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Energetic and economic performance analyses of photovoltaic, parabolic trough collector and wind energy systems for Multan, Pakistan

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ABSTRACT

Pakistan is going through a severe energy crisis due to an increasing gap between demand and supply. Its current energy needs are heavily dependent upon conventional thermal power plants which mainly use oil and gas. In addition to the economic problems associated with importing oil for Pakistan, the burning of fossil fuels for the production of electricity releases vast amounts of greenhouse gases. As an alternative to the current scenario, in this paper the energetic and economic performance of green energy technologies such as photovoltaic (PV), parabolic trough collector (PTC) with and without storage, and wind energy systems are analyzed and compared with respect to their potential for electricity generation for the city of Multan, Pakistan. Each system is designed taking a nominal 10 MWe capacity as a reference. Hourly meteorological data are used to estimate hourly insolation on a fixed PV module and for PTC's with East–West and North–South tracking. Results show that PV and PTC systems without storage have approximately the same output with capacity factors of approximately 20%. The electrical energy output of the wind turbines was very low with a capacity factor of ~2%. PTC's with 7.5 h storage and a solar multiple of 3.5 showed the best result for electrical energy output with a capacity factor of 46%. A cost analysis is performed assuming a 30 year lifetime for PV and a 35 year lifetime for PTC. The Levelized Cost of Electricity (LCOE) is found to be 0.192 USD/kWh for PV systems, 0.273 USD/kWh for PTC systems without storage, and 0.226 USD/kWh for PTC systems with 7.5 h of storage. The results of the economic study show that based strictly on economic considerations green energy technologies can be utilized if the government supports the investment by giving incentives and subsidies.

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Nomenclature

A	total area of photovoltaic solar plant (m^2)
A_0	total area of CSP solar power plant (m^2)
A_{coll}	parabolic trough collector area (m^2)
E	electrical energy output (Wh)
E_{ptc}^{max}	maximum electrical energy output of PTC system
E_t	annual energy output (Wh)
F_t	annual fuel cost (USD)
G_{std}	standard photovoltaic reference irradiation (W m^{-2})
I	initial investment (USD)
$I_{b,n}$	beam insolation normal to the mirror (Wh m^{-2})
I_{PV}	hourly insolation in the orientation of solar panel (Wh m^{-2})
L_{SCA}	length of a single solar collector assembly (m)
$L_{spacing}$	length of spacing between troughs (m)
M_s	solar multiple (dimensionless)
M_t	annual maintenance cost (USD)
$P_{installed}$	rated power capacity of the power plant (MW)
$P_{output,A=1}^{max}$	maximum output of the model with $A=1$ m^2 (W)
P_R	performance ratio
Q_{coll}	thermal energy collected by the trough collectors (Wh)
Q_{HE}	thermal energy available for heat engine (Wh)
Q_{HE}^{max}	maximum thermal energy capacity of heat engine (Wh)
Q_{stor}^{max}	storage size in units of energy (Wh)
Q_{stored}	thermal energy stored (Wh)
U^*	friction velocity (m s^{-1})
U_z	wind speed at an elevation of z meters (m s^{-1})
W	collector aperture width (m)
W_{eff}	effective width of mirror aperture (m)
Z	elevation (m)
Z_0	roughness length (m)
f	focal length of collectors (m)
k	universal von Kármán constant
n	lifetime of power plant (years)
r	discount rate
t	number of the years in LCOE calculation
t_{stor}	storage size in hours (h)

Indices

AEDB	Alternative Energy Development Board
CF	capacity factor
CSP	concentrating solar power
DNI	direct normal insolation (kWh m^{-2} day^{-1})
EW	east west
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
LCOE	Levelized Cost of Electricity (USD/kWh)
NREL	National Renewable Energy Laboratory
NS	north south
PTC	parabolic trough collector
PV	photovoltaic
TES	thermal energy storage
TMY	typical meteorological year

Greek letters

η_{HE}	efficiency of heat engine
η_P	solar cell efficiency
η_{total}	total efficiency of the PTC system
η_{st}	efficiency of thermal energy storage systems
θ	angle of incidence (radians)
θ_Z	solar zenith angle (radians)

1. Introduction

Renewable energy technologies are playing an increasingly important role in the sustainable development and well-being of states as fossil fuel resources are being depleted throughout the world. Wind and solar energy resources are considered to be two of the most important sustainable energy resources in the world [1]. The worldwide growing demand for sustainable energy has been investigated in a large number of studies [2–6]. The global growth trend of renewable energy technologies in 2011 was explored in [7] by Awan et al., and according to it the largest growth rate is for PV which is 74% followed by Concentrated Solar Power (CSP) with 35%, solar water heating with 27%, wind power technology with 20% and then biodiesel with 16%. Other renewable technologies have a growth rate which is less than 3%. The present share of renewable energy sources in power generation was only 5% in 2011 as shown in Fig. 1. According to this figure, the largest share in global power generation scenario is from fossil fuels and nuclear which are contributing 77.9%, followed by

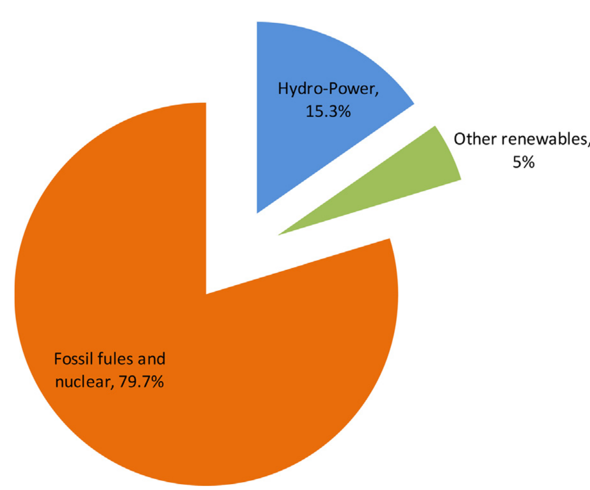

Fig. 1. Global share of resources in electrical power generation. Adapted from [8].