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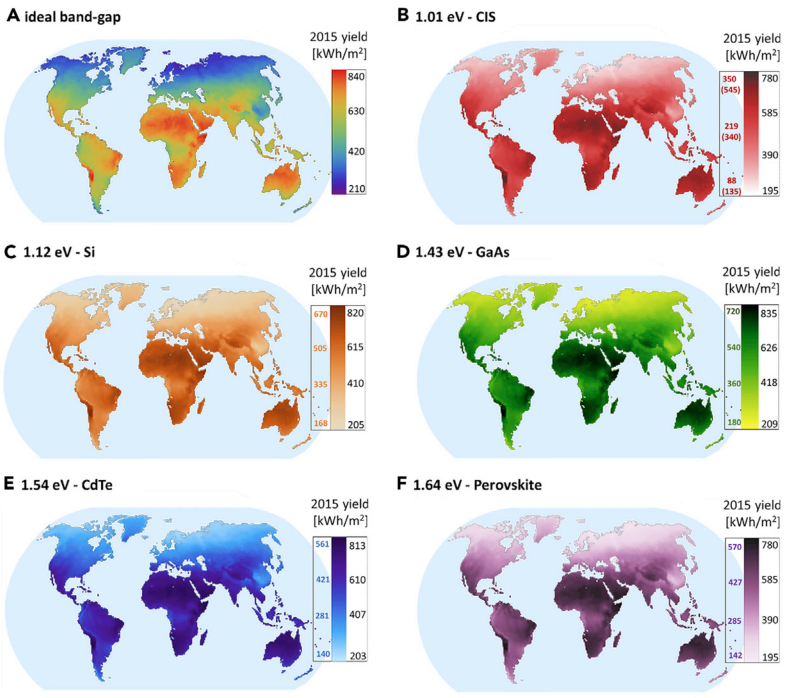
Energy Yield Limits for Single-Junction Solar Cells



In this paper, we present energy yield limits for five solar cell technologies, including Si, CdTe, GaAs, and perovskites. Furthermore, we derive an empirical relation that allows a straightforward approximation of energy yield from lab-measured efficiencies for any solar cell material. The relation also enables a fair comparison between solar cells with different band-gaps. Moreover, we show that harvesting efficiencies correlate with Köppen-Geiger climate zones, allowing translation of solar cell performance between regions with similar climate.

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HIGHLIGHTS

Introducing a simple equation to relate lab-measured efficiencies and energy yield

Showing that harvesting efficiencies correlate with Köppen-Geiger climate zones

Presenting energy yield limits for five solar cell materials

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Energy Yield Limits for Single-Junction Solar Cells

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SUMMARY

"Energy yield" is a key performance metric that describes generated electricity (kWh) in a realistic operating environment, with significance beyond that of the lab-measured power conversion efficiency. Herein, we present fundamental energy yield limits based on 2015 global satellite data for solar cells with various band-gaps, including established technologies such as Si and CdTe and emerging materials such as perovskites. Based on an adapted detailed-balance model with experimental validation, we derive an empirical relation that allows approximating harvesting efficiencies from standard testing condition efficiencies. This equation provides a straightforward way to calculate energy yield for any new technology and enables a fair comparison of lab-measured devices with different band-gaps. We find that the ideal band-gap for maximizing energy yield is 1.35 eV. We show that harvesting efficiencies correlate with Köppen-Geiger climate zones, which indicates that results obtained in a given climate can be translated to other regions with similar climate.

INTRODUCTION

In 1961 Shockley and Queisser published one of the most influential papers in photovoltaics (PV) research, entitled "Detailed Balance Limit of Efficiency of p-n Junction Solar Cells."[1] The power conversion efficiency has, since then, become the accepted figure of merit for solar cells. However, the conversion efficiency is not a perfect metric. Solar cells with the same efficiency measured in the lab can generate a significantly different amount of electricity when operated outdoors. This effect is especially significant if the solar cells are made from different materials.[2] Studies have shown differences as large as 8% depending on environmental/geographical conditions when comparing CdTe and Si solar cells.[3]

Energy yield captures the full picture by measuring energy production in a given location over time (kWh). Energy yield, hence, combines the technological properties of a solar cell with the conditions under which it is operated. Energy yield is also required to establish the levelized cost of electricity or LCOE[4] (ct/kWh), a key metric for economic performance. Moreover, incentive programs have shifted toward prioritizing energy yield as a metric over installed nameplate capacity (W), which only depends on the conversion efficiency measured in the lab under standard testing conditions (STC).[5] Yet despite its significance, energy yield, or the related harvesting efficiency,[6] play far less prominent roles in research than STC efficiencies. Many researchers in PV will be able to quote the current single-junction world record efficiency from the top of their heads, but far fewer will be able to tell with the same ease how much electricity per m^2 this device would be able to provide under ideal conditions.

Context & Scale

"Energy yield" is a key metric for solar cells and describes generated electricity (kWh) in a realistic operating environment. The significance of energy yield goes beyond that of the conventional lab-measured conversion efficiency. A simple translation between those metrics, however, is missing. In this paper we present fundamental energy yield limits calculated from 2015 global satellite data for various solar cells, including established technologies such as Si and CdTe and emerging materials such as perovskites. Based on a detailed-balance model with experimental validation, we derive an empirical relation that allows a straightforward approximation of energy yield from lab-measured efficiencies for any solar cell material. The relation also enables a fair comparison between solar cells with different band-gaps. Furthermore, we show that harvesting efficiencies correlate with Köppen-Geiger climate zones, allowing translation of solar cell performance between regions with similar climate.