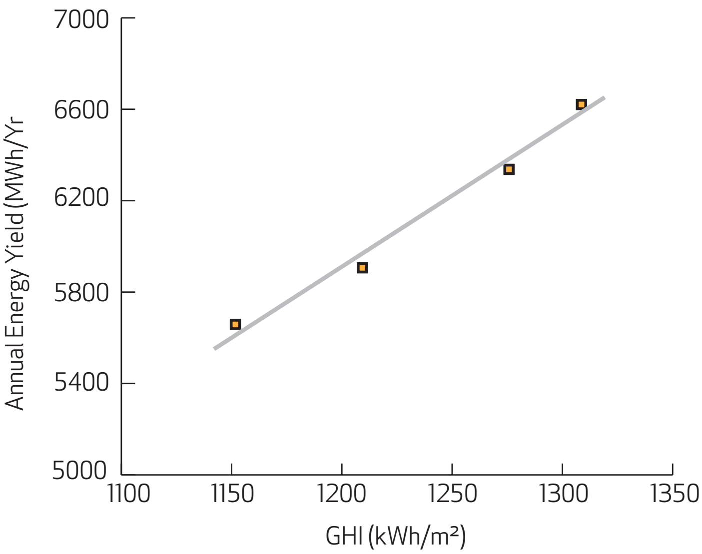
How the variance in incident irradiance can influence the energy yield and financial position of a photovoltaic installation in Singapore

This whitepaper analyses the level of variance seen over a 15 year period in annual irradiance profiles in Singapore and how this variance will affect the performance of a REC photovoltaic installation and the impact on financial returns under different irradiance conditions. The incident irradiance fluctuation in Singapore will be quantified by Global Horizontal Irradiance (kWh/m²) values while the financial return will be measured by levelized cost of energy (LCOE), payback period and internal rate of return (IRR) for a given solar installation over a 25 year period.

Introduction

For most solar plants, the relationship between annual Global Horizontal Irradiance (GHI) levels (kWh/m²) and the output from a solar installation is relatively linear. Figure 1 demonstrates the variation in annual output from an actual 5.7 MW REC PV plant in Richelbach, Germany. Over the 4 year operational periods of the plant, the GHI levels fluctuate by 15% causing close to proportional changes in energy yields.

Figure 1: Annual Energy yield of 5.7 MW PV plant in Richelbach, Germany over 4 years with various GHI levels *Source: REC*



With such a linear relationship existing between plant annual energy yields and the corresponding GHI level for that year, it becomes important to characterize annual GHI variability and include it in both PV system output and financial modelling.

Irradiance Data

The irradiance data used in this study was taken from the Meteorological Service records of the National Environment Agency of Singapore (NEA). These measurements, taken over a 15 year period, are measured at ground level and measure for Global Horizontal Irradiance (GHI) (kWh/m²) which accounts for both direct and diffuse irradiance. These measurements are consistent with less than 2% of missing or abnormal data in 14 of the 15 years. To mitigate for the missed days and account of seasonal variations, the average value of the previous 10 and next 10 days was used with Eq.1 shown below. Within the 20 days considered, missing data was replaced by subsequent days.

Equation 1: Equation used to calculate revised GHI values for each of the available years of NEA data

$$Ir_n = \frac{(Ir_{n-10} + .. + Ir_{n-1}) + (Ir_{n+1} + .. + Ir_{n+10})}{20}$$

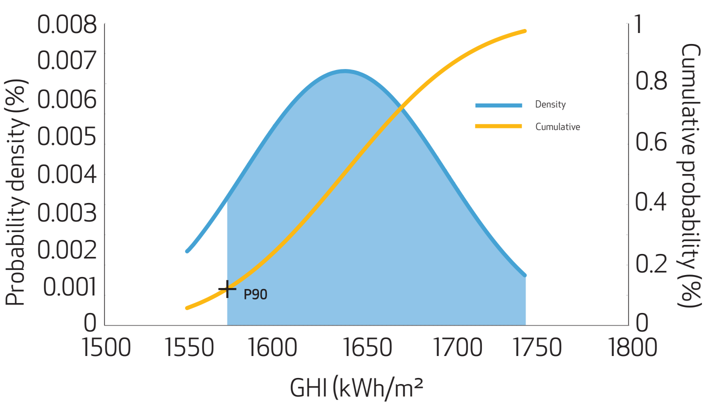
Table 1: Revised GHI values for each of the 15 years of available NEA data along with P1 to P99 levels.

Year	Recorded GHI (kWh/m²)	Lost Days	Revised Annual GHI (kWh/m²)
1	1732.62	9	1774.74
2	1668.88	4	1685.96
3	1613.04	14	1681.08
4	1686.98	8	1724.55
5	1640.72	5	1664.41
6	1547.47	8	1582.54
7	1609.97	9	1648.22
8	1690.21	0	1690.21
9	1648.74	7	1675.80
10	1607.3	0	1607.30
11	1542.08	4	1556.22
12	1742.5	1	1749.86
13	1612.79	0	1612.79
14	1607.7	0	1607.70
15	1585.58	2	1594.00
Average	1635.77	(Average) P50	1660.72
P99	1560.18	P10	1710.81
P90	1587.12	P1	1771.01

Table 1 shows the revised annual GHI values along with P1, P10, P50, P90 and P99 values that have been calculated. In a normal distribution of expected annual GHI values, the P90 level would represent a 90% likelihood that the GHI of any given year would exceed it while the P10 would correspond to a 10% likelihood of being exceeded.

For this dataset a normal distribution has been assumed, a typical practice in the natural sciences concerning random variables with uncharacterized distributions. The normal distribution of a range of

Figure 2: Probability Density and Cumulative Probability plots with the shaded area indicating the 90% probability of any given year exceeding the P90 GHI value.



values is typified by the bell curve, where the mean value is the highest probability result. 68% of values in this range lie within a single standard deviation away from the mean with 95% and 99% lying within two and three standard deviations respectively.

An illustration of the P90 value can be seen on Figure 2. Here the shaded area indicates the 90% cumulative probability of any given year having a GHI value greater than the P90 value. In this plot the probability density curve follows a normal distribution and indicates the specific probability of any given year having a specific GHI value.

Financial analysis was then performed assuming the P1 to P99 GHI levels were consistently attained for the 25 year lifetime of the PV system in order to compare the LCOE and IRR under the sensitivity analysis. In doing so, it was possible to derive a sense of the risk in investing in a photovoltaic installation in Singapore after accounting for GHI fluctuations.

Financial Modelling

To provide a perspective of how the annual flucatuations in GHI can affect the financial returns of an investment in a solar installation, a set of assumptions need to be determined and held constant. An arbitrary solar installation in Singapore,with a total solar array size of 500 kW (2000 REC 250 Peak Energy Series panels), will be used as the basis for this model. Other assumptions used in the model such as installation cost ($SGD) electricity tariff from the grid ($SGD /kWh), performance ratio (%) are shown in Table 2.

Table 2: Installation assumptions applied to financial model

Parameter	Value
Installation Size (Wp)	500,000
Installation Cost ($SGD)	1,000,000
Equity/Debt Financing %	100% Equity
Maintenance Cost ($SGD)	14,000
Maintenance Cost Annual Increment (%)	4.0
Performance Ratio (%)	80.0
Electricity Tariff ($SGD/kWh)	0.20
Electricity Tariff Annual Increment (%)	3.0
Power Import/Export %	100% self-consumption
Equity Discount Rate (%)	6.5
Annual System Output Degradation (%)	0.70

All assumptions are in line with typical solar installation data published as well as internal REC calculations. Using these assumptions it becomes possible to calculate all the initial and running costs as well as the annual returns from the installation based on a given annual GHI. The fixed performance ratio is the key metric here, as it refers to the system yield from the incident irradiance (GHI). A plot of annual discounted cash position over a 25 year period is shown for each of the P10, P90 and actual annual GHI values in Figure 3 along with a results metric in Table 3.

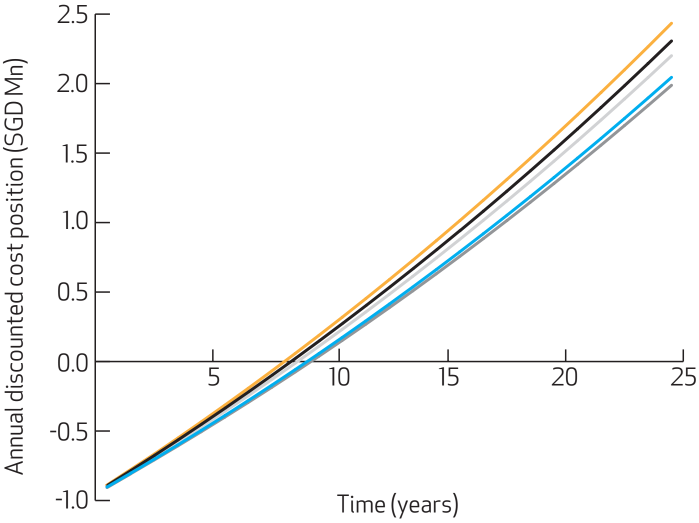


Figure 3 & Table 3: Figure 3 (above) shows the annual discounted cash position profile for each of the five GHI scenarios analyzed. Table 3 (below) shows the metrics typically used to weigh the financial investments and the subsequent performance of a given solar installation at each GHI scenario.

Parameter	P99	P90	P50	P10	P1
Levelized Cost of Energy ($SGD/kWh)	0.178	0.175	0.167	0.162	0.157
Payback Period (years)	9.67	9.51	9.10	8.84	8.54
Internal Rate of Return (IRR) (%)	11.30	11.57	12.30	12.79	13.38

Result

After using each of the five GHI scenarios as the baseline irradiance conditions, it is evident that the financial metrics of an investment in each scenario are not vastly different. In the higher than expected irradiation scenario, (i.e. the P1), the payback period for a typical 500 kW rooftop installation in Singapore would be 8.5 years at an IRR of 13.38% while in a worst case scenario, (i.e. the P99), the corresponding numbers would be 9.67 years and 11.30%. However the more pertinent numbers to analyze are the P10 and P90 scenarios, which demonstrate that it is highly likely that over the lifetime of a system in Singapore, the output of a similar solar installation would return an 8.8 to 9.5 year payback period with an IRR of 11.57 to 12.79%. This difference of only 6 months and 1.22% in IRR is typical of a low risk investment.

REC Solar Pte. Ltd.
20 Tuas South Avenue 14
Singapore 637312
Singapore
Tel: +65 6495 9228

NE-18-15.11.2014