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# The value of module efficiency in lowering the levelized cost of energy of photovoltaic systems

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ABSTRACT

One standard that is used to compare different energy generation technologies or systems is the levelized cost of energy (LCOE). The relatively high LCOE of photovoltaics (PV) is an obstacle to adopting it as a major electricity source for terrestrial applications. In a conventional PV system, the cost of the module contributes approximately half of the expense and the other costs are together summarized as balance of system (BOS). A large portion of the BOS is not related to the peak power of the system, but can be either proportional to or independent of the total installation area. Across different PV systems with the same installation area, this part of BOS ($/W) is directly dependent on the module efficiency. Therefore, the LCOE is affected by the module efficiency even if the module price ($/W) remains the same. In this paper, we compare the LCOE across PV systems with equal installation areas but with modules of different efficiencies installed with fixed tilt, 1-axis tracking or 2-axis tracking. We conclude that: (1) at a given module price in $/W, more efficient PV modules lead to lower LCOE systems; (2) when meeting an LCOE goal, the PV module efficiency has a lower limit that cannot be offset by module price; and (3) both 1-axis and 2-axis tracking installations provide lower LCOEs than fixed tilt installations.



**Contents**



## 1. Introduction

The photovoltaic (PV) industry is the fastest growing power industry in the world. In the last decade PV production grew by more than 35% per year [1,2]. Technological improvements, increased economies of scale, and strong policy support have contributed to this experience. Nevertheless, compared with traditional energy sources used to generate electricity, like fossil fuels, without policy support PV energy production is limited in its wider application because of its relative high cost. Cost reduction for PV can be achieved through combination of market, tax and regulatory incentives (e.g., tax credits, rebates, solar energy mandates) and research and development (R&D) support [2]. R&D funding is crucial for increasing energy efficiency of PV modules. As is shown in this paper, increased module efficiency can reduce levelized (i.e., lifetime) energy production costs of PV systems. This work compares the energy cost of PV systems that adopt different module efficiencies and different configurations. It also identifies approaches to achieve lower energy production costs for this technology.

One measure to compare different PV technologies is levelized cost of energy (LCOE), a concept that was introduced at the beginning. The LCOE is calculated using the solar advisor model (SAM) [3].

To compare the LCOE of systems with different module efficiencies and different configurations, we specify a reference system that

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allows the comparison to be implemented under the same baseline conditions. We choose a 1 MW commercial PV installation with fixed tilt angle at Phoenix, AZ and specify all the performance and financing parameters.

Starting from that reference system, we quantitatively analyze the influence of module efficiency on the LCOE of fixed tilt PV systems by evaluating the change in energy production and system expense as a function of module efficiency. The LCOE's dependence on module efficiency is displayed as a group of curves with each curve calculated for a particular module price. This group of curves shows that with PV modules of the same \$/W value, those with higher module efficiencies lead to lower system LCOEs. The same information presented in another format demonstrates that there is a minimum required module efficiency below which the system LCOE cannot achieve a certain goal no matter how low the module cost.

Flat plate PV systems mounted on 1-axis and 2-axis trackers generate two additional sets of curves. These curves when compared with those for the fixed tilt system show that installations with trackers provide a lower LCOE.

Our comparisons across different PV technologies are based on a specific set of reference conditions. Varying these conditions can change the absolute values of the LCOEs, but the tendencies will be maintained: (1) Low LCOE requires high PV module efficiency and (2) tracking lowers the LCOE.

## 2. Levelized cost of energy (LCOE): a measure to characterize PV systems

The levelized cost of energy (LCOE) is "the cost that, if assigned to every unit of energy produced (or saved) by the system over the analysis period, will equal the total life-cycle cost (TLCC) when discounted back to the base year" [4]. The LCOE can be calculated using the following formula:

$$\mathrm{LCOE} = \frac{\mathrm{TLCC}}{\left(\sum_{n=1}^{N} Q_n/(1+d)^n\right)} = \frac{\left(\sum_{n=0}^{N} C_n/(1+d)^n\right)}{\left(\sum_{n=1}^{N} Q_n/(1+d)^n\right)} \quad (1)$$

where $C_n$ is the cost for year $n$, $Q_n$ is the energy output for the year $n$, $d$ is the discount rate, $N$ is the analysis period.

The discount rate appears in Eq. (1) to compensate for the time value in the currency. The LCOE in this work does not consider inflation and is called real LCOE; in contrast, LCOE that incorporates inflation is called nominal LCOE.

Eq. (1) requires two sets of information: (1) system cost items, payment method, financing and incentives; and (2) performance parameters and case study location. The first set determines the value of TLCC and the second set determines the actual energy output. In this work, we do not vary the payment method, financing and incentives, location, or performance parameters (other than module efficiency) so we can focus on the influence of PV module efficiency.

LCOE is calculated by running solar advisor model (SAM), a performance and economic model based on Eq. (1) that is designed to facilitate decision making for people involved in the renewable energy industry [3]. SAM was developed by the National Renewable Energy Laboratory (NREL) in collaboration with Sandia National Laboratories and in partnership with the U.S. Department of Energy (DOE) Solar Energy Technologies Program (SETP).

## 3. Reference system for LCOE analysis: 1 MW commercial system at Phoenix, AZ

The LCOE analysis is first performed on a commercial system that uses silicon flat plate modules with fixed tilt. The cost

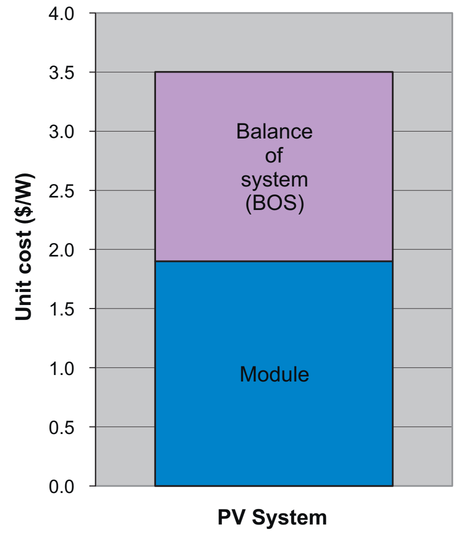


**Fig. 1.** Cost breakdown of the reference system, a representative of current best-practice conventional PV systems of ground-mounted (fixed tilt) type [5].

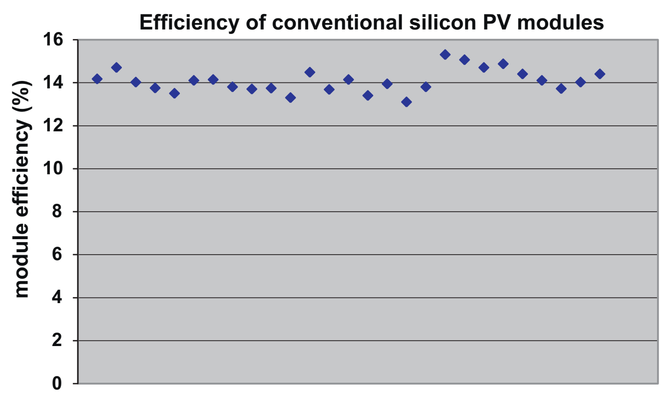


**Fig. 2.** Efficiency of silicon PV modules from 27 models across 11 brands, with module ratings over 200 W [6].

breakdown shown in Fig. 1 is cited from a technical report prepared by Rocky Mountain Institute in 2010 [5]. All the non-module cost items are summarized together as balance of system (BOS).

This reference system has a \$3.5/W total installed cost and a \$1.9/W module cost. The module efficiency is not specified but is described as "conventional PV". Currently, the efficiency of good conventional silicon modules lies in the range of 13–15% (see Fig. 2) so we choose 14% as the module efficiency for the reference system. The other system specifications are shown in Tables 1–3. Using these specifications, SAM calculates a LCOE of 10.71 ¢/kWh. Please note that 10.71 ¢/kWh is the energy cost to the manufacturer or the investor. Comparing with the electricity price on market requires that more tax considerations are incorporated and that the price for sale purpose is higher [4]. For instance, a good estimate of

**Table 1**
Reference commercial system: system location, scale and performance parameters.

| | |
|---|---|
| Location | Phoenix, AZ |
| Capacity | 1 MW |
| Total module area | 7143 $m^2$ |
| Module $\eta$ | 14% |
| Inverter $\eta$ | 96% [7] |
| System derate | 88.5% |
| System degradation | 0.5% [8] |
| Temperature sensitivity of the module performance | −0.5%/°C |
| Tilt angle | Fixed, latitude |