Photosynthetically Active Radiation Monitoring Network in Spain

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Abstract

The main objective is the development of a network of measurement, modeling, database and web services of photosynthetically active radiation (PAR) over mainland Spain.

Keywords: photosynthetically active radiation, PAR, measurement network

1. Introduction

Photosynthetically Active Radiation (PAR) includes wavelengths between 400-700 nm of the solar spectrum. This portion of solar irradiance can be used by plants, algae, and cyanobacteria to fix inorganic carbon in the form of organic carbon throughout photosynthesis.

Unfortunately, only a few radiometric stations can provide PAR measurements on the ground and it is often calculated as a constant ratio of the broadband solar radiation. However, the ratio between PAR and Global Horizontal Irradiance (GHI) is not constant, depends on climatic characteristics, aerosol presence, etc of each location (Ferrera-Cobos et al., 2020a, 2020b).

PAR is of interest in many applications, such as biomass for energy, assessment of energy balance in ecosystems, or crop production for food. Related to water assessment, it may be interesting for monitoring and detection of harmful algae blooms and also in the study of the productivity of microalgae in wastewater treatment for a small population. One of these applications is explored in ALGATEC-CM project, which addresses the technical and economic difficulties that hinder the full industrial implementation of microalgae. One of the objectives of this project is the assessment of the PAR resource in the Madrid region and modeling the best conditions of PAR irradiance and temperature for the growth of microalgae.

The main outcome of this project is filling this absence of measurements, recording measurements of PAR on mainland Spain and providing access to them through a web page. This communication describes the main features of the PAR network and details of its implementation.

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Fig. 1: PAR stations in all Peninsular Spain. In red the stations of the Madrid region

2. PAR Network

The Photosynthetically Active Radiation network consists of twelve stations across Spain located in Lugo (Galicia), Villaviciosa (Asturias), Vitoria (País Vasco), Zaragoza (Aragón), Soria and Salamanca (Castilla León), Albacete (Castilla la Mancha), Córdoba and Almería (Andalucía), Aranjuez, Buitrago and Alameda del Valle (Madrid) as illustrated by Fig. 1.

2.1. Selection of the specific sites for PAR stations

The most representative sites to place the stations were selected using cluster analysis. Estimations of the Spectral Resolved Irradiance product (Muller et al., 2009; Müller et al., 2013) provided by CM-SAF over mainland Spain were used, this product includes the bands of the solar spectrum divided according to the absorption coefficient of different gases, named Kato bands (Kato et al., 1999, Wandji et al., 2015). The PAR estimations were obtained using the bands between 400 nm to 700 nm, whereas GHI estimations needed all the bands corresponding to the whole solar spectrum.

The representative variable was the clearness PAR index, kt_{PAR}, which is similar to the clearness index, kt. In this case, it is defined as the ratio between PAR reaching the Earth's surface and extraterrestrial PAR. After performing the clustering analysis, two regions were obtained: one covering the north of Spain, with some small areas in the second one, that covers the rest of the territory. This division reflects the main climatic characteristics of Spain. Details of the algorithm performed can be found in a previous study (Vindel et al., 2018).

2.2. Network instrumentation and installation

Once the optimal locations were known, the objective was focused on detecting the suitable sites, with clear land and secure places. Several contacts were established with different entities that had the infrastructures and space to install the PAR stations.

Previous to the installation, the horizon was determined using HORIcatcher software. The HORIcatcher (HORICatcher, 2020) consists of a digital camera with a fisheye mirror that works with the Meteonorm software. The software tool allows users to describe horizon obstacles, sunshine duration, and sun exposure reduced by obstacles like trees, houses, or mountains throughout the year.

The basic configuration of stations is described in Table 1.

Tab. 1: Equipment for PAR network

Instrument type	Manufacter / model	Measurement
Data Logger	HOBO / RX3000	Data acquisition
Data Logger	Campbell / CR1000	Data acquisition
Pyranometer	Kipp & Zonen / CM21	GHI
Silicon pyranometer	Apogee / SP-110-SS	GHI
Quantum PAR sensor	Eko / ML-020P	PAR
Quantum PAR sensor	Apogee / SQ-110/120	PAR
Temperature/Relative humidity sensor	Vaisala / HMP45A	T/H
Temperature/Relative humidity sensor	ONSET / S-THB-M002	T/H

All instruments were calibrated before installation by the manufacturers, however, an intercomparison campaign was carried out to verify that all sensors are analogous and in consequence their measurements are reliable. All radiometers were assembled and programmed according to the supplier's instructions and were subsequently monitored. The analysis of the data obtained during the intercomparison campaign concluded that none of them showed significant deviations and that, therefore, all sensors were suitable to be displayed in the network.

The network comprises twelve stations distributed across mainland Spain (Table 2). They were installed according to the characteristics of the places, four stations were installed in a portable tripod (Buitrago, Córdoba, Lugo, and Salamanca), three of them in a stainless-steel and galvanized pole (Albacete, Zaragoza, Vitoria, Villaviciosa) and two are in CIEMAT facilities at Plataforma Solar de Almería (PSA) and Centro de Desarrollo de Energías Renovables, CEDER-CIEMAT in Soria. Nine of the stations are fully autonomous by using GSM network and solar power as an energy supplier, the other two are connected to our local area network.

The PAR network measures continuously with a sampling frequency of 1 min for all variables. An automated data collection protocol was defined to collect the recordings from each station at a centralized server located in Centro Extremeño de Tecnologías Avanzadas (CETA-CIEMAT). Thus, the established configuration allows a daily generation of data files for each station. The recorded variables (PAR, GHI, Temperature, Humidity, and Dew Point) are dumped automatically to the central server via FTP.

The database includes the register of all metadata such as location, sensors, or calibrations. Also an upgrade of procedures is in progress, this will allow to determine and store information related to timestamp, such as quality controls, missing data detection, and verification that record data are within acceptable range limits.

Tab. 2: Localization of all PAR stations.

Station ID	Latitude	Longitude	Height (m)	Climate type	Operational
Albacete	39.042	-2.082	696	Continental Mediterranean	26/03/2019
Aranjuez	40.074	-3.524	505	Continental Mediterranean	11/02/2020
Buitrago	40.992	-3.654	996	Mountain	10/01/2020

Córdoba	37.857	-4.803	106	Continental Mediterranean	27/03/2020
Lugo	42.995	-7.541	495	Oceanic	15/04/2019
Salamanca	40.798	-5.715	290	Continental Mediterranean	13/03/2019
Villaviciosa	43.476	-5.441	662	Oceanic	13/05/2019
Vitoria	42.854	-2.622	525	Oceanic	08/04/2019
Zaragoza	41.727	-0.814	243	Continental Mediterranean	18/03/2019
CEDER-CIEMAT	41.601	-2.508	1051	Continental Mediterranean	15/07/2015
PSA-CIEMAT	37.092	-2.364	400	Standard Mediterranean	21/01/2016
Alameda	40.915	-3.844	1115	Mountain	Scheduled in Sept. 2020

3. Working in progress

PAR may be of interest in several applications, as it has been mentioned before, such as the convenience of using microalgae for wastewater treatment for small communities. The Solar Radiation Group for Energetic Applications (CIEMAT) is currently collaborating in the project *Development of Advanced Microalgae Technologies for a Circular Economy (ALGATEC),* where is participating in an analysis of a methodology for identifying suitable sites to locate High Rate Algae Pond (HRAP) in the Madrid region. HRAP is a low-cost wastewater treatment system designed to achieve secondary wastewater treatment and biomass production from algae. The algae supply the oxygen demand for the bacterial degradation of organic matter, and the bacteria excrete mineral compounds that provide nutrition to the algae. Biogas self-consumption generated from the anaerobic digestion of the sludge (algae and bacteria) produced in the wastewater treatment may help to reduce the energy consumption of the whole plant. The knowledge of microalgae productivity under different climatic conditions can help to carry out an economic feasibility analysis of the system. Fig 2, display, as an example, one of the station ensembles and the results of the conventional regression and ANN models obtained in PSA-CIEMAT station.

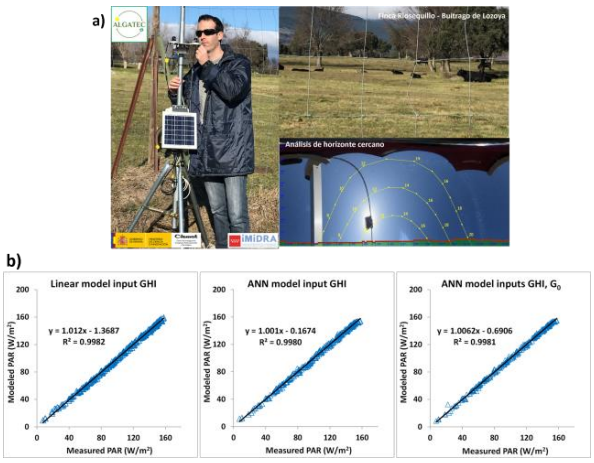

Fig 2. a) Drawn horizon line and Buitrago station assembly, b) Models' validation on PSA station

The ALGATEC project handles three measuring stations that belong to the PAR network described before, implemented in the Madrid region, which are, Aranjuez, Buitrago, and Alameda, the latest not installed yet because of COVID pandemic management difficulties. These measurements will be used to obtain a *Representative Meteorological Week* per quarter, as a concept similar to the *Representative Solar Year* (RSY) for thermoelectric solar plants, to carry out a long-term study of the meteorological variables, which electricity production estimations depend on. The study reflects the variability and the most probable statistical representation in the long-term of the climatology of the location, taking into account the variables considered. Therefore, this concept is transferred to the evaluation of sites for HRAP systems to study the influence of weather conditions in the Madrid region; the long-term behavior of some important meteorological variables for the growth of microalgae in the wastewater system plant is studied, considering that the rest of the necessary growth parameters are enough and in optimal concentration, and depending only on the climate of the location

There are measurement stations providing PAR and other variables, for each cluster resulting from applying the previously explained methodology based on the kt_{PAR}. Therefore PAR estimations from satellite imagery (CM-SAF, EUMESAT) can be adjusted with the data from each of the measurement stations in each cluster. As a result, PAR values will be more accurate. For this, it is necessary at least one-year of data in the sites of Buitrago, Aranjuez, and Alameda stations to do the adjustment.

4. Conclusion

The design, installation, and operation of twelve PAR stations monitoring network have been described in this communication. The PAR network will provide good quality data and aims to grow, facilitate and promote the work of all researchers interested in exploring knowledge of PAR radiation as an energy source, as well as any other studies that need PAR measurements to be developed, as applications on wastewater treatment by microalgae.

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