

e-COST Virtual Mobility report

Title: Review of the bibliography related to the uncertainties in solar radiation and solar energy modelling due to the parameterization of aerosol optical properties

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Introduction

Downwelling surface solar irradiance (SSI) is of importance for many processes crucial for weather, climate and air quality, such as evaporation, heating the surface and the atmosphere, photochemical reactions controlling the production of ozone and other trace gases and secondary aerosol formation, and photosynthesis. In clear-sky conditions SSI is mainly affected by aerosols, and changes with variability of aerosol load and optical properties. Understanding the effect of aerosols on radiative processes is important, but challenging task because of large variability of aerosol sources and therefore their optical properties.

Solar power plant production depends strongly on the amount of SSI. Thus, development and exploitation of solar power plants require accurate knowledge of the effect of different atmospheric variables, including aerosols, on SSI and the solar power production. The objective of this VM was to review the literature related to uncertainties in simulated surface solar radiation and solar power plant production due to uncertainties in the aerosol optical properties that are used for the simulations, and to identify gaps in the existing bibliography.

In the following sections this report describes main findings of studies related to: 1) validation of clear-sky SSI by comparison with measurements; 2) analysis of sensitivity of SSI to aerosol optical properties; 3) estimates of uncertainties in modelled irradiances due to uncertainties in aerosol optical properties; and 4) analysis of the effect of aerosols on solar power generation. We provide a review of the results presented in different studies for cloudless skies since we are interested in the effect of aerosols.

Validation of clear-sky SSI against measurements

Uncertainties in simulated surface solar irradiances (SSI) are usually evaluated based on comparison with measurements, in terms of mean bias error (MBE) and root mean square error (RMSE). Such comparisons were reported for individual (Neher et al., 2019; Abreu et al., 2012; Xia et al., 2007) or regional and worldwide locations (Garcia et al., 2008; Salamalikis et al., 2021; Roman et al., 2014b, Urraca et al., 2018b). Under cloudless skies the modelled SSI values in these studies are based on aerosol optical properties from measurements (ground-based or satellite) or reanalyses (MERRA-2, CAMS, ERA5, COSMO-REA6).

Garcia et al. (2008) performed validation of clear-sky global solar irradiances (GHI) calculated using AERONET measurements at worldwide locations as input to radiative transfer code, by comparison with collocated measured irradiances. They showed that modelled irradiances were overestimated, with mean difference of $9 \pm 12 \text{ Wm}^{-2}$. Larger differences corresponded to larger AOD values, while differences of $2 \pm 10 \text{ Wm}^{-2}$ were reported for Mauna Loa Observatory, site characterized by very low aerosol load. They also emphasized the important effect of high surface albedo in cases of large aerosol load. In such case the surface albedo could be overestimated by AERONET, resulting in larger surface irradiance; this effect is more pronounced for large aerosol load, due to multiple scattering.

Abreu et al. (2023) compared modelled and measured surface irradiances, GHI and direct normal irradiance (DNI) in Evora. Radiative transfer simulations were performed using three different sources of data of aerosol optical properties and water vapour: AERONET measurements, MERRA-2 and CAMS reanalyses. Validation of AOD, AE and WV from the two reanalyses datasets was performed based on comparison with AERONET. The irradiance calculations were performed using libradtran and two less sophisticated models: SMARTS and REST2. Comparison of modelled irradiances based on AERONET, CAMS and MERRA-2 with measurements showed MBE of 3.0%, 4.8% and -0.3%, respectively, in case of DNI, and 2.9%, 2.8% and 1.6% in case of GHI. Based on the results for Evora, they concluded that either set of parameters could be used with either RT model with similar accuracy for that location.

Salamalikis et al. (2021) analyzed simulated DNI based on CAMS at worldwide locations, for the period of 2003-2017. Validation of AOD, as one of the crucial parameters influencing DNI, by comparison with AERONET, showed RMSE of 0.11 and MBE between -0.3 and 0.71. The simulated DNI based on CAMS was compared with simulations based on input data from AERONET. It showed MBE values between -4.1% and 5.3 %, with the smallest values in northeastern and northwestern America (0.4 %) and western Europe (0.2 %), and the largest values in northern Africa, southern and southeastern Asia.

While the focus of these studies was mainly on global and direct components of irradiance, Xia et al. (2007) also compared diffuse and global photosynthetically active (PAR) irradiances with measurements at a suburban site in Xianghe, northern China, characterized by large AOD (annual average value of 0.82). Their modelled irradiances were obtained using SBDART radiative transfer model, along with aerosol properties from AERONET measurements. The reported values of MBE between model and measurements were 6.2 Wm^{-2} , 7.9 Wm^{-2} , -1.7 Wm^{-2} and -3.0 Wm^{-2} for global, direct, diffuse and global PAR irradiances, respectively. The corresponding RMSE values were 10.8 Wm^{-2} , 10.1 Wm^{-2} , 8.1 Wm^{-2} , and 6.2 Wm^{-2} .

Sensitivity of SSI to aerosol optical properties

Studies which report sensitivity analysis of modelled SSI to input parameters used different approaches. Xia et al. (2007) used collocated measurements of aerosol optical properties and

surface irradiances to analyze dependence of SSI (global, direct and diffuse) on AOD for different solar zenith angles (SZA). In order to diminish the impact of water vapour (WV), they used SBDART radiative transfer calculations, and scaled the measured irradiances that corresponded to changing WV amount to those with predetermined WV. Their results show linear dependence of global and direct irradiances on AOD for $\text{AOD} < 0.5$, and nonlinear dependence for larger AOD values. They proposed parameterization to describe these irradiances as functions of AOD and SZA.

Obregon et al. (2018) analyzed sensitivity of SSI to AOD, single scattering albedo (SSA) and WV and proposed a model based on this analysis to estimate SSI using these parameters. Using libradtran, they modelled SSI for a wide range of realistic values of AOD, SSA and WV. The sensitivity analysis was based on relative differences between these SSI values and those corresponding to conditions with minimal values of the three considered parameters (Figure 1). Their results showed the decrease in SSI with increasing AOD and WV and decreasing SSA. The SSI decrease due to AOD increase was less prominent for less absorbing aerosol (larger SSA values), as shown on panels 1.a - d of Figure 1, due to enhanced multiple scattering and thus increase in diffuse irradiance. Similarly, panels 3.a - d of Figure 1 show that in presence of less absorbing aerosols, the decrease in SSI due to increase in WV is less pronounced. Using SSI relative differences, Obregon et al. (2018) proposed two models: a three-parameter (considering AOD, SSA and WV) and a two-parameter model (considering only AOD and WV), to estimate the effect of these parameters on SSI. The models were verified by comparison with measurements at a number of locations, and then they were further used to estimate aerosol and water vapour effects on SSI over the Mediterranean basin and globally (Obregon et al., 2020; Obregon et al., 2021), based on data from CERES (Clouds and the Earth's Radiant Energy System) SYN1deg products.

Using measurements in Marsaxlokk, Malta, Bilbao et al. (2014) analyzed the impact of total ozone column (TOC), WV, AOD (at 550 nm) and Ångström exponent (AE) on SW (global, direct and diffuse) and erythemal (UVER) irradiances, at different SZA intervals. Their analysis showed the decrease of UVER irradiance with increasing TOC, on average by $-0.31\% \text{ DU}^{-1}$. Global and direct SW irradiances decreased with increasing WV. The relative variation in case of global irradiance was between $-2.4\% \text{ cm}^{-1}$ and $-4.5\% \text{ cm}^{-1}$, increasing with increase of SZA. UVER, SW global and SW direct irradiances decreased with increasing AOD and this effect was more pronounced for larger SZA. The relative variation was between -28.1% and -52.4% per unit AOD in case of UVER irradiance, and between -13.5% and -41.4% per unit AOD for SW global irradiance. However, it was noted that changes in SW irradiance due to AOD could be affected by WV.

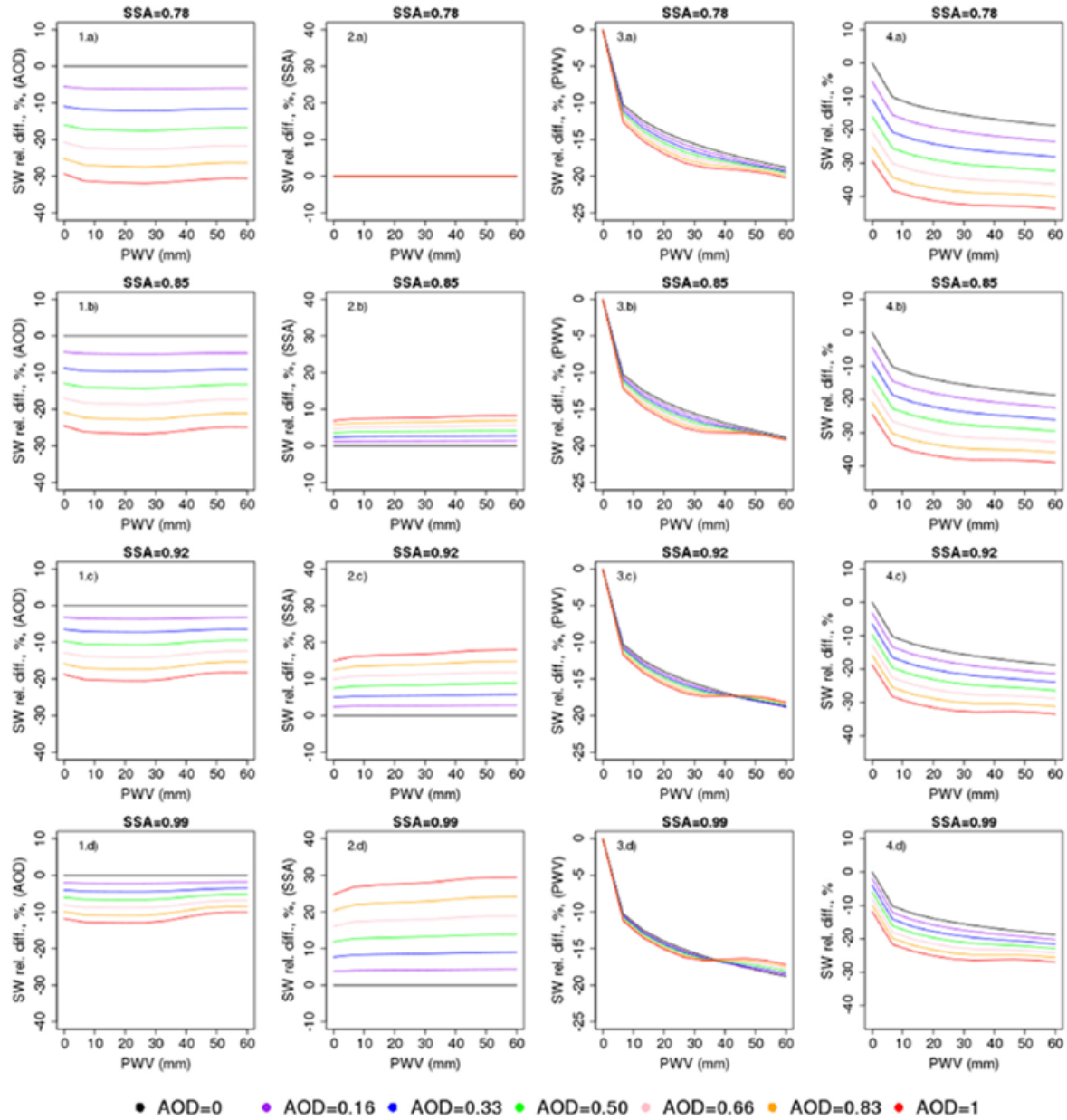


Figure 1. Relative differences of SW global irradiances: due to AOD, as function of precipitable water vapour, PWV (1.a, 1.b, 1.c, 1.d); due to SSA, as function of PWV (2.a, 2.b, 2.c, 2.d); due to PWV, as function of PWV (3.a, 3.b, 3.c, 3.d); due to AOD, SSA and PWV simultaneously, as function of PWV (4.a, 4.b, 4.c, 4.d). The relative differences are shown for different AOD and SSA values. (adopted from Obregon et al., 2018)

Uncertainties in modelled irradiances due to uncertainties in aerosol optical properties

Few studies quantified the SSI uncertainties due to the propagation of uncertainties in the input parameters in radiative transfer calculations (Belluardo et al., 2016; Witthuhn et al., 2021; Roman et al., 2014 a,b). In these studies the authors used different sources of input parameters (ground-based and satellite measurements, reanalysis) and different approaches, as described below.

Belluardo et al. (2016) used Monte Carlo method to estimate uncertainties in modelled surface irradiances in different spectral regions (UV-B, UV-A, VIS, NIR, SWIR, total SW). The aerosol properties and WV amount that were used as input into the RT model were obtained from AERONET (Kanzelhöhe Observatory) and their uncertainties were: Ångström turbidity parameter β (0.025), Ångström exponent AE (0.08), SSA (0.05), asymmetry parameter ASY (0.05) and WV(10%). Other input parameters considered in the analysis were extraterrestrial spectrum, SZA, surface albedo, O₃. The reference case, representative for the measurement site, was characterized by low aerosol load and almost non-absorbing aerosols. The obtained uncertainty in the modelled GHI due to uncertainties in aerosol optical properties was less than 1% and decreased from UV-B to SWIR. The largest contribution to uncertainty in DiffHI was reported for β (uncertainty of 22.2% in total spectrum). Since uncertainties in modelled SSI due to uncertainties in input parameters depend on the parameters' reference values, they performed additional analysis for a wider range of realistic input parameter values. The obtained GHI combined uncertainty was 2.9 – 5.9 %, with a large contribution of the uncertainty in the extraterrestrial spectrum. The individual effects of aerosol properties were less than 1 %, with the largest effect of β (0.36 %) and SSA (0.14 %). The maximum combined effects in different spectral regions were also reported and they showed decrease from 49% in UV-B to 3.5% in SWIR.

Witthuhn et al., (2021) used radiative kernel method to estimate uncertainties in modelled surface irradiances (GHI and DNI). Radiative kernels were calculated assuming a 1% increase in the corresponding parameter value. Aerosol properties used as input parameters (AOD, AE, ASY and SSA) were based on CAMS RA, and were validated against measurements at 25 AERONET stations in Germany; the obtained MBE and RMSE were used as estimates of uncertainties in these properties. The reference case corresponded to average values of aerosol properties for year 2015, which they found representative for the period of interest (2003-2019). It is a case of relatively low aerosol load and weakly absorbing particles. The uncertainties in DNI and GHI (Table 1) show significant effect of AOD uncertainties on DNI, and less pronounced effect on GHI.

Table 1. R, RMSE and MBE for comparison between aerosol optical properties from CAMS RA and AERONET measurements and uncertainties in modelled DNI and GHI due to uncertainties in aerosol optical properties (Witthuhn et al., 2021)

	R	RMSE	MBE	Δ DNI (Wm^{-2})		Δ GHI (Wm^{-2})	
AOD(550 nm)	0.66	0.09	-0.00	+29.3	+0.3	+5.6	+0.1
AE (440/870 nm)	0.51	0.36	-0.12	+4.1	-1.4	+0.5	-0.2
SSA (550 nm)	0.13	0.07	-0.03	+3.2	-1.4	+2.5	-1.1
ASY (550 nm)	0.33	0.04	-0.00	+4.8	-1.1	+0.7	-0.0
Total				+30.1	-2.5	+6.2	-1.2

Using input parameters from different satellite measurements, Roman et al. (2014a) performed RT calculations (SW and UVER: global, direct and diffuse components) for nine locations in Spain. Monthly average values of input parameters were used for RT calculations, as follows: AOD (at 443 and 670 nm) and AE from MISR; SSA (at 354 and 500 nm) from OMI; WV column from MODIS. Uncertainties in AOD, AE and WV were determined based on comparison with AERONET measurements, and their values were:

$$\sigma(\text{AOD}_{440}) = 0.074, \sigma(\text{AOD}_{675}) = 0.054$$

$$\sigma(\text{AE}) < 0.5 \text{ for } \text{AOD}_{440} < 0.25$$

$$\sigma(\text{WV}) = 0.38 \text{ cm for } \text{WV} = 0.5 \text{ cm}, \sigma(\text{WV}) = 0.52 \text{ cm for } \text{WV} = 3 \text{ cm}$$

These were combined with standard deviations of the monthly averages, and then used to estimate the uncertainties in irradiances at the surface (Table 2). The uncertainties in SSA were assumed to be the standard deviations of the monthly average values.

While Roman et al. (2014a) considered individual contribution of uncertainties in different parameters to uncertainties in modelled SSI, Roman et al. (2014b) estimated the combined effect of uncertainties in AOD, AE, SSA, O_3 and WV. The estimated uncertainties were 4-10 % (below 40 Wm^{-2}) for global SW and 8-17 % (below 40 Wm^{-2}) for global UVER. They also performed comparison with measurements at different SZA values and obtained the following results:

- a) for $\text{SZA} < 50^\circ$, ΔSW was within $\pm 10\%$, and it rapidly increased for $\text{SZA} > 75^\circ$;
- b) for $\text{SZA} < 50^\circ$, ΔUVER was within $\pm 20\%$, and it increased for $\text{SZA} > 60^\circ$.

The studies described here showed that the uncertainties in AOD have significantly larger effect on diffuse and direct surface irradiances than on global irradiance. The effect of variability of

wavelength dependence of aerosol optical properties was not considered, except in case of AOD. Fixed wavelength dependence of SSA and ASY was used, assuming aerosol model from OPAC database that corresponded to dominant aerosol type at the location of interest. Focusing on mineral dust, Fountoulakis et al. (2024) showed the importance of aerosol refractive index model in estimates of spectral dependence of aerosol optical properties and aerosol direct radiative effects.

Table 2. Uncertainties in SW and UVER irradiances (global, direct and diffuse) due to uncertainties in aerosol optical properties and water vapour amount (Roman et al., 2014a)

Uncertainties in SW irradiance due to AOD	
Δ Global	< 5% for SZA < 75° < 3% for SZA < 60°
Δ Direct	< 40% for SZA < 75°
Δ Diffuse	< 45% for all SZA
Uncertainties in SW irradiance due to WV	
Δ Global	< 4% for SZA < 80°
Δ Direct	< 5% for SZA < 80°
Δ Diffuse	< 3% for all SZA
Uncertainties in UVER due to AOD	
Δ Global	< 6% for all SZA
Δ Direct	< 80% for SZA < 75° < 40% for SZA < 50°
Δ Diffuse	< 15% for all SZA
Uncertainties in UVER and SW irradiances due to SSA	
Δ Global	< 4% for all SZA
Δ Diffuse	< 4% for all SZA

The effect of aerosols on solar power generation

Energy production from photovoltaics (PVs) and Concentrated Solar Power plants (CSPs) depends primarily on the levels of the surface solar radiation. Over many of the most insolated regions of the planet aerosols play a role that is as significant (or even more significant) as the role of clouds (e.g., Kosmopoulos et al., 2018; Fountoulakis et al., 2021), Aerosols also affect energy production through other mechanisms (e.g., dust or sea salt aerosol deposition on the panels). Here, we attempted to review the bibliography relative to the propagation of

uncertainties in to the aerosol optical properties used to model SSI to the modelling of solar energy production.

While the reduction in produced solar power in clear sky conditions is mainly due to the effect of aerosols on GHI or DNI, there are also contributions from other factors. Neher et al. (2019) used SolPaRT model for estimation of solar power production in photovoltaic (PV) and parabolic trough (PT) power plants at six locations in western Africa. They found additional reduction of up to 8 % in PVAC compared to reduction in GHI, which was attributed to temperature, reflection and inverter losses; the difference in reduction between PT power and DNI was larger, between 14 % and 20 %. The effect of factors other than GHI and DNI was considered in other studies. Neher et al (2020) carried out PV power calculations based on irradiances from SARA2.1 dataset and noted that, while PV yield was highly correlated with GHI, it was also impacted by temperature. Urraca et al. (2018a) performed simulations to estimate PV power based on GHI from three different datasets (SARAH, ERA5 and COSMO-REA6), and compared the results with data from 39 weather stations in western and northern Europe. Their results revealed that the GHI datasets which showed the best agreement with measurements did not result in the lowest bias in estimated PV power. Further analysis showed that the additional bias was largely due to transposition model, related to the inaccurate estimate of direct and diffuse irradiances. Li et al. (2017) analyzed the impact of aerosol on PV power generation in China. They used irradiance data from CERES as input to PVLIB model to calculate the irradiance incident on a PV panel, for three cases: fixed tilt angle, one-axis and two-axis tracking. The simulations were performed with $1^\circ \times 1^\circ$ spatial resolution over a region covering China, and 3h temporal resolution; the average values of the irradiance were found for 12-year period (2003-2014). They reported the reduction of irradiance incident on the PV panel of 21% for fixed and 34% for two-axis tracking system in highly polluted area of eastern China. Larger reduction in case of the tracking system was explained by the fact that it received more direct irradiance, which is more affected by aerosols than diffuse irradiance.

The studies that analyzed the uncertainties in estimated solar power production did not explicitly consider the effect of uncertainties in aerosol optical properties. Ho et al. (2011) analyzed uncertainties in annual yield of CSP plant and concluded that 45% of variance was due to uncertainties in DNI, while the remaining contribution was from other parameters. Thevenard and Pelland (2013) carried out statistical simulations to estimate uncertainty in modelled average yield of crystalline-silicon PV system in Toronto. They estimated the total uncertainty of 7.9% for the average yield over the system lifetime; among others, this estimate included factors which are affected by aerosols: uncertainties due to long-term averaged solar radiation (5%) and its yearly variability (3.9%), due to transposition model (3%), and due to soiling (2%). They emphasized that these estimates could vary depending on location and the system, however the proposed methodology could be applied using the appropriate assessment of the uncertainty distributions. However, studies related to the impact of aerosols on solar power plant production typically did not estimate the effect of uncertainties in aerosol properties. Polo and Estalayo

(2015) analyzed the effect of AOD on DNI and CSP power production in case of large variability of aerosol load. They derived DNI using Meteosat images along with AOD values from MACC reanalysis at two locations in north Africa and Middle East, and used them in simulations of the power generation for CSP parabolic trough and CSP tower plants. For a location in north Africa, they reported overestimation of DNI by 1 - 6 % compared to measurements, and overestimation of annual energy production by 15 - 17 % for CSP trough plant and 20 % for the CSP tower plant, compared to estimates based on measured DNI values. Detailed analysis showed that these overestimations were largely due to significant underestimation of AOD by MACC reanalysis. Neher et al. (2019) performed analysis of sensitivity of SolPaRT power plant model results to variability in aerosol and meteorological input parameters. For that purpose they used AOD and WV data from six AERONET stations in western Africa, assumed surface albedo values based on surface type, dust aerosol model from OPAC for SSA and ASY, and meteorological parameters from AMMA dataset. They carried out SolPaRT calculations for the observed upper and lower values (95th and 5th percentile) of one input parameter, while other parameters had reference values. Their analysis showed the largest model sensitivity to variability in AOD for both PVAC and PTP power plants and some smaller sensitivity of PVAC to aerosol composition and precipitable water vapour.

Herman-Czezuch et al. (2022) noted that the effect of aerosol type on PV power production varied depending on the used PV technology. Assuming two PV technologies with different spectral responses, polycrystalline silicon (p-Si) and amorphous silicon (a-Si) they used spectrally resolved PV power modelling chain. The model results were validated against measurements in Sankt Augustin in Germany and showed that it performed better than the broadband model. They reported RMSE of 3.2 - 4.1 Wm^{-2} and 4.5 - 5.4 Wm^{-2} , with maximum absolute deviation between modelled and measured maximum power point (MPP) of 22.3 Wm^{-2} and 28.1 Wm^{-2} , for spectrally sensitive and broadband models, respectively. Furthermore, they used the same model to analyze PV power reduction for the two PV technologies, assuming horizontal orientation of PV modules, and for three aerosol types with different spectral AOD and SSA (mineral dust, biomass burning and pollution aerosol). For that purpose, they used aerosol data obtained from airborne in-situ measurements during DACCWA field campaign, to model spectrally resolved direct and diffuse irradiances at surface using libradtran. Their results (Table 3) showed that the effect of aerosol on PV power production depends on PV technology used, with polycrystalline PV modules showing larger sensitivity to aerosol type. This was explained by the fact that the spectral responses of the two technologies show peaks at different wavelengths: amorphous technology covers mainly visible region, while the sensitivity of polycrystalline technology is broader and extends to the near-IR region.

Table 3. Average and maximum changes in global, direct and diffuse irradiances and reductions in PV power (for two technologies - polycrystalline and amorphous) for three aerosol types (Herman-Czezuch et al., 2022)

	Mineral dust		Biomass burning		Anthropogenic pollution	
	Average (Wm ⁻²)	Maximum (Wm ⁻²)	Average (Wm ⁻²)	Maximum (Wm ⁻²)	Average (Wm ⁻²)	Maximum (Wm ⁻²)
Global irradiance	-65.2 (-20%)	-106.4 (-50%)	-48.2 (-16%)	-79.5 (-45%)	-23.5 (-9%)	-41.4 (-34%)
Direct irradiance	-224.4 (-57%)	-386.5 (-100%)	-177.7 (-47%)	-304.4 (-96%)	-98.6 (-30%)	-160.3 (-82%)
Diffuse irradiance	+159.2 (+579%)	+305.4 (758%)	+129.4 (+474%)	+246.5 (+612 %)	+75.1 (+282%)	+135.1 (+336 %)
PV power reduction (p-Si)	11.5 (21%)	19.5 (75%)	8.9 (18%)	15.4 (72 %)	4.3 (12%)	8.1 (60%)
PV power reduction (a-Si)	9.9 (19%)	23.0 (69%)	9.3 (18%)	21.7 (68%)	4.6 (11%)	11.8 (55%)

Del Hoyo et al. (2020) used SMARTS2 model to calculate components of SSI in Santiago, Chile, based on aerosol optical properties and WV obtained from AERONET measurements. Using the simulated irradiances, they estimated power productions of PV and concentrated photovoltaic (CPV) modules. The irradiance components and the PV power production estimates were validated against measurements. Comparison between modelled and measured PV power showed MBE of 1.3 % for monocrystalline and 4.5 % for amorphous technology, attributed to model used to calculate the cell temperature, calculation of global irradiance on a tilted surface, and the impact of soiling. They also noted higher spectral mismatch for amorphous, compared to monocrystalline technology. The modelled effect of aerosols on irradiances was reduction of GHI and DNI by 3.5 % and 14.1 %, respectively, and increase of DiffHI by 35.4%. The estimated annual effect of aerosols on PV and CPV power production was the reduction of 7.2 % and 8.7 % for monocrystalline and thin film amorphous silicon PV technologies, respectively, and a reduction of 16.4 % for CPV power production. These effects are larger than the effects on GHI or DNI. The larger annual reduction of CPV power production due to aerosol compared to conventional technologies was explained by larger effect of aerosols on direct irradiance, in comparison with the effect on global irradiance.

Aerosols also contribute significantly to reduction of solar power generation by deposition on the panels, particularly in desert regions and in highly polluted regions (northern areas of China and India), where it reduces the solar power by more than 50% (Li et al., 2020).

As can be perceived from the above discussion, although we were able to find a few studies describing the impact of aerosols on energy production, we were not able to find studies discussing the impact of aerosol uncertainties when they are used for solar energy modelling.

Conclusion

The reviewed studies showed that simulated GHI and DNI based on aerosol optical properties from AERONET measurements were mostly overestimated compared to measurements, particularly in cases of large aerosol load. The irradiances based on aerosol optical properties from reanalyses were either overestimated or underestimated, depending on the reanalysis dataset, the location and aerosol load. Sensitivity studies showed that, in clear-sky conditions, the most important parameter contributing to GHI and DNI was AOD, along with WV, and to a lesser extent SSA. Few studies quantified the uncertainties in modelled SSI due to uncertainties in aerosol optical properties. In case of irradiances modelled based on aerosol properties from AERONET measurements, the uncertainties were found to be below 6% for GHI, and significantly larger in spectral regions towards smaller wavelengths (49% in UV-B). While uncertainties in GHI (total spectrum) are relatively low, uncertainties in the modelled diffuse and direct components are much larger. The uncertainties in modelled irradiances are larger if aerosol properties are obtained from satellite measurements. However, variability of wavelength dependence of aerosol optical properties was not considered in these studies, except in case of AOD, in which AE and its uncertainty were taken into account. This is particularly important when considering uncertainties in estimated irradiances in different spectral ranges. In the described studies fixed wavelength dependence of SSA and ASY was used, for OPAC aerosol model corresponding to assumed dominant aerosol type at the studied location. Furthermore, the effect of diurnal variability of aerosol optical properties was not analyzed in these studies, which is particularly of importance when using measurements from polar orbiting satellites as source of input data for RT calculations or at locations strongly affected by mineral dust or smoke. Further investigation is necessary to specify how uncertainties in the considered spectral shape of SSA, ASY, and AE contribute to the uncertainties in the modelled irradiances.

The impact of aerosols on solar power production is mainly through reduction of SSI and deposition on the solar panels. Aerosols reduce the GHI and DNI and increase DiffHI at the surface. However, the consequent reduction of solar power production is larger compared to reduction of GHI or DNI, due to different additional factors, including technology used, temperature, model used to estimate solar irradiance incident on tilted panel, soiling. While there are studies that analyzed the uncertainties in estimated solar power production, these did not consider the effect of uncertainties in aerosol optical properties.

Linkage to HARMONIA deliverables

This study contributes to the objectives of WG3 (End user engagement towards maximizing aerosol measurement use). Specifically, the study addresses the action deliverables T3.2 “Define the needs of stakeholders, assess the adaptation of photometry aerosol products to increase the usefulness and applicability” and T3.3: "Investigate and report on the role of aerosol uncertainty on user requirements".

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