Renewable Energy 64 (2014) 197–202

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Technical note

# Evaluation of clear-sky conditions in high altitude sites

Germán Salazar [a,*], Carlos Raichijk [b]

[a] Department of Physics, School of Exact Sciences, National University of Salta, Bolivia Avenue #5150, 4400 Salta Capital, Argentina
[b] GERSolar, Institute of Ecology and Sustainable Development, Basic Sciences Department, National University of Lujan, Route 5 & Constitución Avenue, 6700 Luján, Buenos Aires, Argentina

ARTICLE INFO

*Article history:*
Received 18 June 2013
Accepted 1 November 2013
Available online 27 November 2013

*Keywords:*
Clear-sky
High altitude
Iqbal criterion
Clearness index

ABSTRACT

The correct assessment of cloud conditions in any site is important for determining the characteristics of solar resource availability. The criterion proposed by Iqbal has been widely used for this purpose, through the classification of the daily clearness index $K_t$. However, evidence was found to suggest that this criterion may not be applicable to data measured in high altitude sites, because partially cloudy days are incorrectly classified as clear-sky days. This paper analyzes the cloudiness state of the sky by observing the values of the clearness index $K_t$ and the clear-sky index $K_c$. These indices were obtained from reliable global solar irradiance data measured over a year in three places of Argentina located at different altitudes (25, 1200 and 3700 m.a.s.l). ESRA and ARG-P models were used to estimate daily clear-sky global solar irradiation values $H_c$. They also reveal that the most probable value of $K_c$ which corresponds to an actual clear-sky day of a particular location and time depends on the model used to estimate the clear-sky global solar radiation values. Thus, it was confirmed that, unlike the index $K_c$, the Iqbal's criterion does not correctly classify the cloud cover status from data measured in high altitude sites (>1000 m.a.s.l.).

© 2013 Elsevier Ltd. All rights reserved.

## 1. Introduction

Defining the amount of solar radiation available in a site or region is important to evaluate the feasibility of implementing systems that use solar energy to generate electricity. The generation of industrial quantities of electricity from renewable sources, such as solar energy, will be necessary in the future mainly because of two reasons:

i) As the global reserves of coal, oil and gas will eventually be consumed, alternative sources of energy will prove necessary to meet the demands of the ever-growing world population, an estimated 9-14 billion people by 2050, according to UN statistics [1].
ii) The use of renewable energy sources could reduce the emissions of greenhouse gases into the atmosphere, with the subsequent increase in the planet's greenhouse effect (popularly known as "global warming") which is currently affecting the thermal-radiative balance of the atmosphere [2].

The concept of solar radiation in clear-sky conditions is very useful for this type of studies, as it enables to estimate, for a given time and place, the maximum expected response of the system to be set up. A technical and economic feasibility study, even a simple one such as the HOMER software [3–6], needs statistically representative data on the actual availability of the solar resource.

A clear-sky day may be defined as one in which the temporal distribution of incident irradiance is qualitatively similar to the graph shown in Fig. 1a. In this paper the definition of a clear-sky day is parametric and not meteorological since the common meteorological procedure of quantifying the fraction of the cloud-covered sky is carried out by indicating the quantity of portions of sky (eighths [7] or tenths [8]) that are covered. Fig. 1b shows the graphs of measured global solar irradiance for a clear-sky day, a cloudy day and a partially cloudy day. The graph clearly shows the differences between the daily evolution of the global solar irradiance on one clear-sky day and on two non-clear-sky days.

Note that the solar irradiance graph measured on a clear-sky day (green line in Fig. 1b) indicates that there are no clouds moving past the solar disk in its apparent motion across the sky but it does not consider whether there were clouds in other sectors of the sky. For this reason, the definition of a clear-sky day provided in this paper is not meteorological.

Generally, the occurrence of a clear-sky day is not a usual event since the solar disk is very likely to be affected by clouds. Even if the

* Corresponding author. Tel./fax: +54 387 4255489.
*E-mail addresses:* salazarg@unsa.edu.ar, german.salazar@uv.es, germansalazar.ar@gmail.com (G. Salazar), carlosraichijk@yahoo.com.ar (C. Raichijk).

0960-1481/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2013.11.003

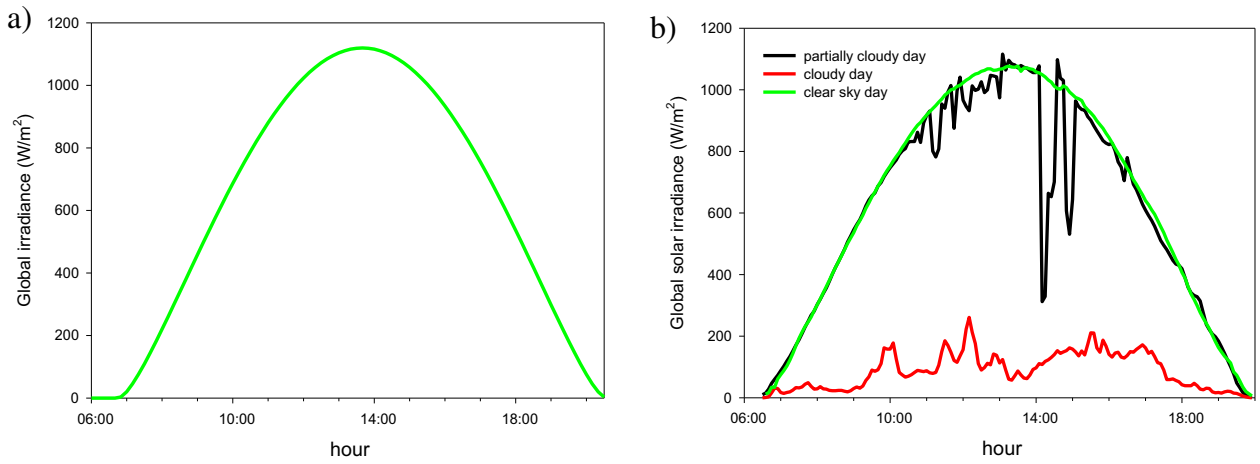


**Fig. 1.** a. Simulation of the ideal temporal distribution of global solar irradiance on a clear-sky day for a site in the vicinity of the Tropic of Capricorn, around the summer solstice. The model used for the simulation was the ARG-P (Salazar et al., 2010). b. Measured values of global solar irradiance for the following days: 12/4/2007 (black line), 12/5/2007 (red line) and 12/19/2007 (green line) in El Rincon Salar (Salta, Argentina). Note the similarities between the forms in Fig. 1a and the measured clear-sky day in Fig. 1b. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

day elapses without any clouds in the sky, the presence of other impermanent components of the atmosphere (mainly water vapour and aerosols) can cause changes in the value of the solar radiation striking the surface [9–11]. For example, in the Atacama Desert (Chile), one of the driest places in the world [12,13], where very few cloudy days might be expected, the daily observed variability of the solar radiation (Fig. 2) is rather significant.

The most common index used to characterize the atmospheric attenuation of incident global solar radiation is called the daily *clearness index*, $K_t$, defined as the ratio of daily global solar radiation measured or estimated on the surface, $H$, and daily extraterrestrial solar radiation, $H_0$:

$$K_t = H/H_0 \tag{1}$$

The temporal basis may also be monthly or annual.

Using this index, Iqbal [9] proposed the following criterion for the classification of the cloudiness of a day:

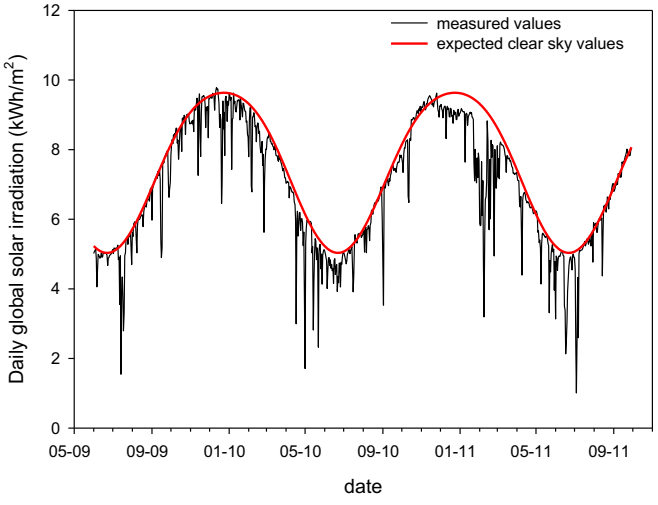


**Fig. 2.** Daily values of global solar radiation measured in San Pedro de Atacama (lat. −22° 58′ 35″ long. −68° 9′ 36.4″, 2394 m). The red line shows the approximate values of the expected clear-sky days. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

$$0.7 \le K_t < 0.9 \Rightarrow \text{clear} - \text{sky day} \tag{2.1}$$

$$0.3 \le K_t < 0.7 \Rightarrow \text{partially cloudy sky day} \tag{2.2}$$

$$0.3 < K_t \Rightarrow \text{cloudy sky day} \tag{2.3}$$

This criterion gives good results for solar radiation values measured in sea-level sites [14,15], but there is evidence that it is not significant for high altitude sites [16]. Since the South American region that has the optimal values of solar radiation is the Plateau Puna [17,18], which is located at more than 2000 m.a.s.l., then it is necessary to find and evaluate an alternative criterion to correctly determine a clear-sky day in this type of geography. Thus, the aim of this paper is to show that the Iqbal's criterion proves impractical to evaluate the type of cloud cover in high altitude sites and to devise a simple method which would accomplish this with its application to unfiltered databases in mind. This review was conducted by using global solar radiation data measured in three sites of Argentina at different altitudes.

The first alternative evaluated was the daily *clear-sky index* $K_c$ defined as

$$K_c = H/H_c \tag{3}$$

where $H_c$ is the incident daily solar radiation under clear-sky day conditions, i.e., the maximum possible solar radiation for a site and day. In this case, the reference value to compare the global solar irradiation H is not the extraterrestrial solar irradiation $H_0$. This implies that there is no intervention of atmospheric radiative transfer phenomena (absorption and scattering) that occur when $H_0$ is used as reference. Before being attenuated by clouds, the extraterrestrial solar radiation loses part of its energy just by passing through the atmosphere. That is why the $K_t$ index, under normal conditions, cannot reach the value 1. The $K_c$ index does reach that value, though, as it represents a ratio of two magnitudes ($H$ and $H_c$) present in the troposphere.

The characteristic value of a clear-sky condition, $H_c$, should be determined empirically from measurements in verified conditions, but this procedure is very difficult to accomplish systematically. If there are no solar radiation data available measured *in situ* under

Download English Version:

https://daneshyari.com/en/article/300090

Download Persian Version:

https://daneshyari.com/article/300090

Daneshyari.com