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A key review on present status and future directions of solar energy studies and applications in Saudi Arabia

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ABSTRACT

Renewable energy is accepted as a key source for the future, not only for Saudi Arabia, but also for the world. Saudi Arabia has abundant potential for exploiting solar energy, which is renewable, clean, and freely available. The average annual solar radiation falling on the Arabian Peninsula is about 2200 kWh/m^2. Applications of solar energy in Saudi Arabia have been growing since 1960. Solar hydrogen production plant situated at the Solar Village, Riyadh, Saudi Arabia, could have been considered as the world's first 350 kW solar-powered hydrogen-generation plant at the time of its inception. The development of solar energy, however, has been relatively low due to several obstacles although utilization of solar energy in its various aspects is very attractive for the country. The main objectives of this study are to address current applications and future aspects of solar energy along with studies conducted in this field and to assess them in the light of available sustainable energy technologies towards establishing energy policies. The solar energy-related topics reviewed include various types of solar radiation correlations, exergetic solar radiation, solar collectors, solar photovoltaic (PV) systems, solar stills, solar-powered irrigation, solar energy-related greenhouses, solar hydrogen, solar water desalination and solar energy education. Some barriers, scenarios and constraints are also covered. The utilization of solar energy could cover a significant part of the energy demand in the country. If a major breakthrough is achieved in the field of solar-energy conversion, Saudi Arabia can be a leading producer and exporter of solar energy in the form of electricity. The geographical location of the country, its widespread unused desert land, and year-round clear skies, all make it an excellent candidate for this.

Contents

Abbreviations: ANN, artificial neural network; ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers; COE, cost of generating energy; COP, coefficient of performance; CoRE-RE, Center of Research Excellence in Renewable Energy; ED, electrodialysis; ERI, Energy Research Institute; GCC, Gulf Cooperation Council; GH, greenhouse; GSR, global solar radiation; HYSOLAR, A Long-term German-Saudi Arabian Cooperative Programme for research, development and demonstration of solar hydrogen production as well as utilization of hydrogen as an energy carrier; KACARE, King Abdullah City for Atomic and Renewable Energy; KACST, King Abdulaziz City for Science and Technology; KAUST, King Abdullah University of Science and Technology; KFUPM, King Fahd University of Petroleum and Minerals; KSU, King Saud University; MD, membrane distillation; MSF, multistage flash desalination; NREL, National Research Energy Laboratory; PCM, phase change material; PTC, parabolic-trough collectors; RBF, radial basis function; R&D, research and development; RD&D, research, development and demonstration; RO, reverse osmosis; SERI, Solar Energy Research Institute; SET, sustainable energy technology; SOLERAS, Solar Energy Research American Saudi: Saudi Arabian-United States Program for cooperation in the field of solar energy program; VC, vapor compression.

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Nomenclature

a,b	coefficient of regression models
C_w	amount of cloud cover (octas)
H	monthly average of daily global radiation on horizontal surface (W/m^2 day)
H_b	monthly average of daily beam radiation on horizontal surface (W/m^2 day)
H_d	monthly average of daily diffuse radiation on horizontal surface (W/m^2 day)
H_D	diffuse irradiation on horizontal surface (Wh/m^2 day)
H_G	global solar irradiation (Wh/m^2 day)
H_0	monthly average of daily extraterrestrial radiation on horizontal surface (W/m^2 day)
K	geographical factor
K_t	monthly average of daily clearness index
L_l	latitude of location (°)
$MABE$	mean absolute bias error
MBE	mean bias error
MPE	mean percentage error
P_{at}	atmospheric pressure (kPa)
PWV	perceptible water vapor
R	coefficients of correlation
R^2	coefficient of determination
R_h	relative humidity (%)
$RMSE$	root mean square error
S	monthly average of daily bright sunshine hours (h)
S_c	solar energy absorbed by the greenhouse cover (W/m^2)
S_G	solar energy incident on the greenhouse (W/m^2)
S_L	solar energy lost to outside the greenhouse (W/m^2)
S_0	monthly mean daily maximum possible sunshine-duration
S_p	solar energy absorbed by the plants (W/m^2)
S_s	solar energy absorbed by the soil (W/m^2)
S_w	solar energy absorbed by the humid inside air (W/m^2)
SS	sunshine duration (h)
t	time (day)
T	temperature (°C)
T_a	air temperature (°C)
T_{max}	maximum ambient (air) temperature (°C)
T_{min}	minimum ambient (air) temperature (°C)
Z	maximum possible daylight hours (h)
θ	doubling time (h)
ϕ	latitude of the monitoring station (°)
ψ	monthly averaged relative humidity factor

1. Introduction

The combined effects of the depletion of fossil fuels and the gradually emerging consciousness about environmental degradation have given the first priority to the use of renewable alternative energy resources in the 21st century [1]. Of all renewables, solar thermal energy is considered to be practically unlimited in the long-term, and is a very abundant resource in the developing world [2]. It is potential source of renewable energy options that is being pursued by a number of countries with monthly average daily solar radiation in the range of 3–6 kWh/m^2, in an effort to reduce their dependence on fossil-based nonrenewable fuels [3].

Saudi Arabia is located in the heart of one of the world's most productive solar regions, which receive the most potent kind of sunlight [4]. The average annual solar radiation falling on the Arabian Peninsula is about 2200 kWh/m^2 [5].

Utilization of solar energy in its various aspects, therefore, is very attractive in this part of the world. Research, development, and demonstration (RD&D) activities in Saudi Arabia have confirmed that solar energy has a multitude of practical uses [6]. Renewable energy stands at something of a crossroads in Saudi Arabia. On the one hand, there have been serious energy analysts in the country who have worked for a greater role of solar energy in national energy policy. Renewable energy is widely praised for the environmental and public benefits it offers. On the other hand, there is a prevailing perception that renewable energy is largely irrelevant in the near- to mid-term planning horizons of industrial and energy investment in the Kingdom. This perception is manifested by the relatively small expenditures on renewable energy demonstration and commercialization projects, in the general lack of consideration of renewable energy in national energy policy development, and in the limited investment capital devoted to renewable energy projects. Energy forecasts in the country project negligible penetrations of renewable energy well into this century [7].