remote sensing

Editorial

Editorial for the Special Issue: Assessment of Renewable Energy Resources with Remote Sensing

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Received: 9 November 2020; Accepted: 12 November 2020; Published: 14 November 2020

Abstract: The development of renewable energy sources plays a fundamental role in the transition towards a low carbon economy. Considering that renewable energy resources have an intrinsic relationship with meteorological conditions and climate patterns, methodologies based on the remote sensing of the atmosphere are fundamental sources of information to support the energy sector in planning and operation procedures. This Special Issue is intended to provide a highly recognized international forum to present recent advances in remote sensing to data acquisition required by the energy sector. After a review, a total of eleven papers were accepted for publication. The contributions focus on solar, wind, and geothermal energy resource. This editorial presents a brief overview of each contribution.

Keywords: renewable energy resource assessment and forecasting; remote sensing data acquisition; data processing; statistical analysis; machine learning techniques

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1. Aims and Goals

The socio-economic development of a region or country is intrinsically associated with energy consumption. Continuous growth is expected in energy demand in countries with a robust emerging economy along the next decade to support enhancing the quality of life and essential services such as food, health, education, transportation, and entertainment.

On the other hand, energy consumption is a remarkable contributor to the growing concentration of greenhouse gases (GHG) in the atmosphere due to the burning of fossil fuels, the energy source with the highest share. Concerns associated with climate change have been driving the development of increasingly efficient technologies to exploit renewable energy resources with low GHG emissions.

However, technological developments in energy conversion are not a unique challenge that will support the expansion of renewable energy resources like solar energy, wind energy, hydroelectric energy, and wave energy. Reliable data on renewable energy resource assessment are also required and essential to ensure sustainable expansion considering environmental, financial, and energetic security.

Renewable energy resources have an intrinsic relationship with local atmospheric conditions and the regional climate. Even small and fast changes in meteorological conditions can significantly affect power generation at different time and space scales. Methodologies based on the remote sensing of the atmosphere are the primary source of information for developing numerical models that aim to support an electric system's planning and operation with a substantial share of intermittent energy sources.

Concerning solar energy, remote sensing technologies and methods become a fundamental tool to deal with the challenging task of solar resource assessment and forecasting in spatial and very short-time scales. The satellite-derived surface solar irradiance measurements are fundamental for high-resolution spatial solar resource assessment. A huge technological advance made satellite data possible at a horizontal resolution of around 500 m every 15 min during the last decade. Solar energy forecasting methodologies based on satellite data also became vital to support electricity system operation with increasing solar power share. Concerning short-term forecasting (or nowcasting), the total sky imagers become a crucial tool to investigate and deal with the high temporal local variability of the surface solar irradiance related to cloud conditions.

Mature and commercially competitive technology for wind power generation is already available around the world. However, wind velocity is highly variable in time and space. The regional climate and local meteorological processes influence wind variability, demanding high-quality tools and methods based on remote sensing techniques for wind energy applications. The leading remote sensing techniques are LiDAR (wind LiDAR and ceilometers), radar, and satellites.

Besides solar and wind energy, other renewable resources also require remote sensing technologies and methods to assess resource availability and variability. We can cite geothermal, hydro, and ocean energy resources, for instance.

Time and spatial complementarity between renewable energy resources is getting more attention from academia and energy stakeholders to increase energy security and improve the energy quality delivered to the consumers. Here, we also have a great opportunity for remote sensing applications.

Finally, remote sensing can help assess and plan the use of renewable resources to improve energy efficiency in buildings and cities based on observations of local environmental conditions.

This Special Issue combines multidisciplinary contributions that address remote sensing aspects applied to the energy sector, from scientific fundamentals to practical energy industry needs. This Special Issue provides interesting contributions and focuses on disseminating scientific knowledge and technological developments for the assessment and forecasting of renewable energy resources using remote sensing techniques in order to support the expansion of the renewable energy share in the energy mix, especially in regions where energy demand is rapidly expanding.

2. Overview, Data, and Methods

This Special Issue is comprised of ten research papers [1–10] and one letter [11]. Figure 1 shows a pictorial word cloud of the Abstract contents of the eleven manuscripts, where the strong multi-disciplinary character of the remote sensing approaches applied to renewable energy is apparent. Table 1 lists a summary of the remote sensing data and methods used and the energy resources investigated.

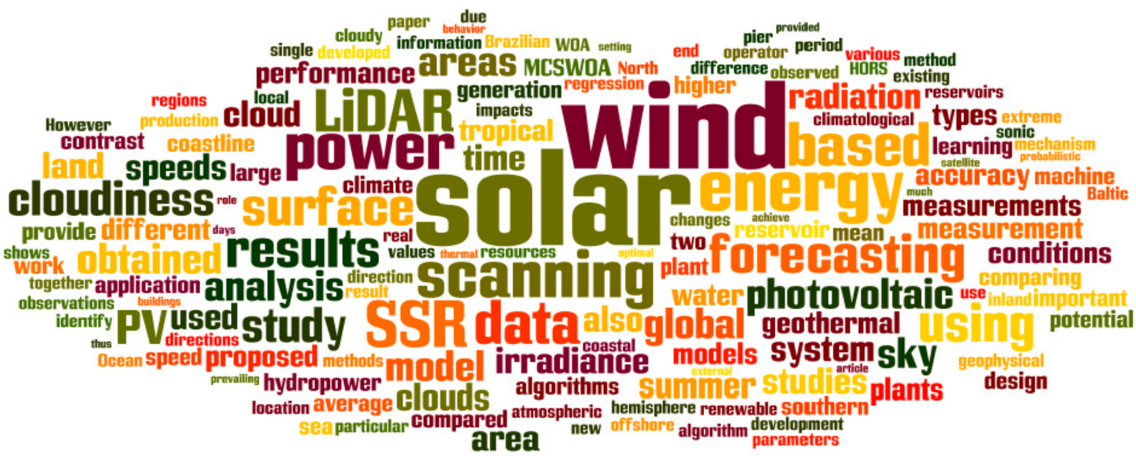

Figure 1. Illustrative map prepared using the words composing the Abstract of the eleven articles published in the Special Issue "Assessment of Renewable Energy Resources with Remote Sensing" of Remote Sensing.

Table 1. Summary list of remote sensing data, methods, and study regions discussed in the eleven articles included in the Special Issue (sorted by the publication date).

Research Article	Energy Resource	Remote Sensing Data and Methods	Study Area
Xiong et al. [1]	PV power	Improved variant of the whale optimization algorithm based on the parameters of PV modules	Guiyang, China
Mondragón et al. [2]	Solar energy	MLRegression, PolRegression, and neural networks based on DNIobservations and all-sky images	SIO in Mexico City
Shimada et al. [3]	Wind energy	Two-parameter velocity volume processing (VVP) method based on LiDAR measurements	HORS in Japan
Alonso-Montesinos [4]	Solar energy	Cloud identification using threshold criteria applied to all-sky images	CIESOL in Spain
Sáez Blázquez et al. [5]	Geothermal energy	Time domain electromagnetic method and electrical resistivity tomography	Central Spain
Park et al. [6]	PV power	Multistep-ahead (MSA) forecasting using meteorological data and historical global solar radiation data	Jeju Island in Korea
Alkadri et al. [7]	Solar energy	SOLENapproach based on 3D terrestrial laser scanning datasets	Citarip, Indonesia
Gonçalves et al. [8]	Solar energy	modeling approaches using the GOES-16 visible imagery, ISCCPdatabase products, and meteorological ground observations	Central Brazil
Young et al. [9]	Wind energy	The global basin-scale and near-coastal wind using a calibrated multi-mission scatterometer dataset	Global coverage
Khalyasmaa et al. [10]	PV power	Machine learning algorithms based on open-source meteorological data and PV system parameters	Astrahan, Russia
Lindfors et al. [11]	Solar energy	Statistical analysis of climate data from two satellite, CLARA-A2and SARAH-2and ground-based pyranometer measurements	Baltic Region

Eight papers describe remote sensing approaches for solar energy applications; three of them focus on PV power generation [1,6,10]. Two articles are focused on wind energy, one using LiDAR measurements from the ground [3] and the other using scatterometers operating in several satellite missions [9]. The last article deals with two methodologies to evaluate the geothermal energy resource [5].

3. Brief Discussion of the Published Articles in the Special Issue

Energy demand is intrinsically associated with population growth, the demographic concentration in urban areas, and socio-economic development, including human well-being with its aspects related to health, education, culture, and entertainment. The Sustainable Development Goals, specifically "SDG-7—Providing clean and accessible energy to the world population" and "SDG-13—Action against global climate change" [12], reinforce the relevance of the Special Issue. Blanco et al. [13] pointed out that 69% of greenhouse gas (GHG) emissions in the world are due to the burning of fossil fuels. Jackson et al. [14] mentioned data pointing to an increase in emissions linked to fossil fuel consumption between 2017 and 2019 of around 1.3% per year. Recent data indicate that about one billion people do not have access to electricity, and more than two billion use solid biomass as stove fuel [15]. The numbers presented above indicate that the energy mix expansion needs a comprehensive approach when considering the socio-environmental issue. Currently, around 81% of the world's primary energy comes from fossil fuels, 25% of which is consumed as electricity, leading to average emissions of 515 g CO_2/kWh. These aspects reinforce the need to make progress in the efficient use of energy resources combined with the decarbonization of the world energy matrix.

Recent data show that more plants for renewable energy sources such as solar, wind, hydroelectric, and geothermal were installed than thermopower plants based on fossil and nuclear fuels since 2015 [16]. Solar and wind resources present high variability intrinsically linked to the environmental and meteorological conditions, and this can significantly affect the quality and safety of the electrical system. The increasing share of such intermittent energy sources requires developing and implementing strategies to manage the electrical system [16], and this has mobilized the international scientific community [17,18].

Mondragón et al. [2] presented an article focusing on forecasting the beam solar irradiance (DNI) to support the concentrated solar power environment. They developed three models for estimating the DNI attenuation percentage under all-sky conditions based on a sky camera with a rotational shadow band (Model TSI 880). Alonso-Montesinos [4] also worked with total sky imagers to develop a low-cost and autonomous cloud detection system in real time. The author pointed out that the system represents a new development in predicting cloud cover and solar radiation over the short term.

Park et al. [6] proposed a novel forecasting model for multistep-ahead (MSA) global solar radiation predictions based on the light gradient boosting machine (LightGBM), which is a tree-based ensemble learning technique. The authors fed the forecasting model with meteorological data and long time series data for global surface solar irradiation for Jeju Island (Korea) provided by the Korean Meteorological Administration. Their experiment results demonstrated that the proposed approach can achieve better performance than other deep learning methods.

Khalyasmaa et al. [10] also focused on a short-term photovoltaic forecasting system based on machine learning methods using remote sensing data. The authors scrutinized the application of different machine learning algorithms, including the random forest regressor, gradient boosting regressor, linear regression, and decision tree regression for a real industry-scale photovoltaic power plant, providing robust forecasting results for either mostly-sunny or mostly-cloudy days.

The long time series of surface solar radiation and cloud cover indexes are crucial indicators of the solar power resource. Two articles [8,11] in this Special Issue focus on analyzing remote sensing data in the land-water interface in a large hydropower reservoir or coastal areas, respectively. Gonçalves et al. [8] used GOES-16 visible imagery, ISCCPdatabase products, and ground measurement sites operating close to a large hydropower reservoir, providing data for the statistical analysis. Their results suggest that floating solar PV power plants in hydropower reservoirs can be an excellent option to integrate renewable energy resources into a hybrid power generation due to the high solar irradiance in the Brazilian territory combined with the prevailing breeze mechanism in large tropical water reservoirs. Lindfors et al. [11] used two satellite climate data records together with ground-based pyranometer measurements and a Baltic region coastline database to conclude that the annual SSR is 8% higher 20 km off the coastline than 20 km inland. For summer, i.e., June–August, this difference is higher than the annual mean value.

Some contributions focused on different topics in solar energy applications, such as the research articles from Alkadri at al. [7] and Xiong et al. [1]. The first paper describes an investigation on the potential application of attribute information stored in point cloud data to support a new computational method for a voxel-based design approach based on shading performance criteria. Xiong et al. [1] improved a variant of the whale optimization algorithm to extract PV model parameters.

This Special Issue encompasses two research articles focused on remote sensing applied to wind energy resource assessment. Shimada et al. [3] compared the wind data recorded by a scanning LiDAR to the observations obtained by a vertical profiling LiDAR operating 400 m apart from each other. The authors executed nine experiments to identify the best practice for offshore wind measurements using the scanning LiDAR and discussed the variations in data availability and accuracy based on the carrier-to-noise ratio (CNR) distribution. Young et al. [9] used a 27 year long multi-mission scatterometer dataset to determine the global and near-coastal wind resource. The authors identified the seasonal patterns of the global wind climate and discussed the differences between the two hemispheres. They also investigated extreme winds, including the speeds for 50 and 100 year return periods.

Unfortunately, we received only one contribution on the geothermal energy resource. Sáez Blázquez et al. [5] evaluated the geothermal conditions of an area in the central region of Spain. The evaluation was based on geological and geophysical studies and, in particular, the time domain electromagnetic method and electrical resistivity tomography. The authors demonstrated that both geophysical prospecting methods constitute a useful tool to define the underground geological characterization and analyze the potential areas for geothermal exploitation.

4. Conclusions

The development of remote sensing approaches to assess and forecast renewable energy resources is relevant to the international scientific agenda. The papers published in this Special Issue provide insights into remote sensing methods to support the information and knowledge demanded by the energy stakeholders. The articles describe approaches based on ground and/or satellite data acquisition to support numerical modeling methodologies based on time series data analysis and advanced machine learning methods to understand the availability and variability of the energy resources. We hope that the readers can benefit from the insights provided by these papers and that the highlights presented in this Special Issue can attract attention to pursue further investigations and meaningful developments in the remote sensing area.

Funding: This research received no external funding.

Acknowledgments: The author would like to thank the IMAR/Unifesp and LABREN/INPE for providing the required infrastructure to develop the research and education activities. Thanks to CNPq for granting a research fellowship to the author. Thanks are also due to MDPI for the opportunity to be a Guest Editor of Remote Sensing. Special thanks also go to the anonymous reviewers for providing valuable contributions in helping the authors to achieve a high standard papers. Finally, I would like to thank the Remote Sensing editorial team, and in particular Traey Wu, for the substantial support during the entire compiling process and editing of this Special Issue.

Conflicts of Interest: The author declares no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

CIESOL	Centro de Investigación en Energía Solar (University of Almería - Spain)
CNPq	Conselho Nacional de Desenvolvimento Científico e Tecnológico (Brazil)
HORS	Hazaki Oceanographical Research Station
IMAR	Institute of Marine Sciences
LABREN	Laboratório de Modelagem e Estudos de Recursos Renováveis de Energia (Brazil)
INPE	Instituto Nacional de Pesquisas Espaciais (Brazilian Institute for Space Research)
LiDAR	Light Detection and Ranging
Unifesp	Universidade Federal de São Paulo (Brazilian Federal University of São Paulo)
MDPI	Multidisciplinary Digital Publishing Institute
PV	Photovoltaic system
SDG	Sustainable Development Goals
SIO	Solar Irradiance Observatory at the Geophysics Institute of the National Autonomous University
SSR	Surface solar radiation

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