system installation include physical properties such as slope, water body, streets, land cover, and grid connectivity. High environmental impacts should be seriously avoided and it is free to access data related to such constraints [21].

Furthermore, the location of solar installation can be influenced by social attitudes [3]. While the literature reported that the majority of the global nations encourage renewable energy [22,23] and especially solar energy [24,25], the establishment of large scale solar has been held back due to limitations such as cost, efficiency, and local regulations [24]. Previously local populations have been blamed for slowing the development of solar systems due to land ownership, however, researchers found that many factors contribute to the way renewable projects are opposed or supported. In fact, even environmentalists were involved in opposing solar projects, especially on rare desert plants and animals [3]. A report from San Luis Valley of Colorado, USA, proved that local people agreed with an environmental group to oppose a concentrated power facility because of the negative impact of the project on the local ecosystem; mostly in regards to transmission line, and despite appreciating another positive role of solar energy on the environment [25]. This evidence is not an exceptional case; despite supporting the expansion of the solar system as well as another renewable energy source, specific projects are often met with serious opposition [17]. Therefore, it is crucial to consider factors influencing public attitude in order to achieve a successful establishment of solar energy and another renewable source.

1.1. Environmental Impacts of Solar Energy Systems

Despite the environmental and social benefits given by solar energy technologies, it also supports remarkable negative direct and indirect impacts on water utilization and consumption, biodiversity, topsoil and dust, social wellbeing and air quality, transmission passages, land use land cover alteration [26,27].

Firstly, water use and consumption should be addressed; solar energy systems are normally installed at open spaces to capture maximum solar radiation, which results in a collection of many types of waste materials that reduce its performance [21,28]. Washing and cleaning such obstacles requires sufficient water [29]. So far, utilizing water for washing panels is the most dominate method used for dust cleaning, especially in large solar farms [30]. Other technologies (electrostatic and chemical sprayers) used in dust removal are either not commercially available or not clearly understood [31,32]. Therefore, water source and availability should be considered while planning to install a solar power system. Secondly, biodiversity must be considered; in some cases, installation of solar farms requires removal of vegetation cover and soil. To reduce the harmful impact on both environment and human beings, feasibility studies should take place with the aim of optimizing renewable energy and conservation goals [33]. Evidence from South Africa revealed that strategic locating of solar energy farm infrastructure could generate a capacity of 548 gigawatts while evading all habitats supporting threatened vegetation [33]. Besides, some species are not easily moved and may be easily attracted to given solar infrastructural parts. McCrary reported that death rates, relative to other anthropogenic influences on birds, reduce for solar farm systems [30]. Threats to biological diversity can be referred to as habitat damage and destruction [28]. There is a great variation in solar system installation in terms of layout design, land use, and footprint [21], and this results in unique approaches on the effects of individual power plants to landscapes. Large solar energy farms may fragment habitat and act as direct obstacles to the movement of wildlife species. The choice of location for solar plants should consider existing species distributions, but wildlife dispersal passages and future distributions will be altered by climate change [26]. Determining species reactions to original climate periods is characteristically indeterminate and scale-dependent, but still, there are available tools to model such distributional periods [28]. Thirdly, human health and air quality must be considered. Large solar energy farms are similar to any other large industrial plants in terms of carriage hazards to air quality, employee health, and the public [28]. These types of hazards comprise soil-borne pathogens [34], increase air particulate matters [30], decrease visibility for drivers on close roads, and pollute water sources [21]. Fourth, land-use and land-cover change must be considered. Energy, and land use land cover are well associated [4]. In the process of installing or establishing energy systems, there is an alteration in biological and physical properties of land cover per m^2, change in people utilization or intention to land use per m^2, and a limited time frame for using land m^2 times yr [35,36]. Recent researchers focused on investigating the relationship between land uses and large solar energy farms, it was found that comprehensive energy conversion sequence of a solar system depends on material acquirement, setup, module creation, assembly, processing and maintenance, material clearance, and decomposition [31]. The indirect impact associated with materials and solar energy is insignificant (22.5 and 25.9 m^2/GWh^1) relative to direct land use [35]. Limited data is available in the literature on the occupation of land by the solar system; however, the lifetime of large solar power farms is typically expected to be around 30–60 years [35]. So far, data is absent throughout the literature on the evaluation of solar system efficiency (W/m^2) and layout, and the infrastructural and architectural plan of solar energy houseplants may influence ecosystem recovery and reversibility [28]. However, ordinary recovery of ecosystems such as arid land can be extraordinarily slow [37].

1.2. Land Tenure in South Sudan

The land is considered to be one of the most multifarious subjects in South Sudan. It mostly affects livelihoods and development progress. In general, there are three categories of land ownership in South Sudan; i.e., public, private, and community land. Private land refers to areas belonging to individuals in freehold or leasehold for a time duration of 30 years etc. Public land belongs to the government and it is typically in freehold. Community land is owned by a given group of people regulated by tribal/clan relationship, and land allocation is based on customary law. In locations under kingdom system, the land is owned and assigned in the king, who then practices his authorities over it via his chiefs and clan leaders. People under a given kingdom have the rights of land ownership, but the king has the final say to gift a piece of land to outsiders, especially charity organizations or investment [38].

The right to land ownership in the community originates from belonging to the community via common tradition. Everyone in a given community is entitled to own land for livelihood, whether as farmer or herder, although the community holds the decision of land and resources management kept for shared use such as water bodies and cattle camps. In South Sudan, there are four major means of accessing land under the customary act, i.e., allocation, inheritance, gift, and purchase [39].

1.3. The Energy in South Sudan

Grid electricity supplied by a thermal system is the only source of energy in South Sudan with poor coverage of only 1% of the entire country [40]. It was reported that the per capita of national electricity is between 1 and 10kWh based on the living style across the country [41]. In the rural areas of South Sudan, people rely on direct biomass (firewood and charcoal) and fossil fuel (kerosene) for cooking and lighting, whereas in urban areas solar array units are applied for lighting and entertainment [42]. Out of the total electricity coverage within the country, about 42 MW power has been installed by private petroleum companies at oil fields and another 21 MW was installed by a private company known as Ezra to supply the capital city Juba [40]. The on-going government plan is to establish large hydro plants along the Nile River. The expected dates for operating these proposed plants are as follows; Juba Barrage 2026, Badden in 2028, Lakki in 2033, Grand Fula in 2035, and finally Shukole in 2040 [40]. Therefore, it is important to support the current situation in South Sudan in general and the study area in particular with an alternative source of energy such as solar.

1.4. Objectives

The aim of this study is to generate informative data on solar radiation that will assist in the establishment of sustainable power production from solar energy in a strategic manner. In this study, the targeted area of application is to support agricultural production within and out of the farm gate. To conduct this work, several factors were taken into consideration, i.e., solar radiation intensity, timely data variation, site landscape, and environment. Various input data were used which includes remotely sensed data of solar radiation time series, a digital elevation model map (DEM), and land used land cover (LULC) map (Figure 1). It should be considered that although some other parameters may influence the study of the solar system such as installation cost, the finding of this work generally supports planning and implementation of solar energy, especially in the area of agricultural production and processes.

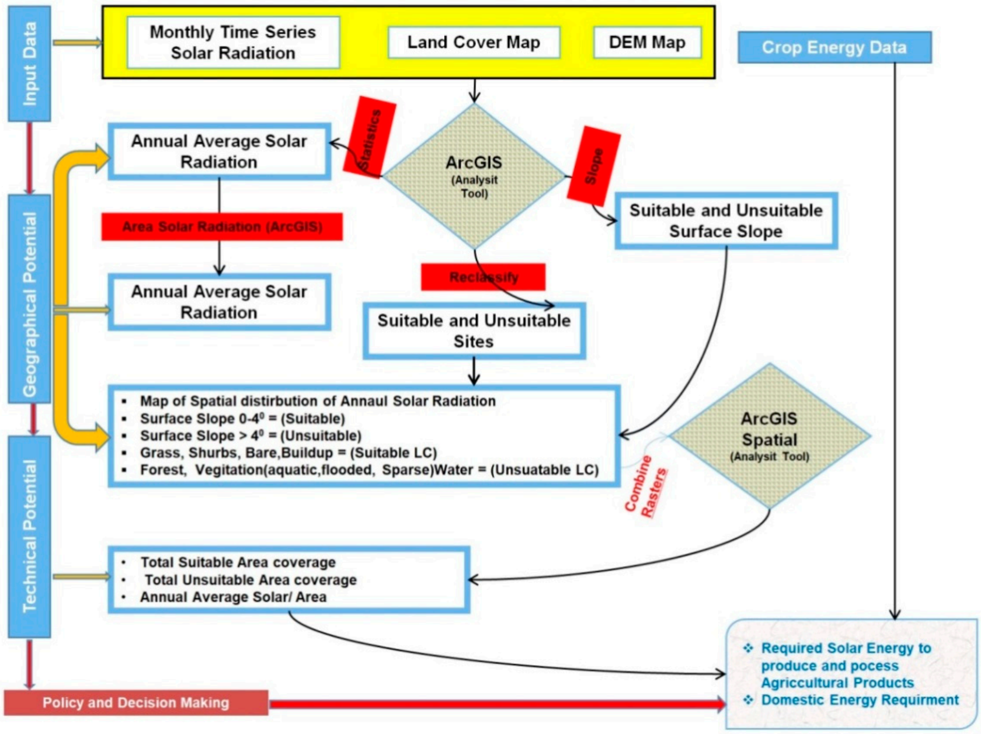

Figure 1. Conceptual framework of solar energy generation.

2. Materials and Methods

2.1. Study Area

The study area is a member of East Africa countries located in the Southern part of the Republic of South Sudan, exactly where the capital city of the country is located (Figure 2B). The study area lies between a longitude of 32°0′0″ E and latitude of 4°0′0″ N with an average total area of about 18,505 km^2 (Figure 2A). The maximum temperature ranges between 32.4 and 35.3 °C and a minimum temperature range between 18.8 and 21.7 °C (Figure 2C). The rainfall period in Jubek state is between April and October with an average of about 100 mm per month, but between December and February, it remains almost dry. The average annual rainfall is about 955 mm. The sun always shines during the dry season, but reduces a bit during training periods. From September to February it shines 8–9 h per day and 6–7 h from March to August.

2.2. Data Set and Processing

2.2.1. Solar Radiation Data

The solar radiation data was obtained through satellite measurements of down solar radiation (DSR) from Terra Climate data. It is a temporal metadata ID in the form of Network Common Data (net CDF) [17]. It is high-resolution data of (1/240, 4-km) available on a monthly basis since 1953–2018. The satellite data was processed in ArcGIS 10.7.1, especially the Spatial Analyst tool. In order to study the trends of solar radiation time series, monthly and annual data were identically obtained during 1958–2018, which was divided into seven intervals (2018, 2008, 1998, 1988, 1978, 1968, and 1958). Terra Climate provides both water balance and meteorological parameters namely; solar radiation, precipitation, maximum and minimum temperature, wind speed, vapor pressure, and evapotranspiration. The principal of this dataset is based on the utilization of climatically maintained interpolation, in order to relate high spatial resolution climatological standards obtained from the World Clim dataset at monthly based time series coarser resolution data. Data were originated and harvested from the Climate Research Unit (CRU) and the Japanese 55-year Reanalysis (JRA-55) in order to produce a monthly dataset of the mentioned parameters i.e., water balance and meteorological. For accuracy and validation of Terra Climate data, [18] conducted a study using ground data for estimated reference evapotranspiration, annual temperature precipitation, and runoff data from flow stream stations. Their results show a highly significant improvement in overall temperature and precipitation mean of subpar correlation of *p* value = 0.8 and 0.90, respectively. Therefore, they recommended the use of the Terra Climate dataset as input in hydrological and ecological investigations at a global scale which requires spatial resolution and long time-series data.

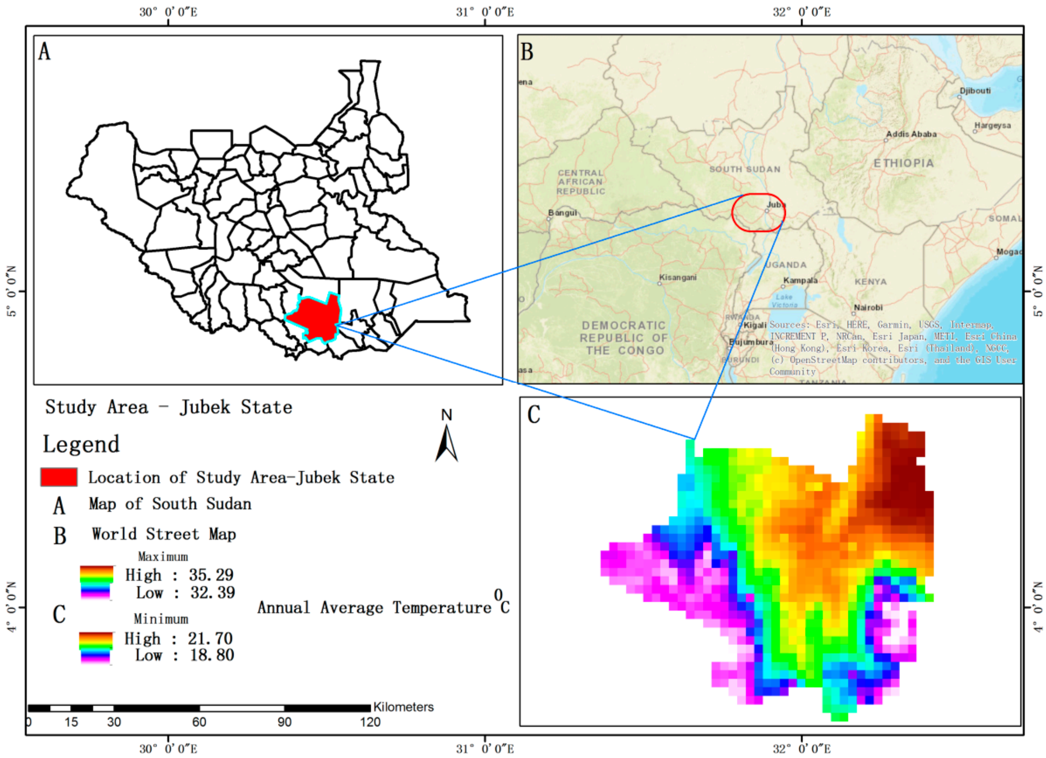

Figure 2. Location of the Study Area, Jubek State, South Sudan.

2.2.2. Digital Elevation Model (DEM)

The digital elevation model (DEM) was obtained from Shuttle Radar Topography Mission (STRM) which contains elevation data for a given location with high-resolution digital topographical data of 30 m. STRM provides an improved radar system that coasted onboard the space shuttle endeavor. STRM is managed by National Geospatial-Intelligence Agency (NGA) and NASA at a global level [25]. For data processing, the slope tool in the spatial analyst of ArcGIS 10.7.1 was used to identify the surface slope, and then the study area was categorized based on the resulting ranges of various locations. This was helpful in differentiating the suitable sites from the unsuitable ones within the study area. Slopes from 0° to 4° were considered suitable for solar radiation projects, whereas slopes more than 4° are unsuitable (Figure 3).

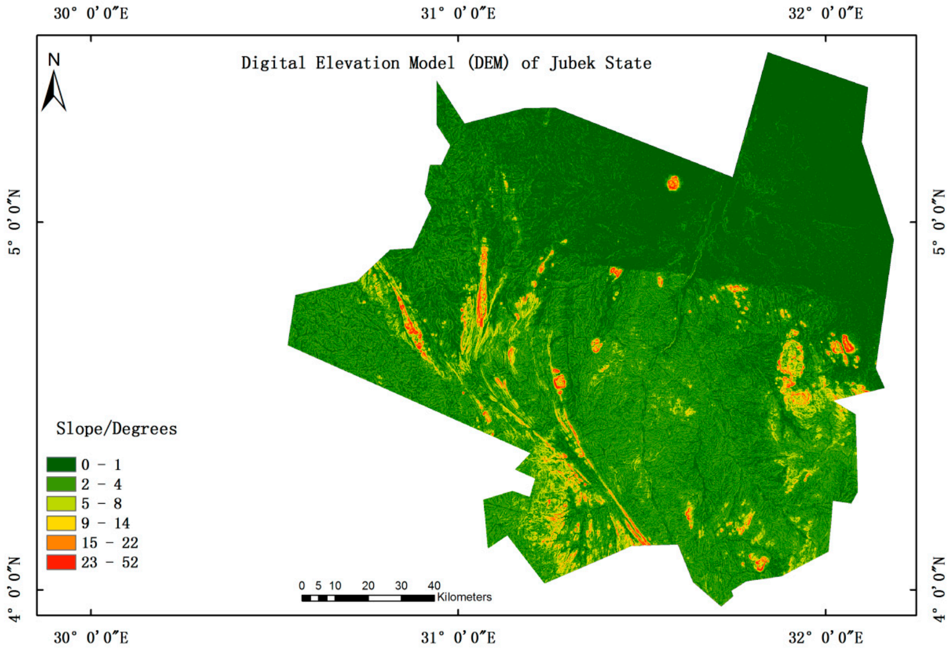

Figure 3. Digital elevation model of Jubek State.

2.2.3. Land Use Land Cover (LULC)

The LULC of the study area was obtained from the Climate Change Initiative (CCI) Land Cover (LC) team for Africa. It is a high-resolution data at 20 m according to sentinel-2A observations for one year, i.e., December 2015 to December 2016 (Figure 4). World Geodetic System 84 (WGS84) reference ellipsoid was the coordinate used and LULC was classified into 10 classes (cropland, trees cover areas, grassland, shrubs cover areas, built-up areas, vegetation aquatic or regularly flooded, bare areas, open water, lichen and mosses/sparse vegetation, and snow and ice) for the study areas, and nine classes were captured with exception of snow and ice land cover [43] (Table 1).

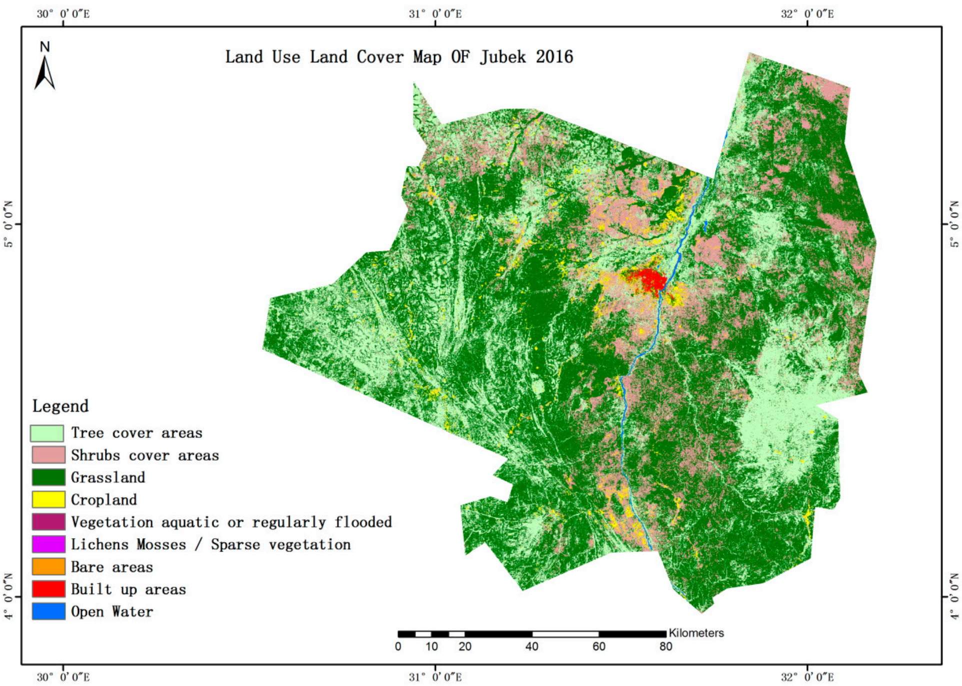

Figure 4. Land use land cover map of Jubek State.

Table 1. Land used land cover classes of Jubek State 2016.

Class Code	Land Cover Class	Area km^2
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 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

2.3. Estimation of Solar Radiation

The first step was to estimate solar radiation for the study area and it was achieved by the help of TEERA high-resolution solar radiation map of Jubek State. It was calculated with the help of ArcGIS 10.7.1 through special analysis tools designed for solar radiation analysis and it was commonly used in the literature [14,18]. The module includes atmospheric effects, location geographic coordinates and elevation, slope, aspect, changing of sun angle at daily and seasonal bases. Shadows effects are a result of nearby topography and they alter the atmospheric transmissivity coefficient [14]. The amount of solar radiation was estimated for the entire sun and sky maps, and the module is the sum of direct and diffuse radiation. DEM as the main input parameter was obtained from Shuttle Radar Topography Mission (STRM), and also the coefficient of the atmospheric transmissivity. The generated grid maps, a total of 12 times monthly and 19 times annually, a sum of global horizontal radiation in Jubek State.

2.4. Estimation of Solar PV Generation Potential

A hierarchical approach was applied for estimating the amount of electric power potential from solar PV [17]. In this study, three types of potentials are defined.

- Geographical potential: refers to the sum of annual solar radiation over the appropriate sites, and during the evaluation various constraints related to the geographical condition were considered.
- Technical potential: refers to the number of locations with considered potentials that can be altered into electric power using solar systems.
- Agricultural production and processing potentials: refers to solar energy required for production and processing agricultural materials through the life circle approach (LCA).

2.4.1. Estimation of Geographical Potential

The study of geographical potential is to locate the most appropriate land cover types for installing solar energy plants while considering geographical limitations within the study area. In a broad sense, there are two types of approaches used for solar system generation. (a) A large scale solar system site located outside of urban or built up areas; (b) rooftop PV mostly are installed within built up areas. In this study, the solar energy potential for both models was estimated. Slopes greater than 4°, farmland, water bodies, and natural reserve areas were considered geographical constrained locations as reported in the literature [18,19]. A land cover map of the study area was extracted from the LULC map developed by the CCI Land Cover team for Africa with high resolution at 20 m based on Sentinel-2A from December 2015 to December 2016 (Figure 4). The extracted map was reclassified into three classes (Buildup, non-buildup, and unsuitable sites) used in the identification of targeted areas in this study (Figure 5). For the purpose of this study, classes provided in this map were reclassified using the ArcGIS map reclassify tool. The restriction and appropriate locations for the establishment of the solar system were identified. The result of solar radiation in a given cell multiplied by its area is known as the solar PV potential at that location (Equation (1)). For calculating rooftop solar potential, Equation (2) was applied.

$$W_i = B_{i\delta\alpha} \tag{1}$$

$$Pi^G = R_i W_i \tag{2}$$

where *Wi* is the accessible roof area in the grid cell *i*, *Bi* is the area covered of the buildup area in the grid cell *i*, δ is the ratio between the area of building rooftop and the total area of buildup, α is the familiarizing ratio of roof-mounted PV system; the geographical potential (*PG*) in grid cell *i* in the buildup area, *Ri* is the annual total amount of solar radiation in the grid cell *i*. The familiarizing ratio frequently changes due to various impacts including planning, roof area shadow, etc. The value of δ generally ranges from 0.15 to 0.3 in most of the previous studies reported in the literature [19]; in this study 0.2 was selected.

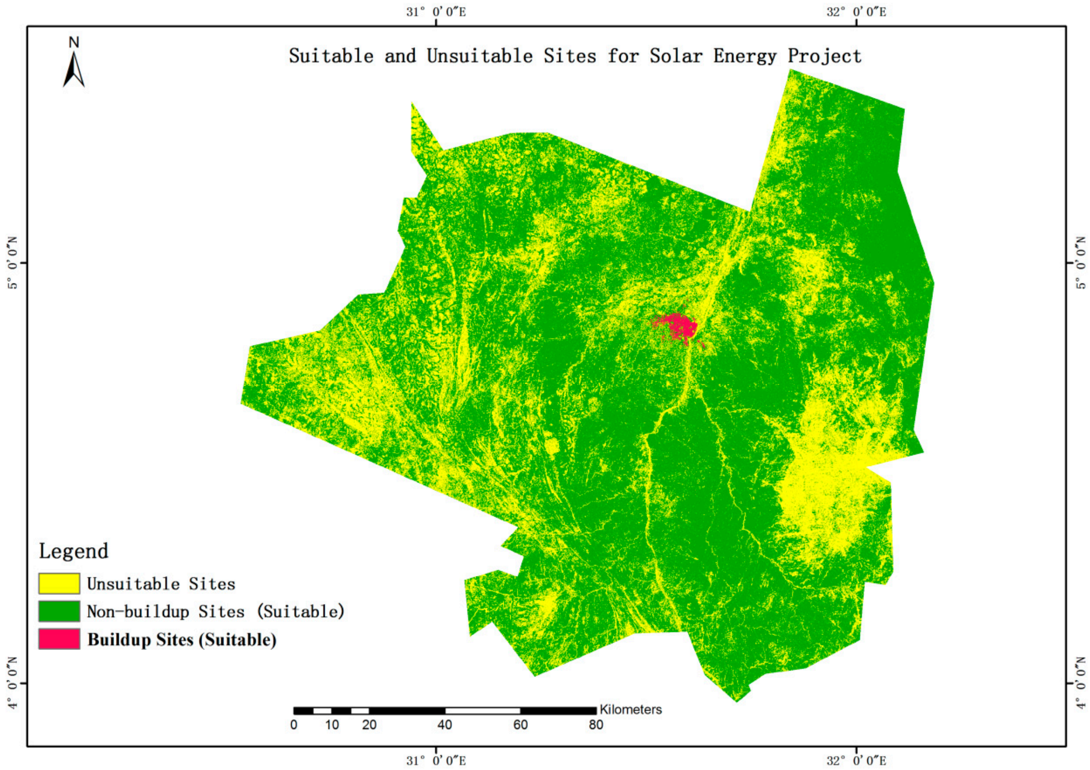

Figure 5. Reclassified land used land cover.

2.4.2. Estimation of Technical Potential

Technical specification of the PV production system is the determined goal while assessing solar energy technical potential of a study area. Three parameters are determining factors of PV generation; i.e., available solar potential of a specific location, capacity, and performance ratio of the solar system. The total annual electric production of PV in the grid cell *i*, was determined by applying Equation (3).

$$E_i = \frac{P_i G_{i\eta T}}{1000\ \mathrm{w/m^2}} \tag{3}$$

where *Pi* is the maximum power of the PV system placed in grid cell *Gi*, is the annual sum quantity of universal radiation on the horizon in grid cell *i*, ηT is performance ratio of the solar system. An ordinary value for the solar system with modules mono or polycrystalline is about 0.75 [44].

2.4.3. Estimation of Solar Energy Requirement for Agricultural Practices

It was generally observed that agricultural yield improvements result in positive energy ratios, and this can be justified by outweigh gained as a result of using fossil energy as an input to agricultural activities; the harvested crops contain more energy than the energy consumed in crop production [45].

Life cycle analysis (LCA) is a well-recommended approach for analyzing a product or a system of environmental impacts such as crop and animal products, and practical evidence was reported by [45,46]. The aim of their study was to study the energy requirement for the mentioned product from up to the farm gate. The selected crops were maize, wheat, sugarcane, beans, oilseed, rape, and potatoes, whereas the animal products were the meat of lamb, poultry, beef, and pork in addition to eggs and milk. Out of the farm gate, in [45] the authors conducted research with the aim of estimating the energy consumed in transporting agricultural products from the farm to consumption locations.

In the LCA approach all energy used in the production process should be considered, and the authors considered direct energy as a type of energy consumed in fertilizer, buildings, machinery, and pesticides together with diesel and other forms of fuel, in addition, energy used in animal production was estimated from feed crops as well as breeding overhead. Their finding was based on UK standards, and it was estimated that energy used by agricultural products ranged from 1 to 6 GJ^{t-1} (Table 2). The difference in energy was directly related to types of crops and animals, in addition to the type of farming system applied i.e., organic or inorganic systems or performing integrated farming or conventional farming [47].

Table 2. Energy required for production(kW^{t-1}) [46].

Product Type	**Product**	**Required Energy kW/h $^{t-1}$** Non-Organic	**Organic**
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 (US)	1019.526	897.294
	Sugarcane (Brazil)	58.338	
	Maize	669.498	
Animal Production	Poultry	4722.6	
	Pig meat	6389.4	
	Beef	8334	
	Lamb meat	6111.6	
	Milk	750.06	
	Eggs	3333.6	

2.5. Overlay of the Data Sets

The main goal of this paper was to estimate suitable locations and to identify the potential of solar energy in the study area. This was achieved by overlaying three data sets; i.e., solar radiation map, LULC map, and DEM map of the study area in one single raster. Using the combined tool of spatial analyst tool in ArcGIS, the raster files were properly combined, resulting in a new raster with a table showing detailed information on these three parameters. Coordinates for each location were then generated. After the combination process, the new raster contained 845 counts/pixels and each count represented a pixel and was helpful in calculating the area size of each category based on LULC and slope angle.

2.6. The Uniqueness of the Study Method

The important task was to identify the suitable and unsuitable land cover with the respected area size for solar energy installation. This was done by reclassifying the obtained LULC map with an initial nine classes to three classes (suitable and unsuitable sites) (Figure 5). The four suitable classes were grassland, shrubs cover, built-up, and bare areas, and the unsuitable classes were open water, lichen and mosses/sparse vegetation, vegetation aquatic or regularly flooded, cropland and tree cover areas. Using the editor tool in ArcGIS, the classes were sorted in ascending order for easily locating pixels under each class. Both the combined raster and attribute tables were displayed, and then marking a group of a given class on the table made it easier to identify each type of class. All related data to solar radiation, slope angle, LULC, and coordinate point were saved in an excel sheet for more mathematical and statistical operations.

The second step was to identify the suitable and unsuitable slopes from the combined raster file. The same procedures followed in the identification of LULC were typically applied for slope angle as well. Here slops from 0° to 4° were classified separately, whereas slope above 4° was grouped under one type. Eventually, all data related to solar radiation, LULC, and coordinate point were saved in an excel sheet for more mathematical and statistical operations.

The obtained results show a mix up of unwanted and wanted LULC and slope angle, i.e., some locations in terms of LULC are perfectly suitable but fall in a surface area with a slope more than 4°, and likewise, some surfaces are within the acceptable range but at unwanted LULC. Therefore, in order to obtained optimum locations, all the unwanted LULC and the slopes should be eliminated from the final map. To achieve this, first, we converted the combined raster into a vector shape using the conversion tool in ArcGIS (raster to polygon tool) and then overlaid it with the combined raster and highlighted all the unwanted pixels for LULC and slope, and then their covered areas were eliminated from the final map. To calculate area per pixel of the combined raster we applied cross multiplication methods to relate the pixels in the original LULC map with the newly combined raster, i.e., area of a single pixel equals the total area of the study area divided by total pixel generated in the combined raster. Therefore, to calculate the total area covered for a given class of LULU or slope, the total pixel under that particular class must be considered.

3. Results

3.1. Spatial Distribution of Solar Energy Resource in Jubek State

The solar energy resource for a given location depends on latitude, variation in a local climate condition, site, and continentality [19,44]. In order to understand site variations in the study area, solar radiation spatial distribution of monthly solar radiation was generated. One single grid unit contains the total values within a given zone [19]. Based on general observation, there is a variation in the amount of monthly solar radiation within the study area; it ranges from 2473.6 to 2564.5 kWh/m^2 (Figure 6). It shows that Jubek state has excellent solar radiation throughout the year with relatively high values recorded in central and Southern sites, moderate in most of the Eastern sites, and reduces towards the Western and northeastern border of the study area.

3.2. Temporal Distribution of Solar Radiation

For effective planning in utilizing solar energy, it requires detailed data on monthly variability of solar radiation. Average monthly solar radiation in the study area from the year 1958 to 2018 is shown in Figure 7. It shows that the highest solar radiation ranges between 2253 and 2286 kWh/m^2 observed in February and November. Moderate values range between 2161 and 2239 kW/hm^2 were recorded during January, March, April, May, September, October, and December. Low values between 1919 and 2099 kW h/m^2 were observed in March and September.

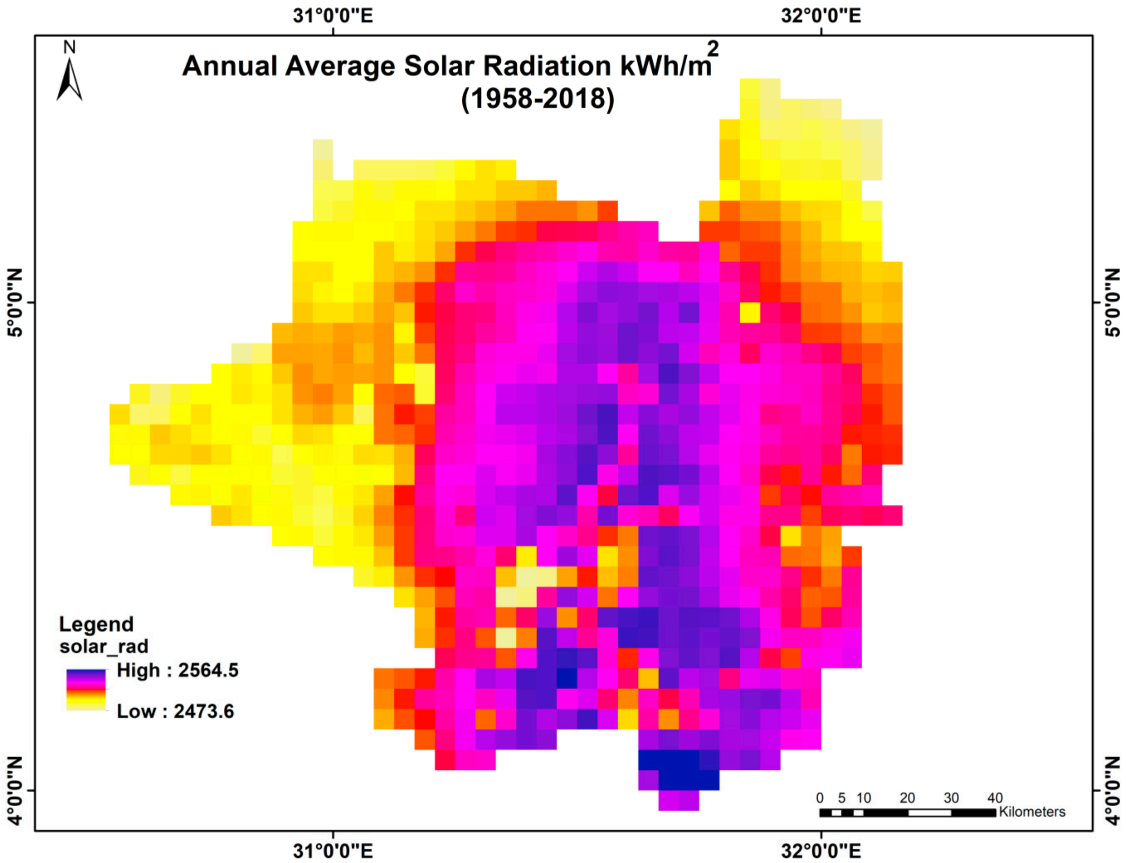

Figure 6. Spatial distribution of average annual solar radiation (kW/m^2).

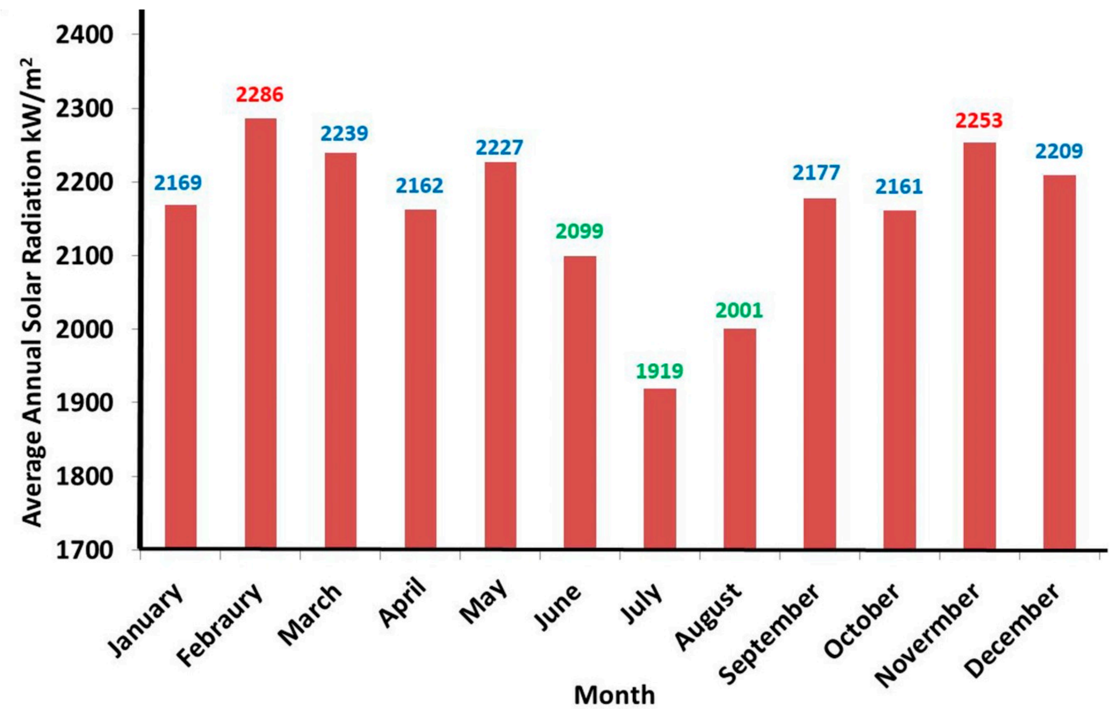

Figure 7. Temporal distribution of monthly average solar radiation (kW h/m^2) (1958–2018).

3.3. Geographic Potential of the Study Area

3.3.1. Suitable and Unsuitable LULC

Figure 8 shows the spatial distribution of suitable and unsuitable LULC for the installation of solar energy before combining the three input raster maps (LULC, surface slope, and solar radiation). In Table 3, both buildup and non-buildup are grouped under suitable sites. Suitable sites cover 63.2% (11,573.4 km^2) of the study area with an equivalent potential solar energy of about 6,355,736 TWh/year. Unsuitable locations account for 36.8% (6740.31 km^2) of Jubek state with solar energy of about 2,972,840 TWh/year. The total pixels generated after combining the three raster maps is 845 for the entire study area of about 18,313.7 km^2.

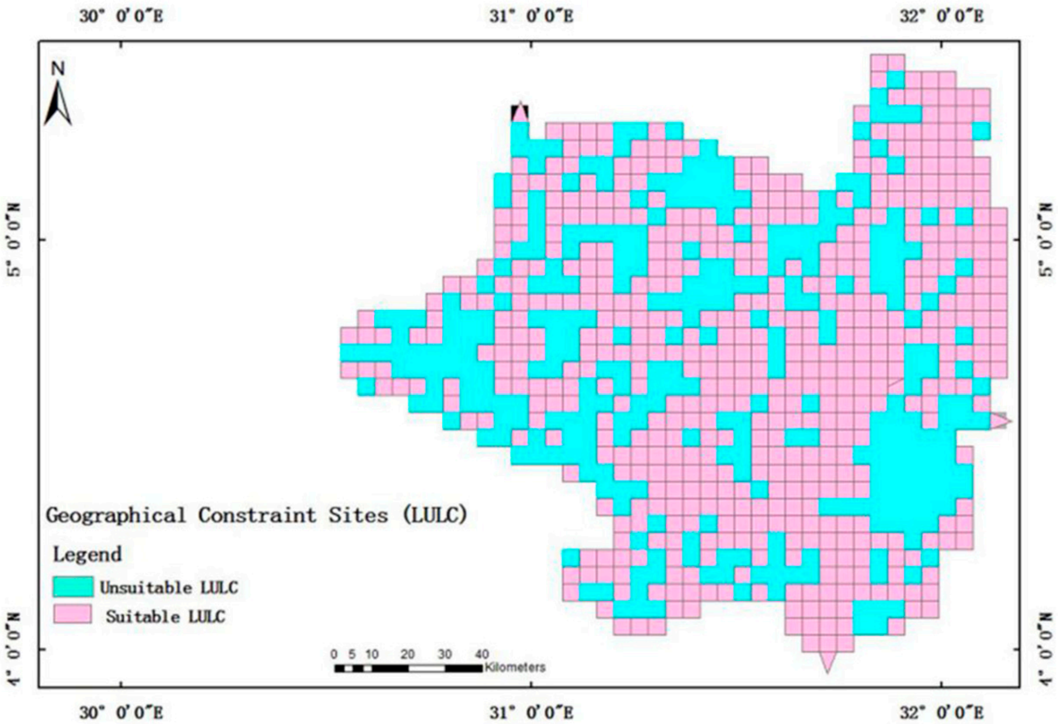

Figure 8. Geographical constraint sites (LULC).

Table 3. Geographic potential of solar energy based on LULC/maximum.

LULC Class	No. Pixel	Area km^2	SR kWh/m^2	GP (TW h/Year)
Buildup Sites	3	65	7592	99
Non-Buildup Sites	531	11,508.4	552,262	6,355,637
Unsuitable Sites	311	6740.3	441,054	2,972,840
Total	845	18,313.7	1,000,908	18,330,329

SR = solar radiation; GP = geographical potential

3.3.2. Suitable and Unsuitable Surface Slop Angle

Figure 9 shows the spatial distribution of suitable and unsuitable surface slopes for installation of solar energy before combining the three raster maps (LULC, surface slope, and solar radiation). In Table 4, unsuitable surface slopes were grouped from 5° to 52°, whereas the suitable surface slopes were separately classified as 0°, 1°, 2°, 3°, and 4°. The suitable slopes account for 95.5% (17,490.13 km^2) of the study area with potential solar energy about 4,832,980 TWh/year. Unsuitable sites covered 4.5% (823.57 km^2) of the study area and about 63,064 TWh/year amount of solar energy.

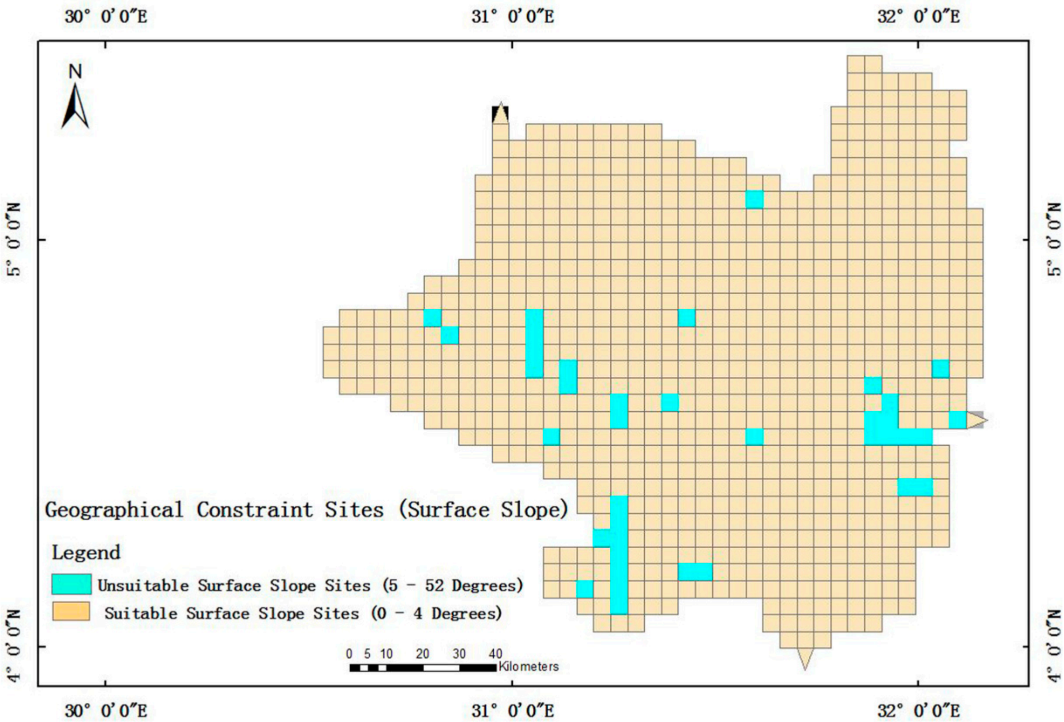

Figure 9. Geographical constraint sites (surface slope).

Table 4. Geographic potential of solar energy based on surface slope/maximum.

Slope (Degree)	No. Pixel	Area km^2	SR kWh/m^2	GP (TW h/Year)
0	338	7325.5	307,475	2,252,402
1	295	6393.5	302,483	1,933,937
2	133	2882.5	204,358	589,064
3	32	693.5	70,712	49,041
4	13	281.7	30,298	8536
5-52	34	736.9	85,582	63,064
Total	845	18,313.7	1,000,908	18,330,329
SR = solar radiation; GP = geographical potential				

3.4. Technical Potential

Combining and Overlaying Raster Maps

This section shows the uniqueness of the method used. It illustrates the development of a single raster map containing the three different input data used in this study, i.e., solar radiation, LULC, and surface slope maps (Figure 10). In the combined raster file, one pixel equals 0.046 km^2, and all the calculated area size shown in Tables 3 and 4 is based on this fact. After combining the three input raster files, the pixels with same unsuitable classes were eliminated from the suitable classes, thus Table 5 shows a reduction in the area covered and potential solar energy of the suitable location, while an increase for the case of unsuitable sites based on comparisons of results addressed in Tables 3 and 4.

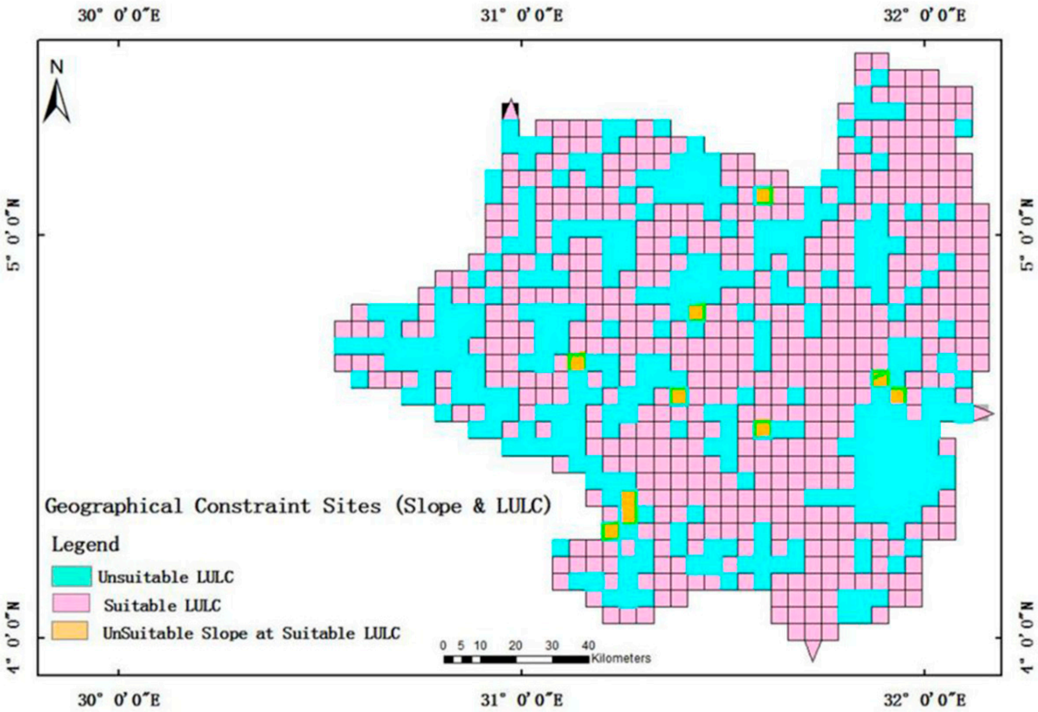

Figure 10. Optimum geographic constraint sites (slope and LULC).

Table 5. Optimum geographic potential of solar energy in Jubek State/maximum.

LULC Class	No. Pixel	Area km^2	SR kWh/m^2	GP(TW h/Year)
Buildup Sites	3	65	7592	99
Non-Buildup Sites	518	11,226.6	538,741.5	6,048,247
Unsuitable Sites	324	7022.1	459,490.3	3,226,568
Total	845	18,313.7	1,005,823.8	18,420,355
SR = solar radiation; GP = geographical potential				

Therefore, the final area for each class shows that the actual geographical solar radiation potential at the suitable and unsuitable locations was found to be 6,048,346 TW h/year (Table 5).

3.5. Solar Energy Requirement for Agricultural Practices

The energy requirement for processing agricultural products was obtained from the literature, then the expected available solar energy was integrated with the energy requirement for crop and animal products in order to assess the ability of solar energy to improve agricultural productivity and food quality. Table 6 shows the estimated energy required to produce 1 ton of some selected field crops and animal products. For producing 1 ton of crop, it requires energy ranging between 58.39×10^{-6} and 1477.9×10^{-6} GW h and area size between 10.7 to 306.3 km^2, whereas energy requirement for per ton of animal production ranges between 750.1×10^{-6} and 8334×10^{-6} GW h and area of about 137.8 to 1531.5 km^2 (Figures 11 and 12, respectively).

Table 6. Estimated energy and land size for installing solar system for producing and processing 1ton of agricultural product.

Product Type	Product	RE (GW h^{t-1})	Farming Type	RL (km^2)
Arable Crop	Wheat	700×10^{-6}	Non-Organic	128.6
	Oilseed rape	1478×10^{-6}	Non-Organic	271.6
	Potatoes	406×10^{-6}	Non-Organic	74.5
	Barley	631×10^{-6}	Non-Organic	115.9
	Field beans	697×10^{-6}	Non-Organic	128.1
	Soya beans	1011×10^{-6}	Non-Organic	187.4
	Sugarcane	58×10^{-6}	Non-Organic	10.7
	Maize	669×10^{-6}	Non-Organic	123
	Wheat	597.27×10^{-6}	Organic	109.8
	Oilseed rape	1666.8×10^{-6}	Organic	306.3
	Potatoes	411.144×10^{-6}	Organic	75.6
	Barley	733.392×10^{-6}	Organic	134.8
	Field beans	677.832×10^{-6}	Organic	124.6
	Soya beans	897.294×10^{-6}	Organic	164.9
Animal Production Production	Poultry	4723×10^{-6}		867.8
	Pig meat	6389×10^{-6}		1174.1
	Beef	8334×10^{-6}		1531.5
	Lamb meat	6112×10^{-6}		1123.1
	Milk	750×10^{-6}		137.8
	Eggs	3334×10^{-6}		612.6

RE = required energy; RL = required land

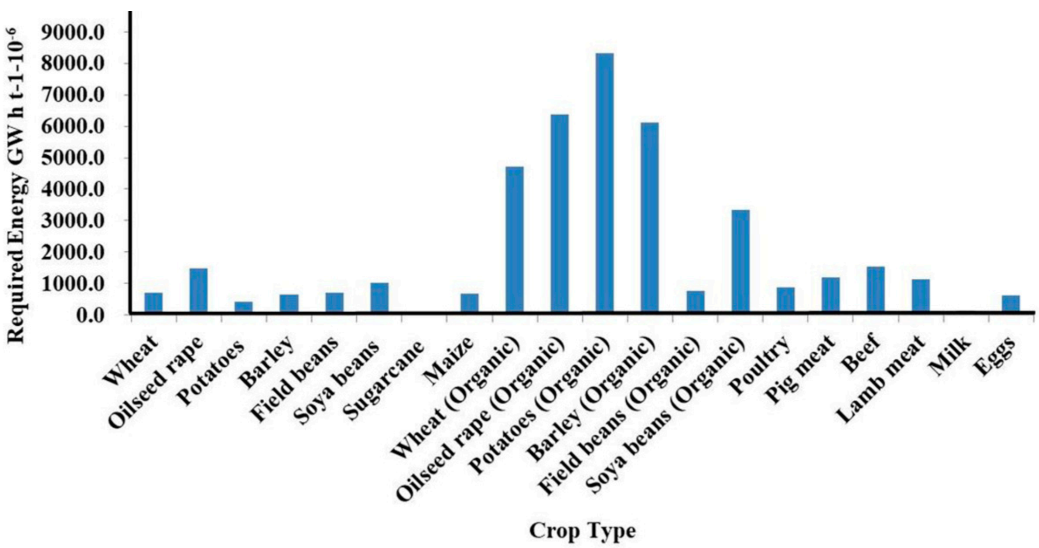

Figure 11. Solar energy requirement for agricultural production and processing.

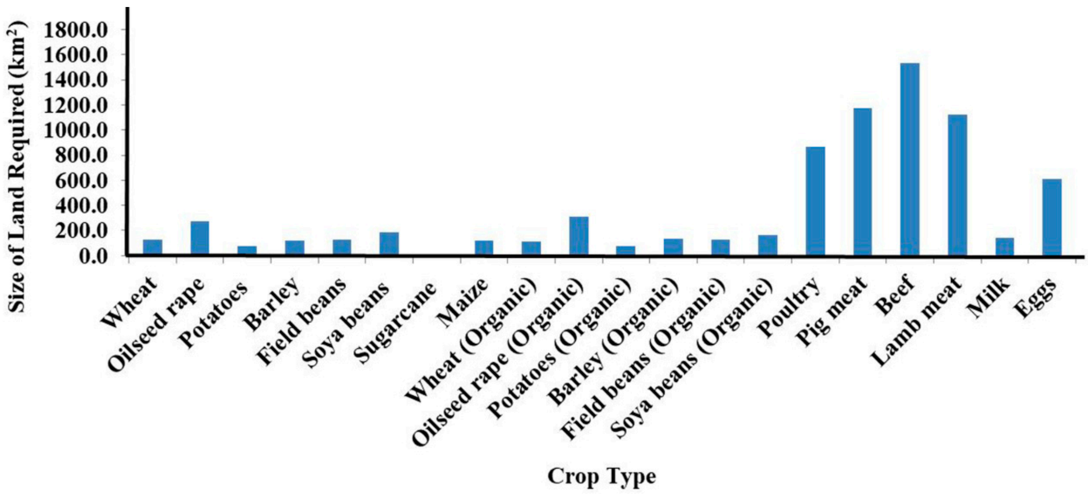

Figure 12. Required area for installing a solar farm for agricultural production and processing.

3.6. Sensitivity Analysis

Multi-criteria decision making while planning for solar energy always results in uncertainty due to various reasons; some are related to the lack of adequate evidence by the decision-makers to produce precise input data. The resulted uncertainty may lead to imprecise findings. To overcome this, it is important to conduct a sensitivity analysis that quantifies the impacts of each input on the outcome modelling. In this study, we performed a sensitivity analysis to identify the relative effects of input factors of the assessment model on the energy output. The performance ratio in Equation (2) is a key input factor for the identification of solar energy technical potential, with a general value ranging between 0.75 and 0.85. As shown in Figure 13, an almost linear (R^2 = 0.945) relationship between technical potential and the performance ratio was indicated, revealing that total technical potential would increase by61.3 GW h/year if the performance ratio is increased by1%.

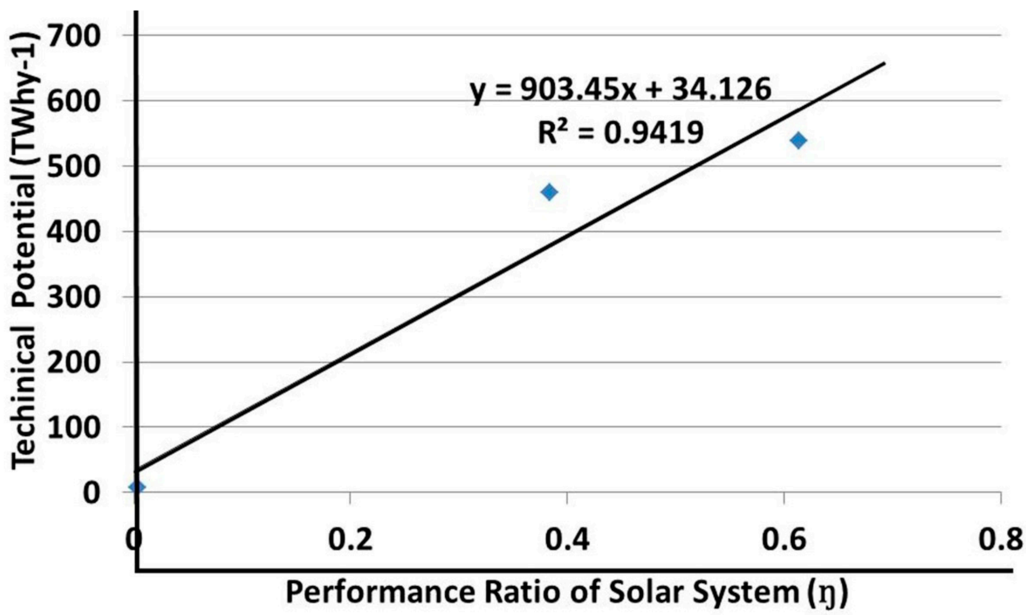

Figure 13. The sensitivity of total potential to the performance ratio of the solar system.

4. Discussion

Although in this study suitable and unsuitable sites for a solar farm is well identified based on the requirements, it needs further investigation on their distance to main human settlements, agricultural fields, climate conditions, terrain, and other renewable energy potential locations. Furthermore, a ground survey should be considered while considering the buildup areas for solar energy, i.e., the buildup areas could be other objects other than a building roof. Top roof of urban areas are the suitable location for installing solar energy systems. In this study, observations from recent high-resolution images (Google Earth) show that the buildup area is dominated by residential, public, and commercial buildings. Limited access was observed for paved roads, one bridge connected the main city with the Eastern bank, no railways throughout the study area, and one airport. This shows that our result for solar energy potential of the buildup classes is more practical in the sense that solar energy can be installed in most of the buildup area. However, we highly recommend a future ground investigation to identify the exact appropriate locations. Results for suitable classes other than buildup areas have no implications and can be considered as presented in this paper. The spatial distribution result based on the LULC map indicated that the buildup areas represent only 0.23% of the study area and are located at almost the central part (Figures 4 and 5). Therefore, connection to the grid will only be feasible from areas close to the buildup areas [48], whereas location far away from the grid connection will apply stand-alone approach to access electricity from the solar system [49].

In order to improve agricultural productivity in terms of yield increase, it is more practical to introduce land transformation policy by changing grassland and shrub cover into agriculture [50], this will result in 11,344.3 km^2 of the study area will be added to agriculture land instead of the current 352.2 km^2. Establishment of food processing industries at locations close to the farmland has two benefits, i.e., direct and indirect benefits. The direct benefit is an improvement of food quality for better storage and transporting [51], whereas indirect benefits are reduction of transport costs of the raw products to processing units [52] and creating job opportunities for the local people [53] will eventually result in poverty reduction in the study area.

The temporal distribution map shows that it is possible to access a huge amount of energy throughout the year, in both cases maximum and minimum solar radiation (Figure 7). Table 5 shows that the study area has an annual solar energy potential of about 6,048,346 TWh/year, thus, is significantly higher than the projected per person demand (5–140 kW) in South Sudan from the years 2013–2025 [42]. Based on this projection, our findings show that the study area requires 69.0158 GWh/year in order to meet the literature projection; this result is based on the fact that the population of the study area is about 492,970 people.

Based on the sensitivity analysis, Figure 13 revealed that 0.1% of the suitable location for solar installation within the study area has a solar energy potential energy of about 61.3 GWh/year; therefore, to meet the study area electricity demand 0.11% (1249.2 km^2) of the suitable locations is required.

Though our study outcomes revealed that the study area have great potential for solar energy technologies, it is important to consider some drawbacks of such technology, such as negative direct and indirect impacts on natural resources i.e., water utilization and consumption, biodiversity, topsoil and dust, social wellbeing and air quality, transmission passages, and land use land cover alteration [26,27]. Such drawbacks can be overcome by proper policies and strategies that will reduce the negative effects on the ecosystem. However, in all aspects solar energy provides a practical solution for energy scarcity, especially in rural sites [27]. The flexibility of land tenure in South Sudan will promote the adaptation of solar technology at local and national levels, thus will create a friendly investment situation and will eventually assist the developmental activity and reduce poverty in the country.

Table 6 shows the estimated solar energy required to produce 1 ton of some selected field crops and animal products. For producing 1 ton of crop, it requires energy ranging between 58.39×10^{-6} and 1477.9×10^{-6} GW h and an area size between 10.7 and 306.3 km^2, whereas the energy requirement for per ton animal production ranges between 750.1×10^{-6} and 8334×10^{-6} GWh and area of about 137.8 to 1531.5 km^2. Therefore, the solar potential of the study area is more than enough to meet both domestic and industrial development. The research approach used in this study tackled multidimensional routes, making it unique in nature, especially for the study area; therefore we highly recommend a step-by-step approach in other locations in South Sudan or any location across the globe with the same energy and environmental situation.

5. Conclusions

The spatial distribution result based on the LULC map indicated that the buildup areas represent only 0.23% of the study area and are located at almost the central part. Therefore, connection to the grid will apply for areas close to the buildup areas [48], whereas locations far away from the grid connection will apply the stand-alone approach to access electricity from the solar system [49]. Agricultural productivity can be improved in the study area if land transformation policy is applied; thus, 11,344.3 km^2 will be added instead of the current 352.2 km^2. This will promote the establishment of agro-processing industries in different locations of the study area which will eventually lead to poverty reduction through improvement of food quantity and quality, and job creation for the local and rural communities. The temporal distribution map revealed that the study area has annual solar energy of about 6,048,346 TWh/year, out of which only 69.0158 GWh/year is required to meet the local demand of 492,970 people residing the study area, thus requires0.11% (1249.2 km^2) of Jubek State. This gives a green indicator for wide investment especially in the agribusiness sector to make optimum utilization of solar energy. For producing 1 ton of crop, it requires energy ranging between 58.39×10^{-6} and 1477.9×10^{-6} GWh and area size between 10.7 and 306.3 km^2, whereas the energy requirement for per ton animal production ranges between 750.1×10^{-6} and 8334×10^{-6} GWh and area of about 137.8 to 1531.5 km^2. Therefore, solar potential of the study area is more than enough to meet both domestic and industrial development. The simple method applied in this study makes it unique, especially for the study area, thus, it can be applied to some other locations following the same steps.

Author Contributions: Conceptualization, A.J.A.G. and J.D.; methodology, A.J.A.G. software, A.J.A.G. validation, A.J.A.G. and J.D.; formal analysis, A.J.A.G.; investigation, A.J.A.G.; resources, J.D.; data curation, A.J.A.G.; writing—original draft preparation, A.J.A.G.; writing—review and editing, A.J.A.G., M.B. and G.A.A. visualization, A.J.A.G.; supervision, J.D.; project administration, J.D.; funding acquisition, J.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Science and Technology Support Projects (No.2015BAC02B06), The Chinese Ministry of Environmental Protection (No.STSN-05-11), and Zhejiang Provincial Natural Science Foundation LY18G030006.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Holdren, J.P. Population and the energy problem. *Popul. Environ.* **1991**, *12*, 231–255. [CrossRef]
2. Coyle, E.D.; Simmons, R.A. *Understanding the Global Energy Crisis Recommended Citation*; Purdue University Press: West Lafayette, IN, USA, 2014; ISBN 9781557536617.
3. Brewer, J.; Ames, D.P.; Solan, D.; Lee, R.; Carlisle, J. Using GIS analytics and social preference data to evaluate utility-scale solar power site suitability. *Renew. Energy* **2015**, *81*, 825–836. [CrossRef]
4. Leyman, P.; Vanhoucke, M. Althusser, Louis y Foucault, Michel—The Soul is the Prison of the Body. *Int. J. Prod. Res.* **2015**, *9*, 2771–2786. [CrossRef]
5. Rafiee, A.; Khalilpour, K.R. Renewable Hybridization of Oil and Gas Supply Chains. 2019. Available online: https://www.sciencedirect.com/science/article/pii/B9780128133064000112 (accessed on 25 December 2019).
6. Darling, S.B.; You, F.; Veselka, T.; Velosa, A. Assumptions and the levelized cost of energy for photovoltaics. *Energy Environ. Sci.* **2011**, *4*, 3133–3139. [CrossRef]
7. Drury, E.; Brinkman, G.; Denholm, P.; Margolis, R.; Mowers, M. Exploring large-scale solar deployment in DOE's SunShot Vision Study. In Proceedings of the 2012 38th IEEE Photovoltaic Specialists Conference, Austin, TX, USA, 3–8 June 2012; pp. 763–768.

8. Goodrich, A.; James, T.; Woodhouse, M. *Residential, Commercial, and Utilityscale Photovoltaic (PV) System Prices in the United States: Current Drivers and Cost-Reduction Opportunities*; National Renewable Energy Lab (NREL): Golden, CO, USA, 2012; pp. 1–58.
9. Nichols, W. Expanding wind and solar power does not mean additional. Available online: http://www.businessgreen.com/bg/analysis/2331389/iea-expanding-wind-and-solar-power-does-not-mean-additionalcosts (accessed on 28 February 2014).
10. Stein, E.W. A comprehensive multi-criteria model to rank electric energy production technologies. *Renew. Sustain. Energy Rev.* **2013**, *22*, 640–654. [CrossRef]
11. Calvert, K.; Pearce, J.M.; Mabee, W.E. Toward renewable energy geo-information infrastructures: Applications of GIScience and remote sensing that build institutional capacity. *Renew. Sustain. Energy Rev.* **2013**, *18*, 416–429. [CrossRef]
12. Dawson, L.; Schlyter, P. Less is more: Strategic scale site suitability for concentrated solar thermal power in Western Australia. *Energy Policy* **2012**, *47*, 91–101. [CrossRef]
13. Hossain, J.; Sinha, V.; Kishore, V.V.N. A GIS based assessment of potential for windfarms in India. *Renew. Energy* **2011**, *36*, 3257–3267. [CrossRef]
14. Charabi, Y.; Gastli, A. PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation. *Renew. Energy* **2011**, *36*, 2554–2561. [CrossRef]
15. Kabir, M.H.; Endlicher, W.; Jägermeyr, J. Calculation of bright roof-tops for solar PV applications in Dhaka Megacity, Bangladesh. *Renew. Energy* **2010**, *35*, 1760–1764. [CrossRef]
16. Hong, L.; Lund, H.; Mathiesen, B.V.; Möller, B. 2050 pathway to an active renewable energy scenario for Jiangsu province. *Energy Policy* **2013**, *53*, 267–278. [CrossRef]
17. Hoogwijk, M.; Graus, W. *Global Potential of Renewable Energy Sources: A Literature Assessment*; EcoFys: Utrecht, The Netherlands, 2008; p. 45.
18. Clifton, J.; Boruff, B.J. Assessing the potential for concentrated solar power development in rural Australia. *Energy Policy* **2010**, *38*, 5272–5280. [CrossRef]
19. Sun, Y.W.; Hof, A.; Wang, R.; Liu, J.; Lin, Y.J.; Yang, D.W. GIS-based approach for potential analysis of solar PV generation at the regional scale: A case study of Fujian Province. *Energy Policy* **2013**, *58*, 248–259. [CrossRef]
20. Kuiper, J.; Koehler, D.; Ames, D.P.; Lee, R.; Quinby, T. Web-based mapping applications for solar energy project planning. In Proceedings of the American Solar Energy SocietyConference (Solar 2013), Baltimore, MD, USA, 16–20 April 2013; pp. 663–669.
21. Hernandez, R.R.; Hoffacker, M.K.; Murphy-Mariscal, M.L.; Wu, G.C.; Allen, M.F. Solar energy development impacts on land cover change and protected areas. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 13579–13584. [CrossRef] [PubMed]
22. Wolsink, M. Wind power and the NIMBY-myth: Institutional capacity and the limited significance of public support. *Renew. Energy* **2000**, *21*, 49–64. [CrossRef]
23. Bell, D.; Gray, T.; Haggett, C. The "social gap" in wind farm siting decisions: Explanations and policy responses. *Env. Polit.* **2005**, *14*, 460–477. [CrossRef]
24. Carlisle, J.E.; Kane, S.L.; Solan, D.; Joe, J.C. Support for solar energy: Examining sense of place and utility-scale development in California. *Energy Res. Soc. Sci.* **2014**, *3*, 124–130. [CrossRef]
25. Farhar, B.C.; Hunter, L.M.; Kirkland, T.M.; Tierney, K.J. *Community Response to Concentrating Solar Power in the San Luis Valley*; National Renewable Energy Laboratory: Golden, CO, USA, 2012; pp. 65–163.
26. Saunders, D.A.; Hobbs, R.J.; Margules, C.R. Biological consequences of ecosystem fragmentation: A review. *NCASI Tech. Bull.* **1999**, *2*, 469–470. [CrossRef]
27. Vrînceanu, A.; Grigorescu, I.; Dumitraşcu, M.; Mocanu, I.; Dumitrica, C.; Micu, D.; Kucsicsa, G.; Mitrica, B. Impacts of photovoltaic farms on the environment in the Romanian plain. *Energies* **2019**, *12*, 2533. [CrossRef]
28. Hernandez, R.R.; Easter, S.B.; Murphy-Mariscal, M.L.; Maestre, F.T.; Tavassoli, M.; Allen, E.B.; Barrows, C.W.; Belnap, J.; Ochoa-Hueso, R.; Ravi, S.; et al. Environmental impacts of utility-scale solar energy. *Renew. Sustain. Energy Rev.* **2014**, *29*, 766–779. [CrossRef]
29. Fthenakis, V.; Kim, H.C. Life-cycle uses of water in U.S. electricity generation. *Renew. Sustain. Energy Rev.* **2010**, *14*, 2039–2048. [CrossRef]
30. Mani, M.; Pillai, R. Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations. *Renew. Sustain. Energy Rev.* **2010**, *14*, 3124–3131. [CrossRef]

31. He, G.; Zhou, C.; Li, Z. Review of self-cleaning method for solar cell array. *Procedia Eng.* **2011**, *16*, 640–645. [CrossRef]
32. Lamont, L.A.; El Chaar, L. Enhancement of a stand-alone photovoltaic system's performance: Reduction of soft and hard shading. *Renew. Energy* **2011**, *36*, 1306–1310. [CrossRef]
33. Fluri, T.P. The potential of concentrating solar power in South Africa. *Energy Policy* **2009**, *37*, 5075–5080. [CrossRef]
34. Gołaszewski, J.; de Visser, C.; Brodziński, Z.; Myhan, R.; Olba-Zięty, E.; Stolarski, M.J.; Buisonje, F.; Ellen, H.; Stanghellini, C.; van der Voort, M.; et al. State of the Art on Energy Efficiency in Agriculture. In *Project Deliverable 2.1*; Country data on energy consumption in different agroproduction sectors in the European countries; AGREE: Athens, Greece, 2012.
35. Diffendorfer, J.E.; Compton, R.W. Land cover and topography affect the land transformation caused by wind facilities. *PLoS ONE* **2014**, *9*, e88914. [CrossRef]
36. 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]
37. Parker, S.S.; Cohen, B.S.; Moore, J. Impact of solar and wind development on conservation values in the Mojave Desert. *PLoS ONE* **2018**, *13*, e0207678. [CrossRef]
38. Mennen, T. *Customary Law and Land Rights in South Sudan*; Norwegian Refugee Council: Oslo, Norway, 2012.
39. Forojalla, S.B.; Galla, K.C. *Land Tenure Issues in Southern Sudan. Key Findings and Recommendations for Southern Sudan Land Policy*; USAID: Washington, DC, USA, 2010.
40. 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 5 May 2018).
41. National Bureau of Statistics. *National Baseline Household Survey*. 2009, pp. 1–175. Available online: http://www.erfdataportal.com/index.php/catalog/65 (accessed on 2 December 2019).
42. African Developement Bank South Sudan. An Infrastructure Action Plan South Sudan. In *A Program for Sustained Economic Growth*; 2013; pp. 1–321. Available online: https://www.afdb.org/en/countries/east-africa/south-sudan/infrastructure-action-plan-in-south-sudan-a-program-for-sustained-strong-economic-growth (accessed on 5 December 2019).
43. Šúri, M.; Huld, T.A.; Dunlop, E.D.; Ossenbrink, H.A. Potential of solar electricity generation in the European Union member states and candidate countries. *Sol. Energy* **2007**, *81*, 1295–1305. [CrossRef]
44. 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]
45. Williams, A.G.; Audsley, E.; Sandars, D.L. *Determining the Environmental Burdens and Resource Use in the Production of Agricultural and Horticultural Commoditites*; Main report; Cranfield University: Cranfield, UK, 2006; p. 97. Available online: https://www.researchgate.net/profile/Eric_Audsley/publication/265084052_Determining_the_environmental_burdens_and_resource_use_in_the_production_of_agricultural_and_horticultural_commodities_Defra_project_report_IS0205/links/544e841c0cf29473161be279.pdf (accessed on 20 December 2019).
46. Luetzow, M. Appendix 1.18: Food and Agriculture Organization of the United Nations. *Encycl. Toxicol.* **2005**, 511–516. [CrossRef]
47. Africa Land Used Land Cover. 2016. Available online: www.2016africalandcover20m.esrin.esa.int/download.php (accessed on 20 December 2019).
48. Zhao, X.G.; Wan, G.; Yang, Y. The turning point of solar photovoltaic industry in China: Will it come? *Renew. Sustain. Energy Rev.* **2015**, *41*, 178–188. [CrossRef]
49. Wang, S.; Zhang, L.; Fu, D.; Lu, X.; Wu, T.; Tong, Q. Selecting photovoltaic generation sites in Tibet using remote sensing and geographic analysis. *Sol. Energy* **2016**, *133*, 85–93. [CrossRef]
50. FAO. *Food and Agriculture Organization in the 21st Century: Ensuring Food Security in a Changing World*; FAO: Rome, Italy, 2011; Available online: http://www.fao.org/3/i2307e/i2307e.pdf (accessed on 25 December 2019).
51. Coskun, A.; Vardin, H.; Bulent, K. Improvement of Food Safety and Quality by Statistical Process Control (SPC) in Food Processing Systems: A Case Study of Traditional Sucuk (Sausage) Processing. In *Quality Control of Herbal Medicines and Related Areas*; IntechOpen: London, UK, 2011; Available online: http://cdn.intechweb.org/pdfs/23468.pdf (accessed on 10 December 2019).

52. Food Standards Australia New Zealand. Poultry Standards (Australia Only). 2006. Available online: https://www.foodstandards.gov.au/code/primaryproduction/poultry/Pages/default.aspx (accessed on 2 December 2019).
53. Karnani, A.; McKague, K. Job creation in the Mozambican poultry industry. 2014. Available online: https://www.researchgate.net/publication/271443876_Job_Creation_in_the_Mozambican_Poultry_Industry (accessed on 2 December 2019).