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Comparison of typical meteorological year and multi-year time series of solar conditions for Belsk, central Poland

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ABSTRACT

The deployment of solar energy projects in a given region requires a precise estimation of potential solar resources. For that purpose, generating a typical meteorological year is of great importance, although in principle it is a tool used in construction or engineering. Various methods for deriving typical meteorological years have been developed, but their final results can be significantly different. In this paper, two major methodologies (TMY3 method and ISO 15927-4 standard) were applied to 12-year measured data series recorded during the period 2003–2014 in Belsk, central Poland. The sums of global solar radiation obtained in typical meteorological years were compared to the long-term average measured sums of global solar radiation in order to decide which method can be recommended as best reflecting solar conditions in Poland. According to this study, the differences between the respective TMY data sets and long-term measured data set (measured with percentage root mean square error – %RMSE) are bigger than 5%. ISO 15927-4 standard slightly better approximates solar conditions in central Poland than TMY3 method – the %RMSE equals 5.25% and 6.71% respectively.

1. Introduction

Due to the small number of measuring stations that record global solar radiation reaching the Earth's surface, there is a need to find an alternative source of reliable solar data while assessing the solar resources in a given region. A typical meteorological year (TMY), originally created for engineering purposes (e.g. building's heating, cooling), can be used to estimate these resources. TMY is a collation of weather data (temperature; air humidity; wind speed and direction; global, direct and diffuse radiation), most frequently presented as hourly values, describing the characteristics of the yearly weather pattern of a given location [10]. Increasingly often such data are used to model the quantity of solar energy reaching the Earth's surface, and the calculated values are used for estimating the potential of this energy resource [2,18,22,25,30]. However, since the TMY purposely exclude information about anomalous or extreme weather conditions, determining a solar farm's electricity production on this basis can give results that are different from the actual ones [31]. Among many statistical methods that allow calculating the values of meteorological variables for the TMY, the most known in American literature is the TMY method [11] and its last, modified version – TMY3 method [28]. This method is one of the most commonly adopted approaches when developing TMY weather files, and it is applied by i.e. Üner and İleri [25]; Gawin and Kossecka [10]; Sawaqed et al. [23]; Skeiker [24]; Janjai and Deeyai [12]. Another American method is the WYEC (Weather Year for Energy Calculation) [7]. In Europe the TRY (Test Reference Year), also known as the Danish method, is often used [16]. International Organization for Standardization (ISO) also established a TMY for energy calculations. It was approved by CEN (Comité européen de normalisation, European Committee for Standardization) as EN ISO 15927-4 standard. It specifies a method for constructing a reference year of appropriate meteorological data suitable for assessing the average annual energy for buildings' heating and cooling [4]. There are also other methods for deriving the TMY, only the most widely known were mentioned above, but their final results can be significantly different from one another. Studies have been conducted in order to compare them and find the one best reflecting solar conditions in a given place. The results of different TMY-generating algorithms have been compared with long-term average measured data in Greece [1], Syria [24], Thailand [12], Iran [8], China [13], South Korea [14] and Hong Kong [6]. This yielded positive results, i.e. showed good agreement with the long-term average measured data during the year. In Australia it has been found that the

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difference between TMY and average long-term measured data set amounted to less than 7% [15], in China 4% [13], in Thailand 2.7–3.9% [12], and in Nigeria it was less than 3% (in the case of global solar radiation) [21]. Moreover, Chan [5] suggested using special weighting in the TMY3 method, depending on the region for which the TMY is generated, that allows for generating a TMY best reflecting long-term average measured data. There are, however, some recent results showing that TMY data sets should not be considered as a proper alternative for the long-term measured data when it comes to solar resource. Some studies show the limitations of using the TMY in solar resource assessment both in relation to individual stations [3,26,27] and on the spatial scale [20]. The latter is of special interest because it refers to the area of central Poland. Having data from 16 weather stations, the researchers have found statistically significant differences between values of suitability for photovoltaics index calculated on the basis of TMY (ISO 15927-4 standard) and the long-term measured data sets. It should be noticed, however, that this comparison was made using different input data – global solar radiation for TMY and sunshine duration for the long-term measured average data, which leads to certain limitations in the interpretation of the results.

This study attempts to assess the possibility of using TMY data sets as an alternative for the measured global solar radiation data while evaluating the potential solar resource. The main purpose of this paper is to implement two TMY-generating methodologies using long-term measured meteorological and global solar radiation data and to evaluate these TMYs by comparing them to the mean values of the long-term measured global solar radiation data sets (so, in contrary to the previous research by Nelken and Żmudzka [20], the data sets are fully comparable). This type of comparison allows to decide which method could be recommended as the best one for the assessment of solar resource in the region of central Poland. The paper is of special importance because no similar work, comparing different methodologies of generating the TMY, has previously been conducted in the area of Poland. No comparison has also been made between TMY and empirical solar radiation data, enabling one to assess which method best reflects solar conditions in Poland. The reason for that is lack of access to solar radiation data from national measuring network. The only station with publicly available and long enough solar radiation data set is Belsk.

2. Materials and methods

2.1. Study area and data set

Belsk is located in the central part of Poland, about 50 km south from the capital city of Warsaw (Fig. 1). The weather station is situated in rural area, far away from any urban or industrial objects, so that the meteorological recordings are free from any urban influence. It has a temperate climate, representative for the major part of Poland located in the Polish Plain, with average temperatures ranging from −1.4° C in winter to 18.8 °C in summer (2003–2014). The meteorological and global solar radiation data have been acquired from the weather station of the Institute of Geophysics of the Polish Academy of Science in Belsk Duży. The station is located at 51°50′10″ north latitude, 20°47′34″ east longitude and at an elevation of 188 m. Hourly values of temperature, relative humidity and wind speed, as well as daily sums of global solar radiation have been obtained for the twelve-year period from 2003 to 2014.

The data set lacked some values. To complete the data, missing

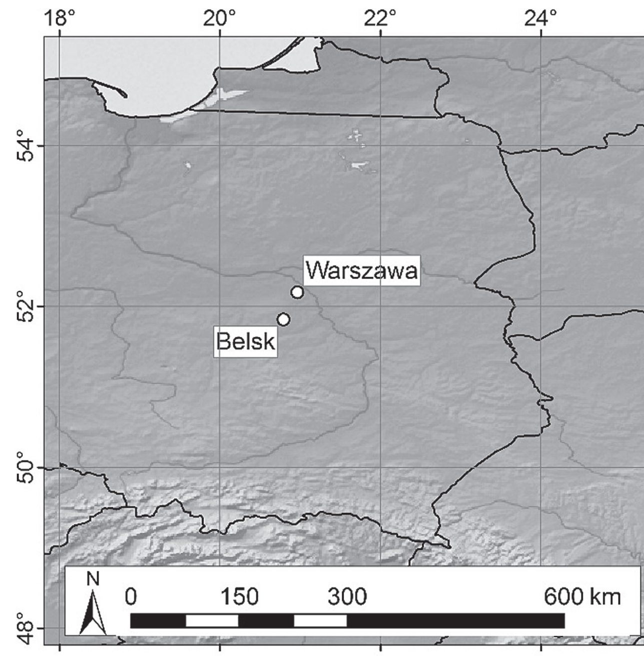

Fig. 1. Location of Belsk and the capital city of Poland – Warsaw (Warszawa).

values of mean daily temperature, relative humidity, wind speed and global solar radiation were replaced by estimated values. For gaps not longer than 3 days, missing values were generated by a linear interpolation method. There were only 9 such gaps, 8 of which were only 1 day long, so missing values accounted for approximately 0.26% of the whole data set. Three months – August, September and November 2003 – were excluded from the data set because of a massive break in measurements. For quality control the technique similar to the one adopted in Refs. [1] and [24] was used – all parameters were checked against empirical upper and lower bounds (e.g. solar radiation ≥0, temperature <40 °C, etc.).

2.2. TMY methods

In this paper, two TMY-generating methodologies have been compared – TMY3 method [28] and EN ISO 15927-4 method [4]. TMY3 is considered by many researchers to be the best and most commonly used in the world [8,12,24], while EN ISO 15927-4 method (hereinafter referred to as ISO), thanks to its standardization and relative ease of use, is often adopted in Poland, including in the case of the only TMY data set officially prepared for engineering purposes [19].

The method used to determine a TMY according to ISO standard involves selecting, by statistical methods, one typical meteorological month (TMM) for each of 12 calendar months from a given period (not shorter than a 10-year series) and concatenating the 12 months to form a TMY. Each TMM is identified by comparing the cumulative distribution function (CDF) of this month for each year with the CDF of this month for all the years in the period 2003–2014 for three major weather indices: dry bulb temperature, dew point temperature and global solar radiation. To illustrate the selection pattern, Fig. 2 shows the comparison of global solar radiation between individual month (June) CDFs and long-term (all Junes) CDF. The statistic used to measure the closeness of each year's CDF to the long-term CDF for a given index is the Finkelstein-