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Modelling the global solar radiation climate of Mauritius using regression techniques☆

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ABSTRACT

The tropical island of Mauritius (20.3°S, 57.6°E), situated in the southwestern Indian Ocean, is blessed with abundant sunshine throughout the year. In this study, eleven regression models grouped into three main categories: sunshine-based, temperature-based and hybrid-parameter-based are investigated using twenty-nine years meteorological data which include sunshine hours, temperature and relative humidity for fifteen stations on the island. Calibration of these models in the varying climatic regimes of the island is performed using global solar irradiation measurements recorded at the fifteen stations. An additional model, Sayigh Universal Formula, is modified through the implementation of a relative humidity factor trend specific to Mauritius and applicable to all regions on the island. The prediction capabilities of all twelve models are determined using statistical evaluation indicators and the better performance of the Sayigh Universal Formula acclimatized to Mauritius is revealed. Spatially clustered cloud cover zones are found to influence significantly the spatial distribution of global solar irradiation on a horizontal surface on the island, which varies from a maximum value of 22.5 MJ/m^{2}day to a minimum of 9.5 MJ/m^{2}day throughout the year giving an average of about 16 MJ/m^{2}day.

1. Introduction

Mauritius relies heavily on imported fossil fuels for its primary energy needs, with a share of 84% comprising mainly of coal and petroleum products [1]. The remaining 16% of the total primary energy requirement is attributed to locally available renewable energy sources which is subdivided into bagasse, hydro, wind, landfill gas, photovoltaic and fuel wood. The dependence on fossil fuels to meet the energy needs of the population has a negative impact on the climate. An increase of 2.6% in carbon-dioxide emissions has been reported in 2013 as compared to 2012 with the energy sector blamed for contributing worth 61.6% of the total emissions [2]. The expansion in population dynamics fuels the need for increased energy consumption [3]. The Government of the Island came forward with a series of strategies in order to mitigate the greenhouse gas emissions. In the policy document entitled 'Long Term Energy Strategy 2009–2025', the Government of Mauritius shares its vision to increase renewable energy share to 35% by 2025 [4]. Renewable energy has the capacity of meeting the increasing energy demands while keeping carbon emissions to a safe level. The current challenge however is to provide reliable affordable energy while transitioning towards renewable energy sources. A set of initiatives has been undertaken in order to encourage sustainable energy development on the island. Attractive policies have been set up and investors have been encouraged to invest in renewable energy technologies.

One of the budgetary measures put forward by the Government is the investment of Rs 400 million (approx. USD 12 million) to increase grid absorption capacity from intermittent renewable sources [5]. This would increase the grid intake capacity for conventional renewable energy sources and therefore account for additional storage capacity coming from renewable energy sources. Blessed with abundant sunshine, Mauritius aims to encourage investments in the solar energy sector. The Government currently seeks international competitive bidding for its energy projects and supports joint ventures between local private firms and international companies. In 2014, local firm Sarako Ltd with the support of German counterpart Tauber Solar Energietechnik GmbH managed to set up a 15.2 MW solar power plant which feeds into the

☆ This manuscript is a collaborative effort.

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country's 66 kV grid, producing 24 GWh electricity and conserving worth 15,000 tons of carbon dioxide emissions per year [6]. Furthermore, the Central Electricity Board (CEB) which is the sole distributor of electricity on the Island negotiated power purchase agreements with a number of selected bidders for photovoltaic projects of 1–2 MW for a total of 10 MW [7]. Further incentives have been taken in the form of increasing the integration of Independent Power Producers (IPPs) and Small Scale Distributed Generators (SSDGs). The solar energy potential of Mauritius has long been recognized as an untapped resource and major steps have been taken in the country's quest towards attaining self-sufficiency.

Knowledge of the spatial and temporal distribution of global solar irradiation on a horizontal surface is vital for implementing solar energy systems. Solar resource information is being used nowadays by both architects and engineers to help design passive solar and daylighting features for buildings. Local global solar irradiation data is also sought by potential solar farm planners in order to locate potentially high solar energy catchment areas. Solar insolation data is also solicited to reveal agro-climatic zones. However, despite the necessity of global solar irradiation data, these are not made readily available due to high cost, maintenance and calibration requirements [8]. Solar insolation measurement instruments were installed in some 15 stations over Mauritius and were able to take readings for the period 1961–1990 [9]. However, due to high maintenance and calibration necessity, very few insolation measurement instruments are still operational. Rather, there are about 20 observation sites that are fully operational and currently taking readings for bright sunshine, relative humidity and temperature over a period of more than 40 years [10]. In line with this, we provide methods for estimating the global solar irradiation in Mauritius using other climatologically available parameters such as bright sunshine, relative humidity and temperature. To the author's knowledge, no study has been performed to estimate the global solar irradiation in Mauritius using various insolation models available in literature.

Many insolation models are available in literature in order to estimate the global solar irradiation on a horizontal surface based on other climatological parameters that have been recorded at the same location. The variation in global solar irradiation is concomitant with changes in meteorological parameters such as relative humidity, temperature, sunshine hours, rainfall, and cloud cover among others. As such, using the right combination of parameters can help formulate an empirical model in order to estimate the variations in global solar irradiation throughout the year. The first model was proposed by Angstrom [11] and made use of the ratio of the average daily global solar irradiation on a horizontal surface to the irradiation that would have been recorded in clear sky condition. Prescott [12] later simplified the linear model by modifying the clear sky condition to extraterrestrial solar irradiation. Based on the Angstrom-Prescott model, various linear regression models such as Jain [13] model for Italy, El-Metwally [14] model for Egypt and Li et al. [15] model for Tibet have been implemented. Dogniaux and Lemoine [16] investigated on the possibility of the regression coefficients of the Angstrom-Prescott model being a function of the latitude of the location. The ratio of global to extraterrestrial irradiation is related to the ratio of sunshine duration. Many global solar irradiation models attempt to correlate these two variables. Ogelman et al. [17] used a second order polynomial function while Bahel [18] used a third order polynomial function in order to correlate bright sunshine hours and global solar irradiation data. Other variations exist such as the linear-logarithmic model provided by Newland [19], the exponential model provided by Elagib and Mansell [20] and the power model developed by Coppolino [21].

Cloud patterns and movements influence the total amount of solar irradiance at the Earth's surface. Models developed by Paltridge [22] and Daneshyar [23] takes into consideration the cloud factor. However, cloud measurements are not readily available and therefore easily accessible meteorological data such as temperature is preferred when it comes to developing insolation models for assessing the resource energy potential of a country. Fortunately there exist temperature-based models such as Hargreaves [24], Annandale [25], and Donatelli and Campbell [26] that relies on the temperature difference between the maximum and minimum temperatures among other variables. Some researchers have tried to use a combination of various meteorological parameters such as relative humidity, maximum temperature, rainfall, pressure and sunshine duration to formulate a model with the objective to describe the variations in global solar irradiation. De Jong and Stewart [27] model employs precipitation data as well as temperature difference between maximum and minimum temperatures at a region in order to estimate the global solar irradiation on a horizontal surface.

The objective of the current study is to model the global solar irradiation climate of Mauritius using regression equations available in literature in an attempt to provide solar farm operators and other relevant stakeholders with a useful and efficient method to estimate the parameter of interest. We employ a combination of mathematical formulation tools coupled to GIS techniques to map the spatio-temporal variations of global solar irradiation of the country. The novelty of this paper is that it explores various insolation models from three different groups, namely: sunshine-based, temperature-based and hybrid-parameter-based, in an attempt to acclimatize them to the region of Mauritius for accurate global solar irradiation prediction on the temporal scale. The various models are rigorously tested on the varying and distinct climatic regimes of the island. A modified version of the Sayigh Universal Formula is proposed to estimate accurately the global solar irradiation of Mauritius.

The manuscript is structured as follows: Section 2 describes the study area, data materials, methods and models investigated; Section 3 presents the results of the acclimatization and testing for the different insolation models at representative stations on the island. Also presented in this section is the formulation of the Modified Sayigh model and its use to describe the spatio-temporal variations of global solar irradiation; Section 4 provides the conclusive remarks of the study performed.

2. Methodology

2.1. Study area

Mauritius, one of the three Mascarene Islands in the south-western Indian Ocean, benefits from the considerable climatic diversity of regions located in the subtropical belt. Of volcanic origin, the Island has an elliptical shape with a surface area of 1859 km^2, major axis measuring 63 km and minor axis spanning up to 43 km. The collection of mountains, valleys and variable terrain slopes portray the complex topography of the Island. A remarkable geomorphic feature is an elevated central plateau about 500 m above sea level which was of origin a caldera located in the central and southwestern regions. The complex topography causes the climate to be diverse and variable, resulting in long humid summers from November to April and relatively short and mild winters from May to October [28]. Owing to the island's location and topography, several weather systems of different scales and amplitudes affect the island [29]. The location of the Inter Tropical Convergence Zone (ITCZ) ensures persistent south-east trade winds (easterlies) across the island, despite the fact that on few occasions westerlies prevail when ITCZ lies south of Mauritius [30]. The wind