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Quantifying economic risk in photovoltaic power projects

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ABSTRACT

Risk analysis is essential for attracting investment to solar projects. This paper measures risk as the variability in internal rate of return (IRR) and estimates it from the uncertainty in (i) future systems prices, (ii) operations costs and (iii) revenues based on energy yield, irradiance and electricity prices. We quantify these risks for photovoltaic (PV) and concentrated photovoltaic (CPV) projects starting in 2016, 18 and 20 for customers selling solar-generated electricity under a fixed feed-in tariff (FIT) and for large business customers displacing electricity loads that they would pay for according to variable market rates. An international comparison of results is provided. Uncertainty in future systems prices causes on average 45% (PV) and 93% (CPV) variation in IRR, which is important to a developer's planning process but is resolvable with negotiated system prices from suppliers. Uncertainty in future operations costs impacts the IRR by on average 17% (PV) and 20% (CPV). Uncertainty in revenues impacts the IRR by at most 3.6%. Furthermore, the analysis shows that overall percentage variability in a project's IRR is much less than the percentage variability in operations costs and revenues, which are the two factors at play once the system is operating.

1. Introduction

In order to conduct an economic analysis of a solar power project it is necessary to estimate a measure of the profitability of the project such as the internal rate of return (IRR). Published work sometimes extends this analysis to estimate the *sensitivity* of the calculations to a *hypothetical* range of values of key inputs. For instance, [1] estimates the sensitivity of IRR to ± 30% variation in system cost, [2] gives the sensitivity of Lifetime Cost of Electricity (LCOE) to ± 10% variation in systems cost and operating cost, [3] calculates the sensitivity of net present value (NPV) to ±25% variation in discount rate, [4] estimates the sensitivity of repayment time to variation in discount rate from 5% to 10%, [5] assesses the sensitivity of IRR to the year in which government incentives are removed, [6] provides the sensitivity of NPV to a range of economic variables and [7] calculates the sensitivity of NPV to ± 30% variation in capital cost and discount rate.

Risk analysis extends such sensitivity analysis to deal with the range of input values *expected in practice*. This is essential in order to convince investors to finance solar projects, which by their nature are capital intensive. However, [8] states that "models for investment in the power sector rarely provide an explicit treatment of risk. Often it is assumed that, given a hurdle discount rate for the cost of capital, NPV positive investments will happen; sometimes the hurdle rates are increased for project risk, but these tend to be ad hoc suggestions." Ref. [9] states "The main stumbling block for solar loans is assessing the risk of the investment." Some sources of risk such as the quality of equipment warranties and the possibility of future changes in tariffs and government regulations are qualitative or subjective. The present paper focuses on those that are directly quantifiable:

(i) uncertainty in future systems prices,
(ii) uncertainty in future operations costs and
(iii) uncertainty in revenues, which are dependent on energy yield, solar irradiance and electricity prices.

While a solar installation is being designed, there are risks associated with unsecured final system prices, particularly for projects planned for the future. Once the system design is finalized, variability in operations costs and revenues impact the associated risk and need to be estimated in advance in order to ensure the

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bankability of the project.

Refs. [10–14] addressed energy yield risk, as opposed to economic risk, based on a statistical analysis of historical irradiance data, which is an important part of assessing uncertainty in revenues, and which the present paper includes as part of its risk analysis. Such an emphasis on energy yield risk is extended to include initial systems costs and operating costs by Ref. [15] based in part on [16], however some of the data in Ref. [16] are assumptions as opposed to empirical estimates.

The methodology used for sensitivity and risk analysis can simply involve running a simulation with various inputs taking specific values of interest, or alternatively it can involve a Monte Carlo analysis taking into account the probability distribution of each input and producing a probability distribution of the profitability measure, typically NPV or IRR. Monte Carlo analysis can be used for investigating the effect of variability in irradiance [11,14], since extensive historical records are generally available from which a probability distribution can be derived. However in the case of systems costs and operations costs, the much smaller amount of data available is generally insufficient for deriving a probability distribution. A probability distribution can be *assumed* [1,15,16], however [6] shows that results are very sensitive to the type of distribution chosen (triangular, rectangular or normal) any of which can be fitted to the available data. The present paper therefore uses Monte Carlo analysis for energy yield and runs the simulation for specific values of interest for system cost and operations cost.

One of the benefits of risk analysis is that, once risk is quantified, the cost of financing can be reduced by securitizing solar loans and engaging rating agencies so as to provide a tradable investment vehicle for institutional investors to consider in relation to their risk/return trade-offs, [17]. Ref. [18] states that “It is critical to increase market participants' understanding of solar risk” and develops a mock securitization process for residential and commercial solar power portfolios. The feedback obtained from rating agencies as to the risk of investing in these portfolios highlights the systems and operations costs and energy yield performance analyzed in the present paper. It also includes a number of other factors for which quantification must be done subjectively on a case by case basis, e.g. the extent of vertical integration in the business model, the equipment quality, the reliability of the equipment warranties and possible future tariff structure changes. Other types of investment risk analyzed by Ref. [19] include the risk of default, future regulatory changes and disruptions in demand, the quantification of which can be dealt with by proxy measures.

A second benefit of risk quantification is that the risk can be transferred through the purchase of solar installation insurance policies, [20]. The quantification of solar risk provided by the present paper together with the work of [18,19] can be used by the insurance industry to provide efficient insurance policies, [21].

In this paper, empirical and estimated values for risk factors (i) through (iii) are used together with a Monte Carlo simulation to quantify the corresponding variability in the Internal Rate of Return (IRR) of both photovoltaic (PV) and concentrated photovoltaic (CPV) projects starting in 2016, 2018, 2020 under a flat rate and a time dependent tariff. Considering projects with future start years introduces greater uncertainty in systems prices than in Ref. [15] and considering a time dependent tariff requires the use of hourly irradiance and electricity price data, whereas flat rate tariffs can be analyzed with annual data.

2. Financial model

Many commercial PV and CPV projects are currently operating in geographical areas with high irradiance and/or high electricity prices [22]. In such areas, the economic rate of return is sufficiently high while economic risk due to the sources of uncertainty described in Section 1 is a relatively minor concern. Our study, therefore, focuses on an area of medium irradiance, Ottawa, Ontario, since risk analysis is more important when expected economic returns are positive but marginal [23]. An international comparison of results is provided including areas of high and medium irradiance.

There may be benefits to delaying the project start date to take advantage of possible future system price reductions and estimates of such reductions are available up to 2020, [31,32,39]. This paper uses these projections of systems prices and tariffs to compare the economics of projects commencing operations in 2016, 2018 and 2020.

The internal rate of return, IRR, is used as a measure of the economic viability of a project as opposed to Levelized Cost of Electricity, LCOE, since the latter involves “levelizing” or averaging the cost of the project over each hour of the day and all times of year. In practice, the dollar value of electric power is dependent upon the time of day and time of year, implying that LCOE is an inappropriate measure [24]. We instead calculate IRR based on the energy yield and the electricity tariff at an hourly granularity over one year. We apply our analysis to the large electricity customers who pay the time-dependent Hourly Ontario Electricity Price (HOEP), as well as demand charges called the Global Adjustment (GA) charge that relates to demand during the Ontario grid's top five peak hours.

We also analyze the IRR resulting from Feed-in Tariff (FIT) projects. Although this tariff is fixed for the duration of the project in Ontario, the contract price paid per kilowatt-hour (kWh) is different depending upon the start date of the project. When different possible start dates are compared, the IRR again becomes a more appropriate measure than LCOE.

Our financial model considers an investment, I in dollars, in a photovoltaic project in year zero, resulting in an expected energy yield, $E_{mh}(t)$ in kWh, during month m and hour h that has a value $V_{mh}(t)$ \$/kWh in year t. We apply this to a FIT project for which $V_{mh}(t)$ is the price at which power is sold to the grid, and also to a load displacement project where $V_{mh}(t)$ is the net electricity bill savings attributable to having reduced the demand in that hour. The revenue or cost saving is therefore:

$$R(t) = \sum_{m,h} E_{mh}(t) V_{mh}(t) \tag{1}$$

Operations costs, $O(t)$, consist of the annual operations and maintenance (O&M) cost, the inverter replacement cost and the end-of-life recycling cost. The IRR is defined as the discount rate at which the Net Present Value (NPV) is zero:

$$NPV = \sum_{t=1}^{25} \frac{R(t) - O(t)}{(1 + IRR)^t} - I = 0 \tag{2}$$

We use IRR in our analysis as opposed to NPV, since the latter involves an assumption about the discount rate. All system and maintenance costs are from sources using United States dollars (USD), and local electricity tariffs in Ontario are converted to USD for consistency.

We quantify the risk of a solar project as the variability in IRR due to the variability expected in three factors (i) – (iii) described in Section 1 which are directly linked to the variables I, O, and R in equation (2).