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Relevance of PV with single-axis tracking for energy scenarios

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ABSTRACT

The two main options on the market for utility-scale photovoltaic (PV) installations are fixed-tilted and single-axis tracking systems with a horizontal north-south-orientated axis. However, only a few global energy system studies consider the latter. The objective of this paper is to investigate the impact of single-axis tracking PV on energy scenarios. For this purpose, two scenarios with and without the single-axis tracking option are studied for 100% renewable energy (RE) systems in 2030. To find the optimum energy mix for both scenarios, the total annual cost computed by the LUT Energy System model is minimized. The satellite-based input global data have a temporal resolution of one hour and a spatial resolution of 0.45° × 0.45°. Furthermore, a model to estimate the annual yield of single-axis tracking PV is proposed and validated by using the PVsyst software. The simulation results are found to be within a 4% margin to the respective simulation results of PVsyst. Both scenarios demonstrate that a 100% RE system is possible at a low cost, where PV and wind power are the dominating generation technologies. Nevertheless, the results also show a significant effect of single-axis tracking PV. The global generation share of PV increases from 47% to 59%, and 20% of the total electricity is generated by single-axis tracking PV, while the share of wind energy decreases from 31% to 21%. Additionally, curtailment, power transmission requirements, storage demand, and the total cost decrease. The global average levelized cost of electricity decreases by 6% from 54.8 to 51.4 €/MWh. The findings indicate that energy system modeling should include single-axis tracking.

1. Introduction

Solar photovoltaics (PV) is one of the most relevant RE technologies, and it is expected to be among the main energy sources of the future (Breyer et al., 2017b; Teske et al., 2015). The global annual installation rate of PV systems in the last five years increased from 29 GW/a to 98 GW/a, resulting in about 403 GW of total installed capacity by the end of 2016 (IEA PVPS, 2017, 2018). One of the key driving factors is cost reduction, which, for generation technologies, is commonly characterized by the learning rate. The learning rate specifies the saving in cost for each doubling of the historic cumulative installed capacity. The prices of PV systems have been decreasing at an average learning rate of roughly 21% over the last few decades (IEA PVPS, 2017; Fraunhofer ISE, 2015), whereas the learning rate averages 39% over the last ten years (ITRPV, 2017).

1.1. Background and motivation

Numerous energy system studies have been conducted to project the energy mix for the coming decades regionally or globally. An overview of the major global energy scenarios is presented in Table 1 and Fig. 1. Most of the scenarios estimate that PV is going to represent a substantial percentage of installed capacity in the future global energy mix. On average, the expected installed capacity of PV is about 10 TW_p, and the proportion is estimated at 16% of the global electricity generation (20% of the total primary energy demand) by 2050. However, some studies are rather conservative. For example, the IEA WEO 'New Policy Scenario' estimates a total installed PV capacity of 1.4 TW_p by 2040, which is roughly 60% less than the average prediction. Notably, the proportion of real-world PV installations has stayed well above the IEA scenarios over the last 20 years (Breyer et al., 2017b; Metayer et al., 2015).

Utility-scale PV mounting systems are generally classified to be of fixed-tilt or tracking type. There are numerous concepts for PV tracking systems; yet, Breyer (2012) found that one of the main economic solutions for utility-scale systems is the single-axis tracking array with a horizontal north-south-orientated axis. Moreover, currently, these tracking options have a significant market share (IEA PVPS, 2017). The single-axis tracking typically increases the yield by 25–30% over a fixed-tilted layout (Huld and Suri, 2009; Narvarte and Lorenzo, 2008). However, tracking systems also require higher capital expenditures (capex) and operational expenditures (opex); hence, economic improvements are not guaranteed. For instance, Breyer (2012)

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Nomenclature

Abbreviations and acronyms

AC	alternating current
A-CAES	adiabatic compressed air energy storage
AEP	annual energy production
AOI	angle of incidence
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BNEF	Bloomberg New Energy Finance
capex	capital expenditure
CCGT	combined cycle gas turbine
crf	uniform capital recovery factor
CSP	concentrating solar thermal power
DC	direct current
DNI	direct normal irradiation
DoY	day of the year
EoT	equation of time
ETP	Energy Technology Perspectives
FLH	full load hours
GHG	greenhouse gas
GHI	global horizontal irradiation
HDKR	Hay–Davis–Klucher–Reindl model
HV	high voltage
IAM	incidence angle modifier
ICE	internal combustion engine
IEA	International Energy Agency
IEA PVPS	Photovoltaic Power Systems Programme of the IEA
IIASA	International Institute for Applied Systems Analysis
LCOC	levelized cost of curtailment
LCOE	levelized cost of electricity
LCOS	levelized cost of storage
LCOT	levelized cost of transmission.
LUT	Lappeenranta University of Technology
LV	low voltage
MV	medium voltage
NOCT	nominal operating cell temperature
OCGT	open cycle gas turbine
opex	operational expenditure
PHS	pumped hydro storage
precip	average monthly precipitation value
PtG	power-to-gas
PtH	power-to-heat
PV	photovoltaic
rampCost	cost of ramping technology
RE	renewable energy
reg	all considered regions
Shell	Royal Dutch Shell
SoC	state of charge
STC	standard test conditions
tech	all considered technologies
TES	thermal energy storage
totRamp	annual ramping values of the technology
TPED	total primary energy demand
VLS-PV	very large-scale PV
WACC	weighted average cost of capital
WBGU	German Advisory Council on Global Change
WEC	World Energy Council
WEO	World Energy Outlook
WWF	World Wide Fund for Nature

Physical quantities-Latin symbols

A_i	anisotropy index
A	surface area
d	distance between PV arrays
E_{gen}	annual electricity generation
f	modular factor for horizon brightening correction
f_{sh}	geometric shading factor
G_{sc}	solar constant
h	hour of the day, height of module installation
h_0	height of measurements
I	global horizontal irradiation
I_0	extraterrestrial irradiation
I_b	beam horizontal irradiation
I_d	diffuse horizontal irradiation
I_{dcd}	direct and circumsolar diffuse irradiation
I_{dh}	diffuse sky and horizon irradiation
I_{gr}	ground reflected irradiation
I_T	total incident irradiation
l	length of the PV array
N	technical lifetime
N_d	number of days in a year
N_h	number of hours in a year
N_{SB}	number of shaded blocks of a PV module
N_{TB}	the total number of blocks of a PV module
P	power
R_b	geometric factor
T	temperature
t_s	solar time
t_{st}	local standard time
V	wind speed at the height of the module installation
V_0	wind speed at height of measurements
w	width of the PV array

Greek symbols

α	absorptance
β	tracking angle
γ	surface azimuth angle
γ_s	solar azimuth angle
δ	declination angle
η	efficiency
θ_i	angle of incidence
θ_z	zenith angle
λ	geographic longitude
λ_{st}	reference longitude of the local time zone
ρ_g	ground reflection parameter
τ	transmittance
φ	geographic latitude
ω	hour angle

Subscripts

amb	ambient
el	electric units
fix	fixed
h	hour index
inv	inverter
mod	module
p	peak or nominal capacity
r	subregion index
sh	shaded
soil	soiling
T	total
t	technology index
th	thermal unit
var	variable