



# Forecast value considering energy pricing in California



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## HIGHLIGHTS

- Solar forecast value is investigated using day-ahead market and real-time market prices.
- Day-ahead and real-time price differentials promote biased bids into the energy market.
- A bias-corrected (improved) day-ahead forecast resulted in lower yearly revenue.
- Adding deviations penalties disincentivizes biased forecasts.

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## ABSTRACT

In this study, production forecast value is investigated using day-ahead market (DAM) and real-time market (RTM) locational marginal prices (LMP) at 63 sites in California. Using the North American Mesoscale (NAM) Model, day-ahead global horizontal irradiance (GHI) forecasts are established and converted to power assuming that a 1 MW solar photovoltaic plant is co-located at each observation site. Using this forecast, energy is hypothetically sold in the DAM. As the RTM occurs, deviations between forecast and observation are settled by hypothetically purchasing or selling energy at the RTM price. Total revenue is calculated by the sum of these two transactions.

Comparison of NAM forecast revenue to perfect day-ahead forecast revenue shows that perfect forecast revenue is always greater. However, yearly NAM forecast revenue is as much as 98% of the perfect forecast revenue for some sites. After a bias-correction is applied to NAM forecasts, NAM forecast revenue decreases. This demonstrates that based on the observed DAM-RTM price spread, biased forecasts can have a higher forecast value than more accurate forecasts. However, when a deviation penalty is assessed, the most accurate forecasts always yield the highest total revenue.

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## 1. Introduction

Forecasting of weather conditions such as global horizontal irradiance (GHI), wind speed, direction, and expected power production is essential for the efficient integration of renewable power into the energy portfolio. For solar, there are two prominent groups that require forecasts: solar power generators and system operators. Solar power generators are entities that own production facilities and profit from the sale of energy. Independent System Operators (ISOs), however, are primarily concerned with grid reliability and require energy forecasts to plan the dispatch of energy, determine spinning reserve requirements, and calculate energy procurement needs. As these two entities have varied interests, there is a mismatch between their individual definitions of the best possible forecast. For instance, it is possible for a power generator

to benefit economically from using biased (rather than accurate) forecasts. This is detrimental to the systems operator's goal of reliability of the power grid [1]. As such, system operators cannot rely solely on market commitment information and generally contract with third party forecasting services to provide independent energy production forecasts.

For the system operator, forecast accuracy is the accepted standard for evaluating forecast effectiveness. Also known as quality [2], accuracy is the deviation between a forecast and a co-located observation. ISOs prefer high-accuracy forecasts as these are most useful for grid reliability purposes. Solar power generators, however, rely on forecast value. Forecast value is the direct monetary benefit of the forecast [2]. As the price of energy is not fixed, forecast quality does not necessarily directly translate to forecast value. For example, a forecast that is of high quality during peak net load times of the day (when energy prices are high and errors are more costly) may be more valuable than a forecast with higher quality only at less critical times. For ISOs, forecast value is a

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secondary consideration and used to minimize energy generation, transmission, and reserve costs on the grid. For example, an under-forecast (predicting too little energy production) would result in over-procurement of energy and possibly result in transmission congestion near the solar power plant. Alternatively, an over-forecast (predicting more energy than is ultimately produced) would result in under-procurement of energy and a purchase of energy from reserves or regulation at additional cost.

In California, the California Independent Service Operator (CAISO) allows solar power producers to participate in the Participating Intermittent Resource Program (PIRP). PIRP requires day- and hour-ahead forecasts in addition to historical observations of energy production and local meteorological data (global horizontal irradiance (GHI), direct normal irradiance (DNI), temperature, and wind) [3]. On the net monthly forecast deviation, ‘uninstructed imbalance energy’ charges are assessed. These monthly settlements can be positive or negative (reimbursement). However, no penalties for individual day- or hour-ahead forecast errors are applied. As such, there is currently no incentive for generators to provide accurate daily forecasts. However, utility-scale solar power plants will eventually participate in the energy market following the same bidding and settlement rules as conventional power sources (as is already the case for Red Electrica in Spain), including wind power (in most energy markets).

Previous studies have investigated the integration of renewable energy (predominately wind power) into energy markets. Using Midwest ISO (MISO) pricing data, Botterud et al. (2011) found that optimal day-ahead wind energy bids are primarily driven by price expectations (rather than forecast energy production) when no deviation penalty is applied. However, adding a deviation penalty diminished the difference between the optimal wind energy bid and the most accurate wind energy forecast [4]. In the Spanish energy market, Fabbri et al. (2005) estimated the costs associated with wind energy forecast errors by assuming that forecast deviations are balanced in real-time by reserve energy and found that error prediction costs can be as much as 10% of the total income annually from the energy generation [5]. Bathurst et al. [6], found that forecast revenue is dependent on the difference between the contract (DAM) price and the imbalance (RTM) price for the UK energy market. There, a Markov-probabilistic forecast was used to determine the most profitable energy commitment. Pinson et al. [7] devised an optimum bidding strategy using forecast uncertainty to dramatically increase revenue. Additionally, Mills and Wiser [8] found that in a 30% solar photovoltaic (PV) penetration scenario day-ahead forecast error and ancillary services costs were \$3.0/MWh and decreased capacity and energy value of PV by 11% (23% for CSP).

From the ISO perspective, the integration of solar energy results in additional cost due to increased uncertainty and variability. Porter et al. (2013) quoted a Public Service Company of Colorado (PSCo) study as directed by the Colorado Public Utilities Commission (CPUC) in which integration costs ranged from \$1.25/MWh to \$6.06/MWh [9]. There, each additional 100 MW of installed solar resulted in an increased cost of \$1/MWh. To reduce these costs, energy forecasts are relied upon. Milligan et al. (1995) found that the most accurate forecast provides the lowest cost of operations when integrating wind power. However, improving a forecast to 100% accuracy has declining marginal benefits [10]. Using price data from the New York ISO (NYISO), Ruiz et al. (2009) showed that a stochastic-based forecast system reduced the cost of operations by up to 2% over a deterministic-based forecast when optimized to the constraints of the power system [11]. In California, assuming 7.5 GW of wind generation, a GE Energy study found that using existing wind forecasting technology saved \$68 million/year in operation costs [12]. Furthermore, the Western Wind and Solar Integration Study (WWSIS, Lew et al., 2010) found that using

state-of-the-art day-ahead wind and solar forecasts in the unit commitment process would reduce Western Electricity Coordinating Council (WECC) operating costs by up to \$5 billion/yr for 25% wind and 5% solar (by energy) penetrations. Using a perfect forecast would result in additional cost savings of \$500 million/yr [13]. A complete review of forecast value studies for renewable energy applications can be found in Chapter 7 of Giebel et al. (2011) [14].

In this study, the value of a solar power forecast in the CAISO system is examined. This is particularly of interest as the CAISO market contained 47% of the nation's installed solar power as of 2010 [15]. Ideally, the value of a forecast would be evaluated from both a power generator's and system operator's perspective. However, modeling forecast value to a system operator is complex and requires knowledge of available resources, start-up and running costs, and the system operator unit commitment rules. These factors vary among system operators and, consequently, such a study would be ISO-specific. Large-scale studies such as WWSIS have already generalized these factors to investigate cost savings due to wind and solar forecasts. Rather, this paper will focus on market participants such as solar power generators (after discontinuation of PIRP). Using CAISO pricing data (Section 2.1), the price difference between the day-ahead market (DAM) and real-time market (RTM) will be examined (Section 3.1). Next, using numerical weather prediction (NWP) solar forecasts (Section 2.2), forecast value (Section 2.3) will be determined for 63 sites in California and geographic data trends explained. Previous studies have not calculated a monetary forecast value in this manner. Furthermore, the effect of a hypothetical deviation penalty on forecast value will be examined (Section 3.2). Finally, solar forecasts will be corrected using a simple model output statistics (MOS) bias-correction function. The value of corrected forecasts will be compared to uncorrected. Overall, it will be shown that when no deviation penalty is included, positively biased forecasts have the highest value to solar power generators. However, when a deviation penalty is included, the most accurate forecast yields the highest value.

## 2. Methods

### 2.1. Energy price data and market structure

Energy price data was obtained from the CAISO Open Access Same-time Information System (OASIS). OASIS has over 4500 nodes at which a Locational Marginal Price (LMP) is reported. These nodes represent locations in the CAISO power grid where energy can be bought or sold into the market. The LMP is the sum of three components: energy, loss, and congestion. The energy component represents the average price of generating a MWh of electricity and by convention is the same at all price nodes. The loss component represents the cost of transmission losses associated with the delivery of electricity to that price node. Lastly, the congestion component monetizes the transmission constraints in delivering electricity to a price node. All LMP components are reported for the day-ahead (DA), hour-ahead (HA), and real-time (RT) markets. DA forecasts must be submitted at 0530 (local time) on the day prior (Day 0 in Table 1) to the operating day. The operating day (Day 1 in Table 1) begins at midnight (0000) and extends 24 h. DA forecasts are provided on an hourly basis for each of the 24 h of the operating day (Table 1). Therefore, the DA forecast horizon is 18.5–42.5 h. Similarly, the HA forecast is submitted 105 min prior to each operating hour. However, in this study, HA prices and forecasts are not used.

DAM LMP (the market price at which a DA forecast is committed) and RT market (RTM) LMP (the price at which settlements are made) from June 1, 2010 to May 31, 2011 were used in this study. Additionally, hour-beginning DAM LMP (e.g. the 0800 DAM LMP

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