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A Comparative Study of Soiling on Solar Mirrors in Portugal and Morocco: Preliminary Results for the Dry Season

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Abstract. Soiling is a factor of major importance regarding any solar energy conversion technology, as in Photovoltaic (PV) panels and, namely, in concentrated solar power (CSP), since scattering due to particle deposition severely reduces the mirror's reflectance. Concerned with this problem, a collaboration between the *Renewable Energies Chair*, University of Évora, Portugal and the *Institut de Recherche en Energie Solaire et Energies Nouvelles*, Morocco, was created to investigate and compare soiling in mirrors in both locations. This research enables the comparison between particle deposition effects in the two climates, crucial to implement mitigation measures. Southern Portugal and Northern Africa have considerable potential for future CSP installations, which makes this study relevant from an economical point of view, as it may influence the maintenance procedures and expected energy production of such CSP plants.

INTRODUCTION

Particle deposition, among other environmental factors, has been intensively studied in PV technology [1–5], since within solar energy conversion technologies, it is the cheapest and the easiest to install, thus the one with highest deployment so far. However, projections show that CSP installed capacity will tend to increase in the near future [6] (due to the particular conjunction of energy storage and dispatchability), especially in locations with high beam irradiance values, I_b, like North Africa and Southern Europe. Nevertheless, interesting studies have been made in this topic [7,8]. Unfortunately, in these locations, dust is of concern and can have severe consequences on mirror's reflectance [9–11]. Considering this, and the fact that Morocco has already started building large CSP plants (such as

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Noor complex in Ouarzazate) and the fact that Portugal is also a prominent country for the implementation of such plants, specially its southern region [12], it is essential to investigate soiling effects on mirror's specular reflectance in both countries. The locations where this study is made are: *Plataforma de Ensaio de Coletores Solares* (PECS), Portugal (38° 34′ 0.01″ N; 7° 54′ 0.00″ W): Green Energy Park (GEP), Morocco (32° 12′ 0.00″ N; 7° 94′ 0.00″ W). It should be noted that it is not only Morocco that can suffer from Saharan desert dust events, since long-range dust transport creates problems in Portugal [13].

This study is the beginning of a comprehensive research regarding soiling, namely for flat mirrors in CSP plants, like in Tower and Fresnel ones (since the measurement methodology is based in a flat mirror, as it will be shown further below).

METHODOLOGY

The methodology is based on the use of a TraCS (Tracking Cleanliness Sensor) system, commercialized by CSP Services (Germany). This system includes 2 pyrheliometers and a rotating mirror mounted on a solar tracker (SOLYS2 from Kipp and Zonen), see **Fig 1.** This apparatus works by comparing I_b, measured by the pyrheliometer towards the sun, with the irradiance reflected by the mirror to the second pyrheliometer, I_b^r. It is then possible to calculate the dirtiness index, λ, to obtain an estimation of the soiling effect on the reflectance, as shown in Eq. (1).

$$\lambda = 1 - \frac{\rho}{\rho_0}, \tag{1}$$

with $\rho = \frac{I_b^r}{I_b}$ and the parameter ρ_0 correspond to the weighted reflectance of the clean mirror, which is used to normalize the measurements. Therefore, if $\lambda = 0$, it means that there is no soiling affecting the mirror's reflectance, while $\lambda = 1$ implies a maximum soiling effect. It should be noted that λ is a dimensionless quantity (between 0 and 1). Manual cleaning is performed every two weeks on both sites, to avoid soiling saturation, mostly in Morocco, and bird dropping effects, which otherwise cannot be controlled. It is worth mentioning that the pyrheliometers, on both sites, are cleaned daily, except on weekends.

FIGURE 1. TraCS systems at PECS (left) and at GEP (right).

Moreover, besides the maintenance protocol, the quality control check procedure and algorithm flow to process the data are presented next:

- Remove values higher than 1 and lower than 0 from the TraCS data (which is already the ratio between the reflected and direct normal irradiance).
- Remove values which correspond to direct normal irradiance values lower than 400 W/m^2 and higher than 1380 W/m^2 from the TraCS data.

- Remove minutely values over and under 1 standard deviation from the respective daily mean from the TraCS data.
- Remove days which have less than 60 minutes of data.
- Calculate daily mean for I_b^r and I_b.
- Calculate ρ_0 for each time the mirror is cleaned and use that value for the next weeks, until it is cleaned again.
- Calculate λ.
- There will be days that due to clouds/bird drops events were removed using the filters referred before. For better readability (if it is assumed a linear increase/decrease of the soiling), the data is linearly interpolated.

The results and discussion will be presented in the next section.

RESULTS AND DISCUSSION

The first results, shown in **Fig. 2**, show that the λ values in Morocco are much higher than the ones found in Portugal by a factor of approximately 3; (particularly when desert dust events happen and reach Portugal). This is expected, since GEP is located near the largest desert of the world, the Sahara Desert, which contributes to higher air particle concentration, compared to PECS, and therefore can lead to higher particle deposition and harsh soiling effect on solar energy conversion technologies. In PECS, except for the case of long-range dust transport and rain (discussed below), the soiling effect behavior is similar between cleanings. The cleanings were performed every two weeks, except for the month of June, where it was performed with a delay of 5 days. It should be note that there was a day with high precipitation during May, however it was an event at the afternoon, lasted for an hour and the wind was blowing mainly from the North (data not shown). Since the TraCS system follows the sun apparent motion and at that period the mirror was facing southwest, it did not allow significant cleaning. However, it should be noted that in a CSP plant, the solar field motion might not be the same, resulting in a different outcome.

For Morocco, and moreover due to the dry hot climate [14], as well as, Portugal, during summer, soiling is considered as an important issue [15]. According to the measurements in Morocco, the λ values generally float between 0.2 and 0.25 after two weeks of mirror exposition without cleaning. Besides, if a specific phenomenon happens, like red rain [16], these values can go much higher, like in 24th of April and 3rd of August, where the measured λ are of 0.46 and 0.27, respectively. The red rain phenomenon will be discussed in detail in the next part of the paper.

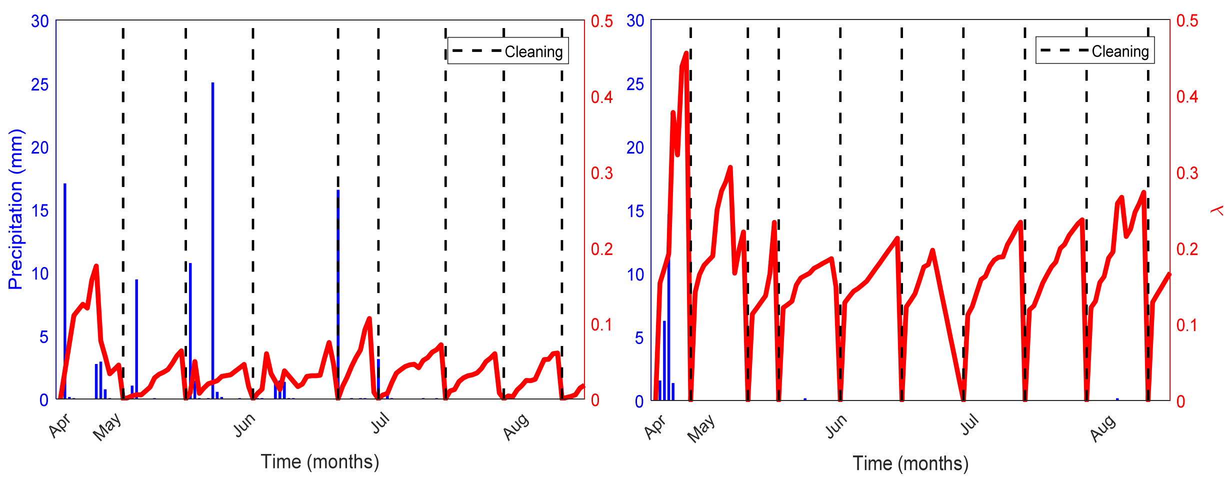

FIGURE 2. Dirtiness index at PECS (left) and Green Energy (right).

The λ value between two weeks, for PECS, usually reaches approximately 0.06. This value was calculated based on the mean values of λ at the end of every two weeks. If this value is divided by the number of days in two weeks, it gives approximately 0.004 per day (assuming a linear increase in reflectance loss), which is denominated as daily dirtiness rate. This value may seem low, but if no cleaning is performed, and if one assumes that particle deposition will keep increasing with this constant rate, this value can achieve 0.12 after a month, which is denominated as extrapolated monthly dirtiness rate. This parameter is extrapolated from the mean λ results after two weeks. Such soiling level will drastically influence CSP performance [17]. For GEP, there is, in a two weeks period, a dirtiness index around 0.2, which per day is approximately 0.013 (more than 3 times the value for PECS). If the same logic is applied as before, after a month if no cleaning is performed, the dirtiness index can reach around 0.4, which is an extremely high value. This value can be even higher, if a dust storm and/or a red rain event happens. The results mentioned before are summarized in **Table 1**.

TABLE 1. Daily and extrapolated monthly dirtiness rates at PECS and GEP.

	PECS	**GEP**
Daily dirtiness rate (%/day)	0.004	0.013
Extrapolated monthly dirtiness rate (%/month)	0.12	0.4

EFFECT OF LONG-RANGE TRANSPORT OF SAHARAN DESERT DUST

Long-range transport of Saharan desert dust have an impact in Portugal, if long-range transport of such events reaches it [13]. On the 21st of April 2018, one of such events started to take place and ended around 24th of April 2018. Barcelona Supercomputing Center (BSC) forecasts depicted its occurrence, see **Fig. 3**. The long-range Saharan desert dust event reached Portugal and caused an important drop on the mirrors optical efficiency. It was the highest drop registered during the campaign for Portugal, approximately 0.18. BSC forecasts are used to access the difference on the effect on both sites, see **Fig. 3**. In PECS it can be seen the effect of such event in **Fig. 4**.

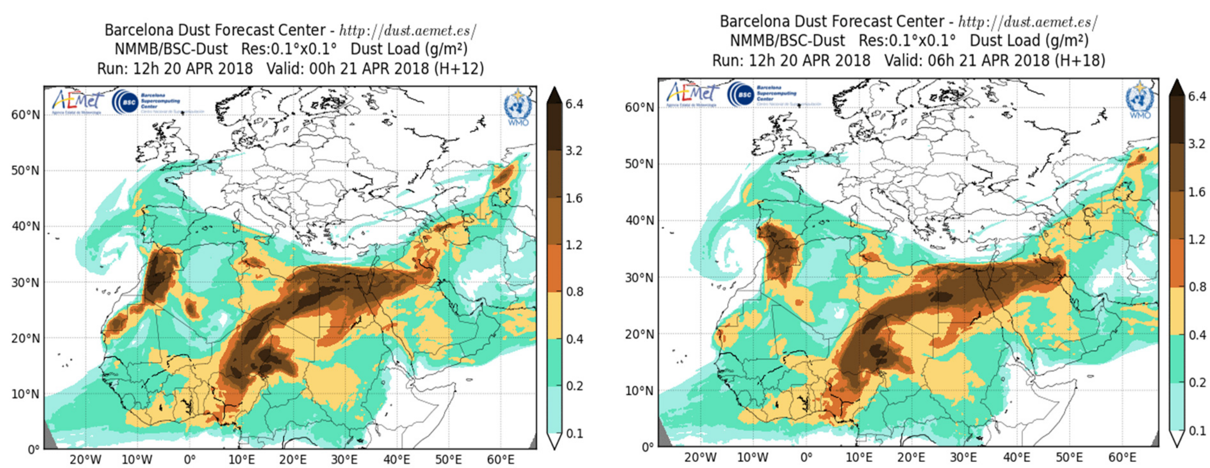

FIGURE 3. BSC forecasts for dust load in April 21 2018 (00:00 h on the left and 06:00 on the right), Data and/or images from the (NMMB/BSC-Dust or BSC-DREAM8b) model, operated by the Barcelona Supercomputing Center (http://www.bsc.es/ess/bsc-dust-daily-forecast/).

Since GEP is closer to the dust source than PECS, it is only natural that the number of particles reaching GEP is higher. For this event, which happened between 21st to 24th April (although the dust deposition may occur over several days after the event due to dust suspension/resuspension), BSC forecasts show a dust load around 6.4 g/m^2, which is a very high value, while for PECS is in the range between 1.6 and 3.2 g/m^2, which at most, is half the dust load forecasted for GEP's location. During the transport, dust will eventually deposit over time, leading to a reduced dust load. GEP registered a reflectance loss around 0.45, while PECS, due to this event, had a loss of approximately 0.18. It is very interesting to note that between both regions, in the desert dust event and in normal conditions, it seem to exist a factor of approximately 3 regarding the soiling effect.

FIGURE 4. TraCS mirror at PECS after long-range transport of Saharan desert dust.

Nevertheless, independently of the location, Saharan desert dust events have a very harsh effect on mirror's reflectance, higher than on PV [13]. Dust forecasts may become very important for cleaning strategies in the future and thus for the electricity market.

RED RAIN EFFECT

One of the major concerns for solar plants operators are the red rain events [18]. Red rain is a phenomenon that happens when a small amount of rain event occurs during a dust loaded atmosphere. This leads to the drop of high dust particles on the mirror surface that agglomerate and stick strongly on it (see **Fig. 5**), which results in a considerable reflectance drop. Indeed, as it can be seen from **Fig. 6**, the reflectance measured on the 24th of April was around 66.2%, which represent a drop of 27.8% from the mirror's initial reflectance and a drop of 19.7% in only one day. It should be noted that this are not normalized λ values, but the absolute ones, regarding the mirror's reflectance in clean conditions.

This phenomenon happens after the coincidence of two events: a high dust load in the atmosphere from the 21st to the 24th of April, causing dust transportation from North Africa to Europe, and a small rainfall of 1.4 mm in the night-early morning of the 23rd and 24th of April.

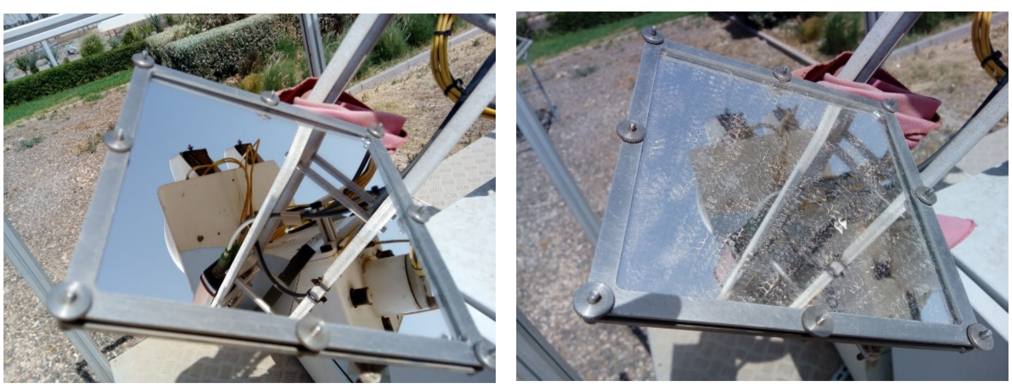

FIGURE 5. TraCS mirror in a clean state (left). TraCS mirror after red rain event at GEP (right).

Reflectance loss is not the only issue related with red rain events, mitigation can be a strong problem for the plants O&M crews. In fact, cleaning the mirrors after red rain events requires a lot of water, and associated labor, to enhance their optical efficiency, which results in higher maintenance costs. This is also concerning since MENA regions are usually associated with water scarcity.

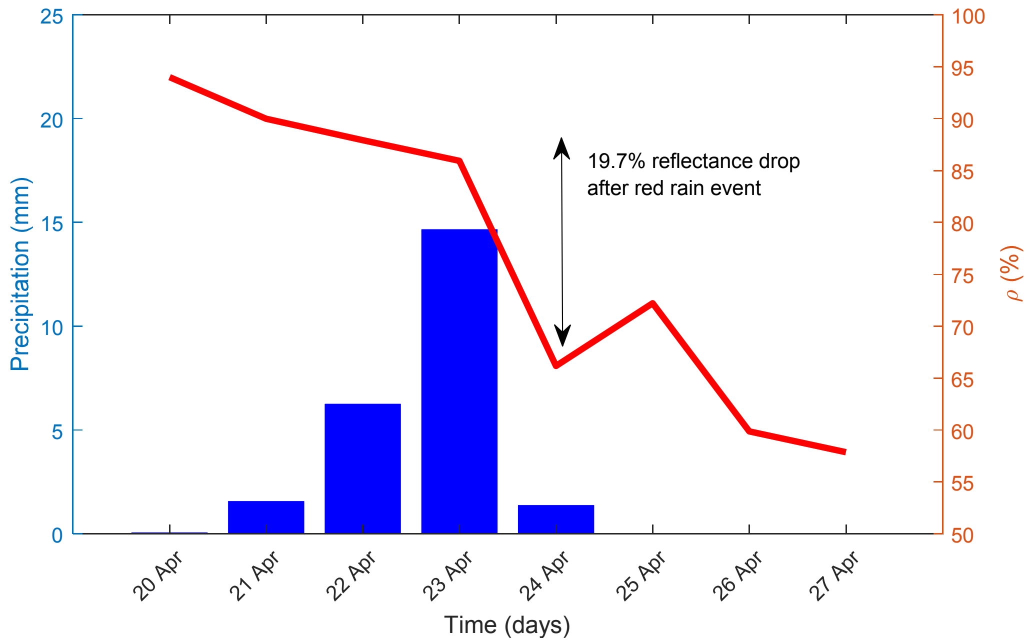

FIGURE 6. Daily reflectance drop of TraCS mirror at GEP due to the Red rain event (Reflectance scale starts at 50%).

CONCLUSIONS

This paper presents preliminary results of the comparison of soiling measurements in Portugal (Southern Europe) and Morocco (Northern Africa). The two countries have good prospects for CSP implementation and thus, soiling needs to start being accounted for. As expected, Morocco is found to have substantially more soiling, with daily dirtiness rates of approximately 0.013 in comparison to Portugal, with just approximately 0.004. Nevertheless, Morocco was affected by a Saharan desert dust storm and some of the dust was also transported to Portugal, attaining dirtiness index of 0.18 and 0.45 for Portugal and Morocco, respectively. Moreover, it was shown how Morocco can be drastically affected by dust followed by a Red rain event, which highlights the need for mitigation techniques and cleaning mechanisms. The use of forecast tools for such events in the management and operation of CSP plants was discussed and perhaps, in the future, they will be useful for mitigation techniques. Moreover, new cleaning mechanisms, spending less water than the ones existing today, need to be developed, since both Portugal and Morocco are countries that may experience or are already experiencing high-water stress levels [19], namely in the areas that have potential for CSP plants implementation.

Future work of this collaboration will be centered in a long term assessment of soiling effect on both locations, including spring effect, when the concentration of pollen and other organic soiling is higher in the atmosphere [20].

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REFERENCES

1. S.C.S. Costa, A.S.A.C. Diniz, L.L. Kazmerski, Dust and soiling issues and impacts relating to solar energy systems: Literature review update for 2012-2015, Renew. Sustain. Energy Rev. 63 (2016) 33–61. doi:10.1016/j.rser.2016.04.059.
2. M.R. Maghami, H. Hizam, C. Gomes, M.A. Radzi, M.I. Rezadad, S. Hajighorbani, Power Loss Due To Soiling on Solar Panel, Renew. Sustain. Energy Rev. 59 (2016) 1307–1316. doi:10.1016/j.rser.2016.01.044.
3. R. Conceição, H.G. Silva, L. Fialho, F.M. Lopes, M. Collares-Pereira, PV system design with the effect of soiling on the optimum tilt angle, Renew. Energy. (2019). doi:10.1016/j.renene.2018.10.080.
4. A. Sayyah, M.N. Horenstein, M.K. Mazumder, Energy yield loss caused by dust deposition on photovoltaic panels, Sol. Energy. 107 (2014) 576–604. doi:10.1016/j.solener.2014.05.030.
5. M. Mani, R. Pillai, Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations, Renew. Sustain. Energy Rev. 14 (2010) 3124–3131. doi:10.1016/j.rser.2010.07.065.
6. EWI, energynautics, Roadmap 2050 – a closer look Cost-efficient RES-E penetration and the role of grid extensions, October. (2011) 144.
7. C. Sansom, H. Almond, P. King, E. Endaya, S. Bouaichaoui, Airborne sand and dust soiling of solar collecting mirrors, AIP Conf. Proc. 1850 (2017). doi:10.1063/1.4984505.
8. A. Sayyah, M.N. Horenstein, M.K. Mazumder, Mitigation of soiling losses in concentrating solar collectors, Conf. Rec. IEEE Photovolt. Spec. Conf. (2013) 480–485. doi:10.1109/PVSC.2013.6744194.
9. S. Bouaddi, A. Ihlal, A. Fernández-García, Comparative analysis of soiling of CSP mirror materials in arid zones, Renew. Energy. 101 (2017) 437–449. doi:10.1016/j.renene.2016.08.067.
10. A.A. Merrouni, F. Wolfertstetter, A. Mezrhab, S. Wilbert, R. Pitz-Paal, Investigation of Soiling Effect on Different Solar Mirror Materials under Moroccan Climate, Energy Procedia. 69 (2015) 1948–1957. doi:10.1016/j.egypro.2015.03.194.
11. R. Conceição, H.G. Silva, M. Collares-Pereira, CSP mirror soiling characterization and modeling, Sol. Energy Mater. Sol. Cells. 185 (2018) 233–239. doi:10.1016/j.solmat.2018.05.035.
12. F. Lopes, H. Silva, R. Salgado, A. Cavaco, P. Canhoto, M. Collares-Pereira, Short-term forecasts of GHI and DNI for solar energy systems operation: assessment of the ECMWF integrated forecasting system in southern Portugal, Sol. Energy. 170 (2018) 14–30. doi:10.1016/j.solener.2018.05.039.
13. R. Conceição, H.G. Silva, J. Mirão, M. Gostein, L. Fialho, L. Narvarte, M. Collares-Pereira, Saharan dust transport to Europe and its impact on photovoltaic performance: A case study of soiling in Portugal, Sol. Energy. 160 (2018) 94–102. doi:10.1016/j.solener.2017.11.059.
14. J. Schilling, K.P. Freier, E. Hertig, J. Scheffran, Climate change, vulnerability and adaptation in North Africa with focus on Morocco, Agric. Ecosyst. Environ. 156 (2012) 12–26. doi:10.1016/j.agee.2012.04.021.
15. W. Anana, F. Chaouki, B. Laarabi, D. Dahlioui, M.A. Sebbar, A. Barhdadi, V. Gilioli, D. Verdilio, Soiling impact on energy generation of high concentration Photovoltaic power plant in Morocco, Proc. 2016 Int. Renew. Sustain. Energy Conf. IRSEC 2016. (2017) 234–238. doi:10.1109/IRSEC.2016.7983994.
16. C. Rodriguez-Navarro, F. Di Lorenzo, K. Elert, Mineralogy and physicochemical features of Saharan dust wet deposited in the Iberian Peninsula during an extreme red rain event, Atmos. Chem. Phys. 18 (2018) 10089–10122. doi:10.5194/acp-18-10089-2018.
17. A. Heimsath, P. Lindner, E. Klimm, T. Schmid, K.O. Moreno, Y. Elon, M. Am-Shallem, P. Nitz, Specular reflectance of soiled glass mirrors - Study on the impact of incidence angles, AIP Conf. Proc. 1734 (2016). doi:10.1063/1.4949219.
18. A. Avila, I. Queralt-mitjans, M. Alarcón, Mineralogical composition of African dust delivered by red rains over northeastern Spain, J. Geophys. Res. 102 (1997).
19. F. Gassert, P. Reig, T. Luo, A. Maddocks, Aqueduct country and river basin rankings: a weighted aggregation of spatially distinct hydrological indicators, 2013.
20. R. Conceição, H.G. Silva, J. Mirão, M. Collares-Pereira, Organic Soiling : The Role of Pollen in PV Module Performance Degradation, Energies. (2018) 1–13. doi:10.3390/en11020294.