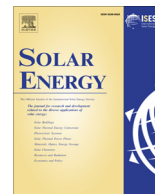




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Review

Atmospheric extinction in solar tower plants – A review

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ABSTRACT

In solar tower plants, radiation losses between the heliostat field and the receiver occur due to atmospheric extinction which varies with site and time. Currently, atmospheric extinction is usually approximated using a few constant standard atmospheric conditions in ray-tracing and plant optimization tools. Some tools allow the input of time dependent extinction data, but such site specific data sets are generally not available for prospective concentrated solar power (CSP) sites. In this paper, the most applied model equations which are implemented in different ray-tracing tools are summarized and compared. Several developed approaches to determine atmospheric extinction are presented. Furthermore, different studies about the effect of atmospheric extinction on the tower plant yield are summarized. It can be concluded that project developers should consider atmospheric extinction and its temporal variation as site specific data sets in power plant optimization, plant yield forecast and plant operation. The effect of atmospheric extinction can account for a reduction of the annual plant yield of up to several percent points and is dependent on the heliostat field size, the operation strategy and the on-site atmospheric conditions. Different approaches to determine atmospheric extinction for solar tower plants at a future CSP site have been developed and validated in the past and can be applied dependent on the prevailing atmospheric conditions. The costs of a power plant can be lowered by reducing the simulation uncertainty since it implies in turn a reduction of risk margins in plant yield forecasts.

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Acronyms

ABC	absorption and broadband correction	MODTRAN	MODerate resolution atmospheric TRANsmission computer code
AERONET	Aerosol Optical Network	MOR	meteorological optical range
AOD	aerosol optical depth	NREL	National Renewable Energy Laboratory
bp	barometric pressure	OD	optical depth
BLH	boundary layer height	PSA	Plataforma Solar de Almería
CESA1	tower facility at PSA	RH	relative humidity
CSP	concentrated solar power	RMSE	root mean square error
DELSOL3	computer code of SANDIA for calculating the optical performance and optimal system design for solar thermal central receiver plants	SAM	System Advisor Model
DNI	direct normal irradiance	SANDIA	SANDIA National Laboratories
DLR	German Aerospace Center, Deutsches Zentrum für Luft- und Raumfahrt	SoFiA	simulation tool for Central Receiver Systems
ECMWF	European Centre for Medium-Range Weather Forecasts	SolTRACE	ray-tracing Code for Complex Solar Optical Systems by NREL
GREENIUS	software tool developed by DLR	SPRAY	ray-tracing software developed by DLR
HELIOs	Computer Program for Modeling the Optical Behavior of Reflecting Solar Concentrators	STRAL	ray-tracing software developed by DLR
HFLCAL	Heliostat Field Layout CALCulation developed by DLR	SVR	standard visual range
HITRAN	high-resolution transmission molecular absorption database	T_{amb}	ambient temperature
LOWTRAN2	Fortran computer program for atmospheric transmittance from 0.25 to 28.5 μm	T_x	transmittance per traveled distance x
LOWTRAN3	Fortran computer program for atmospheric transmittance from 0.25 to 28.5 μm	T_{1km}	transmittance for a slant range of 1 km
MENA	Middle-East and Northern African	T_{600m}	transmittance for a slant range of 600 m
MIRVAL	Monte Carlo program developed by SANDIA National Laboratories	T_{680m}	transmittance for a slant range of 680 m
		Tonatiuh	open source, Monte-Carlo ray tracer
		UAE	United Arab Emirates
		UTC	Coordinated Universal Time
		WinDELSOL1.0	DELSOL3 in a Windows environment
		β_{ext}	extinction coefficient

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1. Introduction

Solar radiation in solar tower plants is attenuated between the heliostat field and the receiver due to atmospheric extinction. Atmospheric extinction is caused mainly by aerosol particles and water vapor which scatter and absorb solar radiation. This process is variable with site and time. Fig. 1 displays two exemplary situations at the CSP tower facility CESA1 at Plataforma Solar de Almería (PSA): one clear (left) and one rather hazy day (right). It can be

seen that a part of the solar radiation is attenuated by the atmosphere dependent on the prevailing atmospheric condition.

To estimate the yield of a CSP plant, usually assumptions about atmospheric extinction are made and in most ray-tracing tools it is only possible to decide between a constant standard clear or a hazy atmospheric condition. Especially in arid environments, e.g. in the Middle-East and Northern African (MENA) region, which are of special interest for CSP due to the high solar radiation potential, this differentiation might not be sufficiently accurate. Recently,

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