Renewable Energy 116 (2018) 88–96

Contents lists available at ScienceDirect

Renewable Energy

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

Interannual and spatial variability of solar radiation energy potential in Kenya using Meteosat satellite

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A R T I C L E I N F O

Article history:
Received 23 May 2017
Received in revised form
12 August 2017
Accepted 22 September 2017
Available online 23 September 2017

Keywords:
Renewable energy
Solar energy
Global horizontal irradiance
Direct normal irradiance
Variability
Kenya

A B S T R A C T

Kenya is faced with a rising demand in electricity resulting from a rapidly growing economy and an increasing population. Being a tropical country, lying astride the equator, solar energy is one of the readily available renewable energy resource options to meet this need. Unfortunately, there is still very low adoption of solar systems in the country which could be majorly attributed to lack of adequate solar resource assessment. Besides, past studies on this area in Kenya only focused on the available amount of solar resource leaving out the issue of variability. To bridge this gap, the temporal and spatial variability of global horizontal irradiance (GHI) and direct normal Irradiance (DNI) is analyzed using 19-year long (1995–2013) Meteosat satellite dataset. GHI interannual variability is low in most parts of the country but DNI has a clearly higher variability except a few locations in the East and Northern desert. Low spatial variability for GHI was recorded for locations within 1225 km^2 while DNI variability was double that of GHI. The results offer readers a quick reference of variability of solar resource at different locations in Kenya which is useful in guiding measurement requirements and consequently in promoting deployment of solar systems.

1. Introduction

Governments all over the world have an obligation to ensure that their citizens have access to energy which is vital for social and economic stability and growth. However, provision of energy services must be done in a sustainable and environmentally benign way. One of the most agreeable ways to strike a balance between energy service delivery and a clean environment is by utilization of renewable energy (RE) sources. Besides the fact that they are sustainable, being replenished freely by nature, their greater advantage is that they produce little or no by-products like the carbon emission. In the light of global warming and climate change which is attributed to anthropogenic greenhouse gases emissions, RE sources have received a global attention especially in electricity generation [1–3].

Kenya, a study area here, is a developing country with a fast growing economy at a current GDP annual growth rate of 5.7%. Additionally, according to the recent census of 2009, the population of Kenya which currently stands at approximately 45 million people is also growing at an estimated rate of 3% per annum. Less than 50% of this population has access to electricity with only 5% of the rural population being electrified [5]. It is therefore apparent that, the electricity sector in Kenya is facing a sharp increase in its demand, a factor which is accelerated by current development strategies in place e.g., the vision 2030 economic blue print of 2012, which comes with huge industrial projects and consequently, heavy energy obligations [6].

To address the electricity and energy problem in Kenya, solar systems including photovoltaic (PV) systems, Solar thermal and building thermal systems are suitable RE options, considering that the country is favorably located astride the equator and therefore, has high insolation rates at an average of 5 peak sunshine hours (The equivalent number of hours per day when solar irradiance averages 1000 W m^{-2}). However, an addition of solar systems to local electricity mix requires means of handling challenges that arise from cloud induced fluctuations of generated power output, which are a major concern to utilities and grid operators. These fluctuations result from variation of solar radiation incident on the PV cell, and therefore, solar radiation variability studies could give grid operators a prior knowledge of their characteristics at specific

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https://doi.org/10.1016/j.renene.2017.09.069
0960-1481/

locations of PV systems' deployment [7].

The radiation reaching the earth's surface can be represented in a number of different ways. Global horizontal irradiance (GHI) is the total amount of shortwave radiation received from above by a surface horizontal to the surface of the earth. This value is of particular interest to flat plate PV installations and includes both direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI). DNI is the solar radiation that comes in a straight line from the direction of the sun at its current position in the sky falling on a surface held at normal to the sun rays. It is relevant for application in solar concentrating technologies including, concentrating solar power and concentrating solar PV [8,9]. In this study, focus is given to the PV technology i.e. flat plate and concentrating PV.

In the Kenya's electricity mix, by August 2014, hydro power generation controlled the largest share at 37.2%. Thermal power plants (medium and high speed diesel power plants) were in the second place providing 30.7% of electricity but these includes emergency power plants which are mainly reserves for drought periods when the hydro power is not sufficient. Geothermal power installed capacity accounting for 27% of Kenya's total electricity production is the third source of electricity [10]. This mix is, however, changing dramatically with accelerated efforts by the government to reduce over-dependency on hydropower to avoid the effects of climate change including shifting rainfall patterns and chronic droughts which threatens the viability of big hydro projects in this region. To shift from the hydro power, while maintaining renewable sourced electricity in Kenya, the government has increased generation from geothermal and wind, and has also indicated interest in nuclear and coal based generation in the future. According to [10]; the electricity production in Kenya by the year 2014 stood at 2,205 MW but has a projected growth of over 500% translating to 21,620 MW of installed capacity by the year 2030 [6,10]. The government has not considered solar PV as a candidate technology in the most recent long-term power system plan towards 2030. In spite of this, Solar PV home systems installed in Kenya have increased rapidly with recent statistics indicating that the country is a leader in the African continent in the number of small scale PV installations. Further, studies show that building water heaters application has increased rapidly in the recent years [17]. Recently, research and development efforts have improved the conversion efficiency of PV cells to as good as 15% by 2014, while laboratory prototypes -not commercialized yet, can give efficiencies up to 30%. Additionally, solar PV plants requires short construction time, very little maintenance costs, and can be built near the consumption, thereby reducing the cost of transmission and distribution losses [8,9,11]. Besides, the costs of solar energy technologies, and most importantly solar PV, have continued to decline rapidly [8,11] and there is therefore the need for system planners to consider these recent developments. Most importantly, solar generated electricity has no greenhouse gases emission during electricity generation, no fuel costs, and no risks of fuel price spikes [2,8], and has therefore the potential to help move the country towards cleaner, reliable, and affordable sources of electricity.

Solar resource assessment conducted in Kenya includes [12] who were among the first to characterize solar irradiation from satellite observation in the region. The study utilized data from METEOSAT 2 limited to a period of two years (1985–1986). This study has vital information on the available amount of global horizontal radiation reaching the earth's surface in three regions namely, Europe, Asia Minor, African continent and parts of Atlantic Ocean. The study further details the annual and temporal variability of solar radiation in the wide study area. [13] also provided solar radiation data in Kenya by mapping annual and monthly potentials of GHI and DNI by using satellite data for a period of three years (2000–2002). In another study [5], reported that Kenya has an average of 5 kWh m^{-2} day^{-1} of solar radiation potential. [14] utilized a digital elevation model to characterize solar energy potential and its spatial distribution and similarly concluded that, Kenya has high radiation energy potential. The study indicated that 34% of the total land of Kenya receives between 5 and 5.5 kWh m^{-2} day^{-1} with another significantly large area covering 26.5% of the total land receiving between 5.5 and 6 kWh m^{-2} day^{-1} while 10.1% of the land receives 6.0–6.5 kWh m^{-2} day^{-1}. While the previous studies have given vital information on the available amount of radiation over Kenya, a complete characterization of solar radiation is one which includes variability of this resource. This issue of variability has not been adequately addressed in the previous studies. Variability may be explained in terms of space, that is, how the solar radiation varies with distance or in temporal, how it changes with time, which is normally in different time scales that is, small time steps from seconds to minutes or longer time scales, running from hours, days or even years [7,9,15]. Variability at these different time steps has different impacts to the grid and causes unexpected sudden changes in power output which is a major concern to grid and utility operators. The knowledge on temporal variability informs the system designers about the quality of solar radiation for the intricate design of solar systems for instance, in the sizing of storage systems. Prior knowledge of variability is also useful in relating statistics of short term measurements to long term ones [7,9,16]. For instance, although a single year of data cannot be used to represent a long term measurement, if low interannual variability for a certain place is recorded, it can be assumed that measurement for a short period could be used to explain long term characteristic of solar radiation. Similarly, low spatial variability can be used to conclude that measurement in one place could represent the characteristic of solar radiation in nearby locations [7].

Studies aimed at determining the effects of solar resource variability on solar PV output and its potential impacts to the systems operators begun in the 1980s [17–20]. There have been increased efforts to conduct solar resource variability analysis globally but such studies have not been conducted in Kenya. [7] characterized the interannual and spatial variability of GHI over US and found out that the consistency of solar resource in that country varies widely in both time and space. They mapped the analyzed results over US and provided the data to the national renewable energy laboratory (NREL) where the data is provided free of charge becoming a very useful reference for investors and policy makers in the solar energy industry of that country. [16] conducted similar analysis for Benelux and characterized solar radiation at the different climatic regions in Benelux based on the available amount and the year-to-year variation of solar radiation over Benelux. However, recent study by Ref. [21] in the European Union (EU) concluded that there is a limited understanding of the variability characteristics of future power system. The study reveals that, even though the EU is aiming to develop a future power system with very high contributions from wind and solar production, only a few studies have analyzed the variability characteristics of such a system, whose primary cause is variability of output from the weather dependent generation options like solar and wind. Similar observations had long been made by Ref. [7] who reported that research on solar resource variability is limited globally.

The purpose of this study is to conduct solar resource assessment to determine not only the available amount but also the temporal and spatial variability of GHI and DNI potential over Kenya. With a focus on variability, this study is expected to fill in the gap in previous similar studies in Kenya. This study is expected to deliver useful solar resource information on suitable locations, as well as the best technologies of deployment for these locations in Kenya. Additionally, the findings in this study are expected to