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Assessment of solar radiation resources in Saudi Arabia

Erica Zell [a], Sami Gasim [b,*], Stephen Wilcox [c], Suzan Katamoura [b], Thomas Stoffel [c], Husain Shibli [b], Jill Engel-Cox [a], Madi Al Subie [b]

[a] Battelle Memorial Institute, 505 King Ave, Columbus, OH 43201, USA

[b] King Abdullah City for Atomic and Renewable Energy, Olaya St., Riyadh 11576, Saudi Arabia

[c] Solar Resource Solutions, LLC, Louisville, CO, USA

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Abstract

Solar radiation resource data are the foundation of information for programs of large-scale deployment of solar energy technologies. While the solar resource in Saudi Arabia and the Arabian Peninsula was believed to be significant based on limited past data, understanding the spatial and temporal variability requires significantly more data and analysis in order to optimize planning and siting solar energy power plants. This paper summarizes the analysis of the first year of broadband solar resource measurements from a new monitoring network in Saudi Arabia developed by the King Abdullah City for Atomic and Renewable Energy (K.A.CARE). The analysis used twelve months (October 2013–September 2014) of data from 30 stations distributed across the country based on one-minute measurements of Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI), Direct Normal Irradiance (DNI), and related meteorological parameters. Network design, implementation, and data quality assurance are described to document the network extent and quality. For the 30 stations, the annual average daily GHI ranged from about 5700 Wh/m^2 to 6700 Wh/m^2 with consistently higher values inland and lower values along the coasts. This indicates that photovoltaic technologies would perform well at any location although extreme high temperatures (over 30 °C annual average in some locations) may degrade the performance of some types of photovoltaic technologies. Annual average daily DNI was much more variable across the stations, ranging from about 4400 Wh/m^2 to over 7300 Wh/m^2 with the highest values and clearest skies in the northwest part of the country. While most regions have sufficient solar resources for concentrating solar technologies, the western inland sites with average daily totals of over 6474 Wh/m^2 (average yearly totals of 2400 kW h/m^2/year) are superior to the eastern sites with average daily totals closer to 5510 Wh/m^2 (average yearly totals of 2000 kW h/m^2/year). This first year of data represents the beginning of a deeper understanding of solar resource characteristics in Saudi Arabia and the Middle East. Although continued measurements are needed to understand the interannual resource variability, the current study should have significant applications for preliminary technology selection, power plant modeling, and resource forecasting.

Keywords: Solar resources; GHI; DNI; Saudi Arabia

Abbreviations: K.A.CARE, King Abdullah City for Atomic and Renewable Energy; RRMM, Renewable Resource Monitoring and Mapping.

* Corresponding author.

E-mail addresses: zelle@battelle.org (E. Zell), s.gasim@energy.gov.sa (S. Gasim), swilcox303@gmail.com (S. Wilcox), s.katamoura@energy.gov.sa (S. Katamoura), tstoffelsrs@gmail.com (T. Stoffel), h.shibli@energy.gov.sa (H. Shibli), engelcoxj@battelle.org (J. Engel-Cox), m.subie@energy.gov.sa (M.A. Subie).

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1. Introduction

The Kingdom of Saudi Arabia estimates the country will need vast energy resources in the coming decades for electricity generation, desalination, and process heat to meet the needs of a rapidly growing population and economy (EIA, 2014). In order to use petroleum for higher value purposes and export, the Kingdom is planning a sustainable energy mix that includes renewable energy based on local resources. Based on an expected large solar resource, solar energy has long been considered promising in Saudi Arabia (Baras et al., 2012; Hepbasli and Alsuhaibani, 2011). The King Abdullah City for Atomic and Renewable Energy (K.A.CARE), as the lead Saudi Arabia government agency for renewable energy, is developing the Renewable Resource Monitoring and Mapping (RRMM) Solar Measurement Network in support of large increases to the Kingdom's solar generating capacity, moving toward a sustainable energy mix for the country. As of 2013, the total installed capacity of solar photovoltaic capacity in Saudi Arabia reached 7 MW (Bryden et al., 2013). New investment in renewable energy in the Middle East and North Africa (MENA) region was estimated at USD 9 Billion in 2013, representing an almost tripling of investment compared to two years prior (McCrone et al., 2014), making the region a small but rapidly growing market. Several major solar Photovoltaic (PV) and Concentrating Solar Power (CSP) plants were commissioned in the MENA region during 2013 and 2014, in Saudi Arabia along with Jordan, Kuwait, and the United Arab Emirates, and several governments in the region have launched tenders or signed purchase agreements (REN 21, 2014).

Whether globally, regionally, or locally in Saudi Arabia, successful solar technology development and power project implementation relies, in part, upon understanding the available solar resource and its temporal, spatial, and spectral characteristics. For project deployment, characterization of the solar resource drives technology selection and project design, and represents the largest source of uncertainty in power project output estimates with implications for financing terms and returns on investments (Schnitzer et al., 2012). Thus, accurate measurements of the solar resource, along with environmental conditions such as ambient air temperature and dust levels which affect project output, are critical to project deployment. Further, best practices in solar resource measurement are well-established, such as those documented by Sengupta et al. (2015).

The current projects in Saudi Arabia have been launched with very limited or outdated measured solar resource data, relying instead on data estimated from satellite-based observations of the atmosphere. While this may be acceptable for the small-scale projects launched so far, a major expansion as planned requires accurate long-term ground-based resource data. With ground-truthing from measured data, satellite-derived model estimates of solar resources can offer more accurate spatial models of solar resources over a long-term time series than either ground-based measurements or satellite-derived estimates alone. Satellite-derived estimates of solar irradiance are particularly in need of ground measurements to improve performance in areas with complex terrain, such as between urban and rural areas, coastal and inland areas, and mountain and valley areas (Perez et al., 2013).

This paper presents an analysis of the first year of solar resource data from a new ground-based monitoring network in Saudi Arabia. The RRMM Solar Measurement Network will be the most extensive and in-depth effort in the MENA region. The network operates in the context of other established global and country-level monitoring networks, such as the Baseline Surface Radiation Network (BSRN) which incorporates 58 stations and has operated since 1991 (McArthur et al., 2005). Existing major country networks also influenced the network design, such as the United States Department of Energy's Atmospheric Radiation Measurement (ARM) Program (Stokes and Schwartz, 1994) and the Australia Bureau of Meteorology solar monitoring program (Forgan, 1996). More recent monitoring networks provide similar country-level examples, such as those deployed in India, South Africa, and United Arab Emirates (UAE) (Blanksby et al., 2013; Kumar et al., 2014). Integration of such ground-based data with satellite-based models can provide a comprehensive and accurate characterization (on the order of ±4% for annual GHI and ±7% to 8% for annual DNI, globally) of solar resources (Eissa et al., 2012; Hoyer-Klick et al., 2011; Alobaidi et al., 2014; Cebecauer and Šúri, 2012). This characterization then provides input for solar resource planning tools, such as the System Advisor Model (NREL, 2015) and PVSYST (PVSYST, 2015), and facilitates policy, planning, research and development, and project deployment.

For Saudi Arabia, up until 2013, only limited solar resource data were available from a historic monitoring network operated by King Abdulaziz City for Science and Technology (Myers et al., 2002), along with some university-collected data (e.g., El-Sebaii et al., 2010). These critical data provided early insights on solar resource levels, and supported satellite-based model validation, but also illuminated the challenges of network operation in a country with a land area over 2 million km^2 that experiences periods of significant airborne dust and extreme heat. Neither the satellite-based nor historic ground-based data fully characterized the solar resource in Saudi Arabia, especially given the country's regional climatic variations and concern about the impact of elevated dust levels and ambient temperatures on system performance (Said et al., 2004; Alnaser et al., 2004; Huraib et al., 1996; Stoffel et al., 2013). A Saudi Arabia-wide monitoring network that began deployment in January 2013 is filling this gap, designed to provide publicly available data for three major purposes: immediate data for project developers, data for solar