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The Impact of Global Warming on Silicon PV Energy Yield in 2100

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Abstract — While the installed photovoltaic (PV) capacity grows to a terawatt scale, effects of global climate change unfold. The question arises, how a changing climate, and especially raising temperatures, will affect the performance of PV installations in the future. In this paper we present an estimate of the reduction in energy yield for silicon PV installations due to global warming in the year 2100. Using IPCC global warming scenarios and published temperature coefficients for today's silicon PV panels, we project median reductions in annual energy output of 15kWh/kW$_P$, with reductions up to 50kWh/kW$_P$ in some areas. Higher efficiency cells and advanced cell and module architectures can significantly reduce these losses.

I. INTRODUCTION

Contemplating the 21st century, two developments seem very likely: 1) the world will get warmer [1], and 2) solar panel deployment will increase [2-4]. Considering these developments in conjunction, the question arises: how will climate change affect solar energy production in the future? It is well known that solar cell performance is affected by local meteorological conditions such as insolation, temperature, water content in the atmosphere [5], and aerosol concentration [6]. The best-established features of current climate change — rising temperature and humidity levels [7] — will result in a performance reduction of all photovoltaic technology, with silicon, the most prevalent photovoltaic technology today [8], being especially sensitive [9].

The impact of global climate change on PV performance has been addressed in a number of studies [10-15]. One challenge that these studies face is the projection of changes in solar insolation over time. An investigation of uncertainties in [10] showed that yield projections that include insolation projections have very large uncertainties. Consequently, there are considerable variations in the projected impact for PV installations for various regions that these studies show. They agree, however, on the overall trend: climate change will likely reduce the power output of solar installations. One parameter that plays a significant role in this reduction is the, arguably, most prominent aspect of climate change: global warming.

In this paper, we present a simple projection of the impact of raising temperatures on the energy yield of silicon PV installations worldwide. The presented results are based on temperature coefficients of PERC type silicon solar cells, and temperature projections according to the RCP4.5 scenario of the Intergovernmental panel on climate change (IPCC).

II. BACKGROUND

The efficiency of a solar cell is a function of temperature for a variety of reasons. The current-voltage characteristics of a solar cell are governed by Boltzmann's statistic, and the explicit dependence on $k_B T$ results in a reduction of the open-circuit voltage with increasing temperature. There are also device dependent aspects, including the temperature dependence of recombination mechanics [16]. In a first order approximation, the temperature dependence of a PV module can be described by a linear temperature coefficient T_C:

$$T_C = \frac{1}{P_M}\frac{d\,P_M}{dT} \qquad (1)$$

Where P_M is the power output of the module at the maximum power point [17]. It should be noted that the actual temperature dependence of a solar cell is not necessarily linear over a wide temperature range, but the approximation is often decent for all practically relevant temperatures. In this study we will use a value of -0.45%/K for T_C, which can be considered a typical value [18].
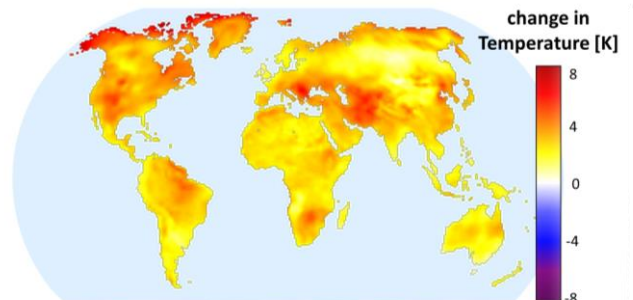

Fig. 1. Projected global temperature change between 2000 and 2100 according to the RCP 4.5 scenario of the IPCC [1]. The average worldwide temperature increase is +1.8K.

Global warming is one of the most well-documented aspects of climate change. Projecting how the temperatures on the planet will evolve is one of the tasks carried out by the IPCC. In this study, we use the Representative Concentration Pathway (RCP) 4.5 scenario to investigate the impact on PV installations. This scenario represents a middle path with greenhouse gas emissions peaking in 2040, and a temperature increase by the end of the century of 1.8K compared to the year 2000. The temperature development around the globe until 2100 is shown in **Figure 1**.

III. Results

The reduction in energy output is calculated simply by multiplying the worldwide solar resource with the projected temperature change and the temperature coefficient. The result of this calculation is shown in **Figure 2**. As temperatures raise nearly everywhere on the land mass of our planet, energy output is reduced everywhere. Areas that are especially affected include the Southern United States, Southern Africa and Central Asia.
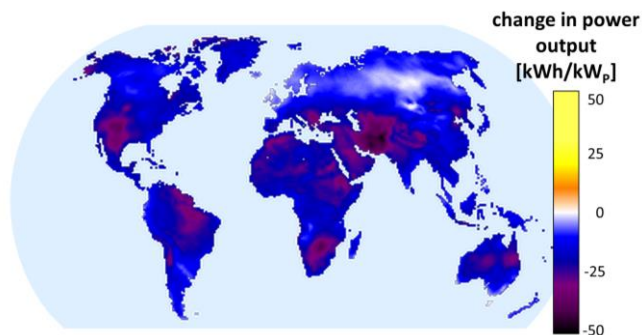

Fig. 2. Projected global change in energy output for a silicon PV installation between 2000 and 2100 for the temperature changes shown in **Figure 1.**

The statistical distribution of the change in energy output over the entire planet is shown in **Figure 3**. The median reduction is approx. 15 kWh/kW$_P$, with some regions reaching up to 50 kWh/kW$_P$.
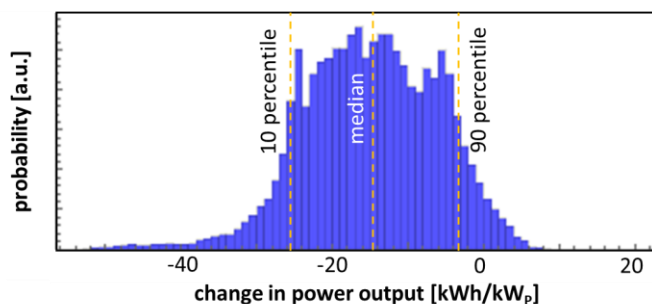

Fig. 3. Histogram of the data shown in **Figure 2**.

IV. Discussion

The shown results just represent one climate scenario, and use one representative temperature coefficient. Within temperature projections, warming scenarios vary over a wide range, depending on the future development of greenhouse gas emissions. The RCP 4.5 scenarios falls within the lower middle of projected temperature changes. Lower and higher levels are covered by the RCP2.6 and RCP8.5 scenarios, respectively. RCP2.6 assumes a peak in greenhouse gas emissions before the end of the decade, and a drastic reduction in emissions

thereafter. The mean likely temperature increase in this scenario is 1.0K. The RCP8.5 scenario assumes raising emissions throughout the rest of the century and project a mean likely temperature increase of 3.7K. Comparing the mean temperature increases in all scenarios gives a good sense of the corresponding projected changes in yield. Hence, in the RCP8.5 scenarios, yield reductions would be more than twice as high as indicated here.

The second factor to affect this calculation is the temperature coefficient of silicon PV modules. -0.45%/K marks a representative value, but coefficients vary depending on technology and cell and module architecture. For silicon PV panels, temperature coefficients between -0.3%/K and 0.6%/K can be found, with the lowest values achieved for HIT type solar cells [19]. Materials with a higher band gap, like CdTe have even lower temperature coefficients [20].

Improvements in cell efficiency have an additional effect on module temperature. As conversion efficiencies increase, more energy is converted into electricity and less into heat [21]. It can be expected, hence, that future solar installations will be more robust towards changes in temperature.

Global warming is not the only relevant aspect of climate change that will affect energy yield. Changes in insolation and humidity will affect the amount of light that reaches a panel. Especially variations in insolation will have an immediate effect that may very well be more noticeable than that of temperature. Insolation variations can largely be considered as an additional factor to the one shown here.

V. Summary

Global warming has an impact on how photovoltaic installations perform. We use a simple performance model to project the likely reductions in performance of silicon PV panels by the end of the century using climate change scenarios from the IPCC and a representative temperature coefficient. Using the RCP 4.5 scenario and a temperature coefficient of -0.45%/K, we find that the energy output of silicon PV installations will be reduced by approx. 15 kWh/kW$_P$, with some regions experiencing losses of up to 50 kWh/kW$_P$.

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