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RESOURCE ANALYSIS OF NP KUNTA SOLAR PARK SITE

A White Paper

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A White Paper

Mohit Joshi and David Palchak, *National Renewable Energy Laboratory (NREL)*

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The U.S. Agency for International Development's (USAID's) Greening the Grid (GTG) is a 5-year program implemented in partnership with India's Ministry of Power (MOP) under USAID's ASIA EDGE (Enhancing Development and Growth through Energy) Initiative. The program aims to support the Government of India's efforts to manage the large-scale integration of renewable energy (RE) into the grid.

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ABSTRACT

India has set a target of 175 GW of renewable energy (RE) capacity by 2022 and 450 GW by 2030. Flexibility is key for efficient integration of renewables. The modern-day RE plants are grid-friendly and can also provide this flexibility. A pilot to demonstrate this flexibility by implementing automatic generation control (AGC) at a solar plant is being conducted by the U.S. Agency for International Development (USAID) under USAID's Greening the Grid (GTG) Program and Renewable Integration & Sustainable Energy (RISE) initiative. This paper presents the resource variability analysis of the 250-MW NP Kunta solar plant site where the AGC pilot project is being implemented. This paper also demonstrates the use of publicly available resource quality data, which can be utilized by various stakeholders to better understand the variability of any existing or potential RE site in India and possibly increase confidence in decisions or help to understand the impacts that can be expected.

List of Acronyms

AGC	automatic generation control
CDF	cumulative distribution function
GTG	Greening the Grid
GW	gigawatt
GWh	gigawatt-hour
IQR	interquartile range
NREL	National Renewable Energy Laboratory
MW	megawatt
NSRDB	National Solar Radiation Database
RE	renewable energy
RISE	Renewable Integration & Sustainable Energy
SAM	System Advisory Model
TMY	typical meteorological year
USAID	United States Agency for International Development
VRE	variable renewable energy

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1 Introduction

The development of renewable energy (RE) resources is on the rise with declining costs, supportive policy, and regulatory ecosystems. Various countries and utilities around the world have set ambitious targets, that provides favorable conditions for development of these resources. RE is often characterized as variable and uncertain. This report focuses on the variability of RE only—as assessing uncertainty would require significant additional analysis. Resource variability directly informs the quality of that resource as measured by capacity factor and power production; and that quality also varies by both location and time. This could be either due to cloud coverage, dust, haze etc. Understanding of variability is not only important for the system operators but also for other stakeholders, such as project financers, developers, planners, utilities, regulators, and policymakers. Project financers and developers are concerned with the technical potential or, in other words, annual capacity factor of any site, as well as the interannular variability of this technical potential. Planners need to assess the variability in various timeframes to plan suitable resources for the future. Utilities need the variability information for portfolio management. Regulators and policymakers need to be aware of the variability to adapt policies and regulations accordingly. System operators assess RE variability for operational planning, including day-ahead scheduling of energy and reserves. In this broader ecosystem of power sector planning and operations, the understanding of variability becomes more important in the present day as variable renewable energy (VRE) also provides these reserves.

India has set a target of 175 GW of RE by 2022 and 450 GW by 2030. The modern-day VRE plants are grid-friendly [1] and can provide flexibility in operations, which is considered key for efficient integration of renewables. A pilot to demonstrate this flexibility by implementing automatic generation control (AGC) at a solar plant is being done by the United States Agency for International Development (USAID) under Greening the Grid (GTG) Program and Renewable Integration & Sustainable Energy (RISE) initiative. AGC systems enable a grid operator to centrally and automatically manage the output of interconnected generators, storage devices, and controllable loads to maintain system frequency and interarea transmission flow schedules [1]. This report presents the resource variability analysis of the 250-MW NP Kunta solar plant site where the AGC pilot project is being implemented. We also compared the resource variability of a 250-MW solar plant at the NP Kunta site with a similarly sized plant at Bhadla solar plant site to demonstrate the value of such analysis and its dependence on location. Note that the comparison is not to rank these sites but to demonstrate the value of understanding the different behavior of different sites.

2 Resource Variability Analysis

The analysis presented in this paper is done based on the publicly available data from RE Data Explorer [2] and the publicly available System Advisory Model (SAM) [3]. SAM is a techno-economic computer model designed to facilitate decision-making through a detailed performance model and a financial model [4] [5]. RE Data Explorer, a web-based geospatial data analysis tool, was developed by NREL in partnership with USAID and several other institutions. This tool can be used to obtain 15 years (2000–2014) solar and 1 year (2014) of wind resource data for South Asia (Bangladesh, Bhutan, India, Nepal, and Sri Lanka). Solar data sets were developed under the National Solar Radiation Database (NSRDB) initiative [6], whereas the wind data set was developed as a part of the GTG India renewable integration study [7]. In RE Data Explorer, users can access information related to technical potential and resource quality for solar at a spatial resolution of 10 x 10 km and wind at a spatial resolution of 3 x 3 km. The temporal resolution of solar data is one hour, and wind data is 5 minutes. This weather data obtained from RE Data Explorer is processed through SAM with default settings, assuming 1.2 DC to AC ratio, standard module, fixed open rack orientation, 96% inverter efficiency, and 14% total system losses to get the time series generation profile for each year.

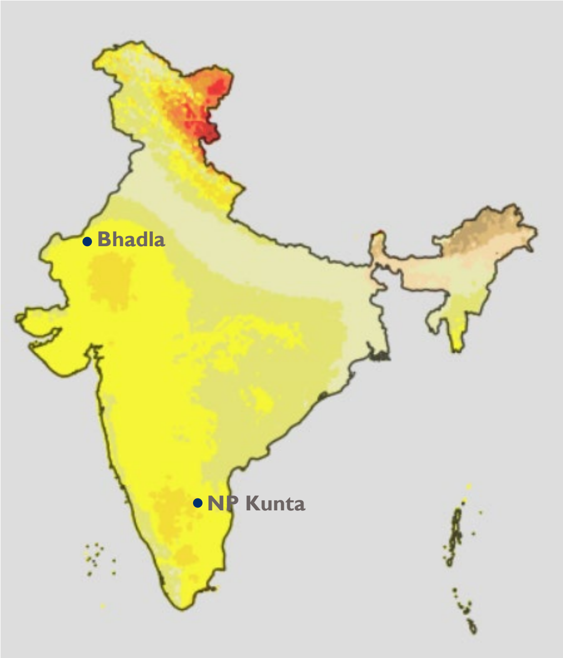

Figure 1. Location of NP Kunta and Bhadla solar park site on P90 value contour map
(Source: RE Data Explorer available at www.re-explorer.org/)

2.1 Annual and Monthly Exceedance Probability Analysis

VRE generation is weather-dependent and will vary from year to year with meteorological conditions. It can be seen from Figure 2 that the output of NP Kunta site (if it had been built) could have varied from 454 GWh to 489 GWh of annual generation between 2005–2014, a difference of 8% between the highest and lowest total annual generation in a given year.

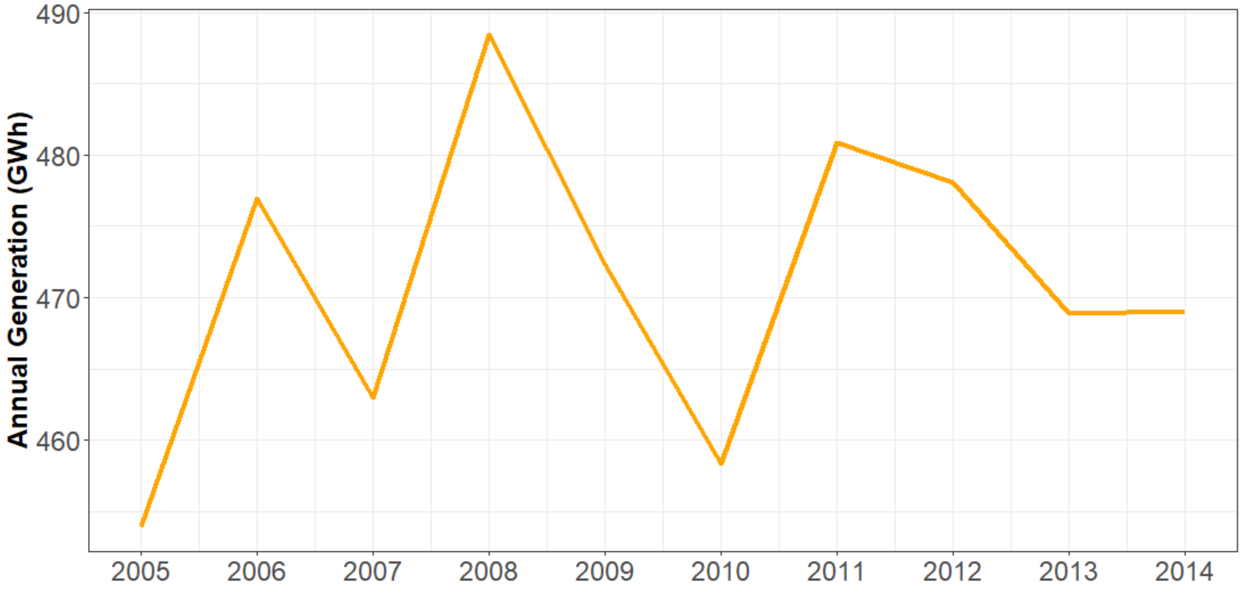

Figure 2. Annual generation based on resource quality at NP Kunta site from 2005–2014

Financial institutions financing a VRE project are often interested in understanding the risk associated with energy generation from these projects. This risk is often represented in terms of exceedance probabilities. Exceedance probability accounts for long-term variability and climate cycles (e.g., monsoons or changes in aerosols), which impacts the energy generation [8]. A 50% probability (P50) estimates the annual generation that will be met or exceeded in 50% of years. The exceedance probability calculation can be done based on either normal distribution's cumulative distribution function (CDF) or empirical CDF. Because the solar data over the years is not normally distributed [9], exceedance probabilities can be calculated based on the empirical CDF. Typical meteorological year (TMY)[1] data is often used to represent the median meteorological conditions based on long-term data but not always close to P50 values, as it is not a simple average of multiple years of data, nor does it represent a median year. This difference between TMY data and P50 value may vary based on the location [8]. Figure 3 shows the annual generation for 10 years of data sorted from highest to lowest (red), with the P10, P50, and P90 values (intersection of blue and red line) along with TMY value (green line) for the NP Kunta site. The exceedance probability means more chances of getting annual generation above that value. The intersection of the TMY line with the annual generation line indicates the exceedance probability corresponding to TMY generation, which is less than 50%.

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[1] The TMY data set is a collection of 12 typical meteorological months without modification to form a single year. See [10] for more details on methodological details of a TMY data set.

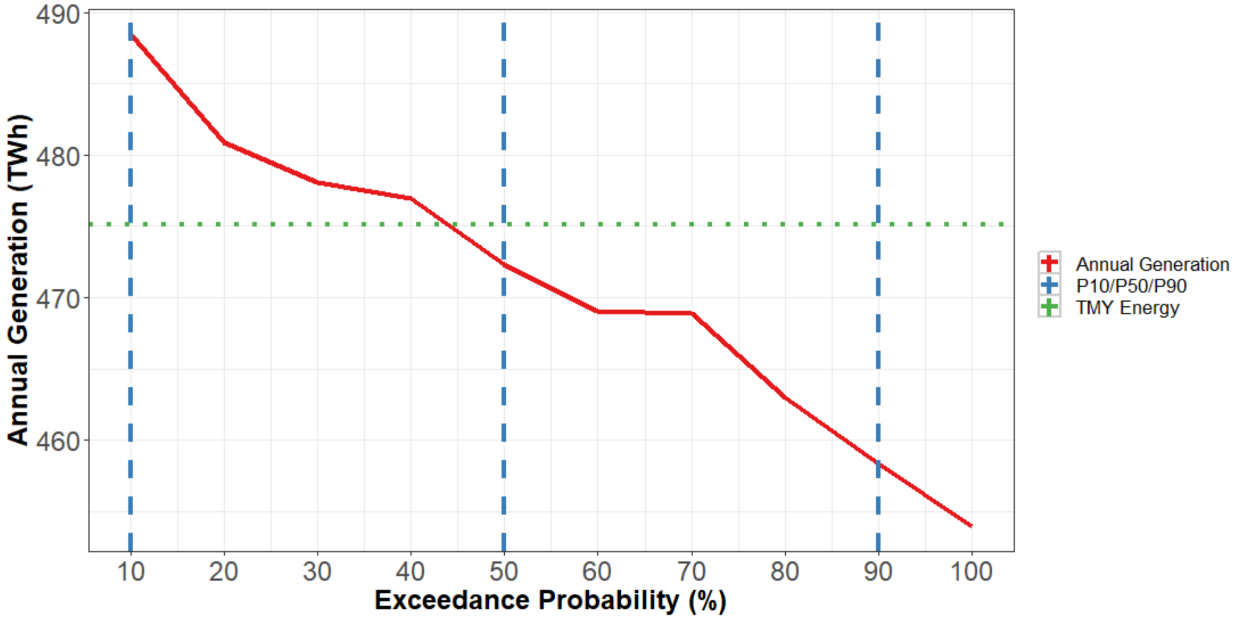

Figure 3. Annual exceedance probability curve for the NP Kunta site

It can be observed from the above figure that the difference between P10 (488.5 GWh) and P90 (458.3 GWh) is only 30.2 GWh, a variation of 6%. For comparison, we also calculated the ratio of P90 and P10 values for NP Kunta and Bhadla solar plant site. A higher value of P90/P10 ratio indicates less interannual energy variability. Bhadla site has 0.98 P90/P10 ratio, whereas the NP Kunta site has 0.94 P90/P10 ratio.

We have also calculated the monthly exceedance probabilities, which would be useful for planners and utilities in energy planning. It can be observed from Figure 4 that the variation in monthly energy is much more in October through December and in February in comparison to other months.

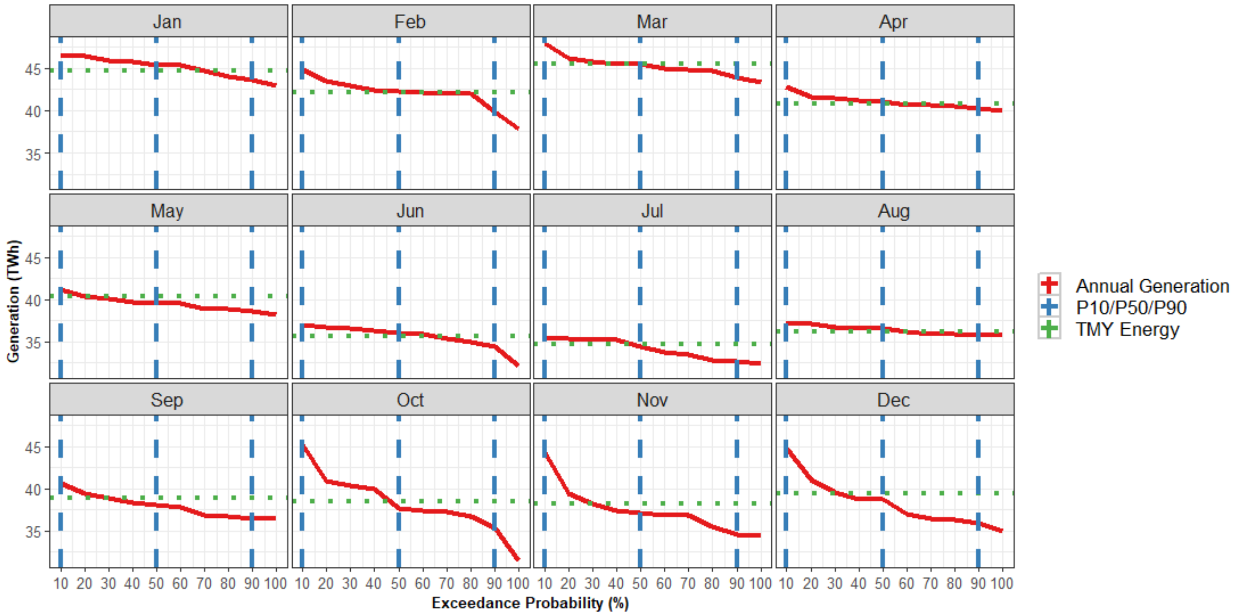

Figure 4. Monthly exceedance probability curve for the NP Kunta site

The seasonal variation of P90/P10 ratio for NP Kunta and Bhadla is shown in table below. The NP Kunta site has more monthly energy variability during October through December, whereas the Bhadla site has more monthly energy variability during July to November in comparison to other months.

Table 1. P90/P10 Ratio of NP Kunta and Bhadla

Month	NP Kunta	Bhadla
January	0.94	0.95
February	0.89	0.94
March	0.92	0.96
April	0.94	0.94
May	0.94	0.96
June	0.93	0.95
July	0.93	0.91
August	0.96	0.91
September	0.90	0.93
October	0.78	0.92
November	0.78	0.92
December	0.80	0.96
Total Year	**0.94**	**0.98**

2.2 Variability Analysis

The maximum possible generation from VRE at any instant varies as it depends on the resource availability, which can change continuously due to metrological conditions. The resource availability at the same time across various years can also change. We analyze both hour to hour as well as interannular variability in the same hour in the following sections.

2.2.1 Hour-to-Hour Variability

Hour-to-hour variability indicates the change in generation between 2 consecutive hours, also referred to as ramp. We analyze hour-to-hour variability across various years through Figure 1, where the width of the box represents the difference between the third quartile (Q3) and the first quartile (Q1) hour-to-hour variability values across these years, and the dots represent the outliers. We find that the range of this variability is very low from January to May for the NP Kunta site, indicating consistent patterns across the years. From June onward, the hour-to-hour changes become more variable, particularly during the monsoon season of July to September.

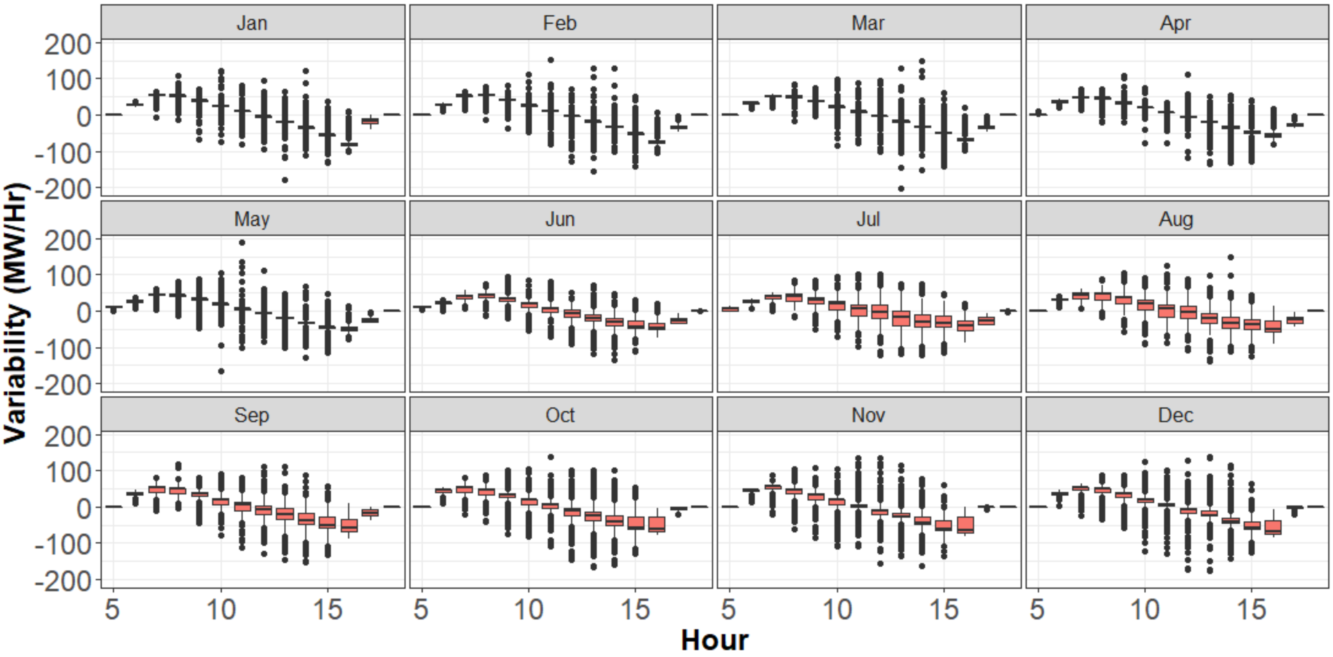

Figure 5. Hour-to-hour variability at NP Kunta

Comparing the NP Kunta site with the Bhadla site, we found that the variation in hour-to-hour variability is also considerably less at the Bhadla site. Figure 6 and Figure 7 show the interquartile range (IQR), which is the difference between the third quartile (Q3) and the first quartile (Q1) of hour to hour variability for NP Kunta and Bhadla sites. The maximum IQR for NP Kunta is around 42 MW during July to December afternoon hours, whereas the maximum IQR for Bhadla is around 18 MW during a few afternoon hours in July through August.

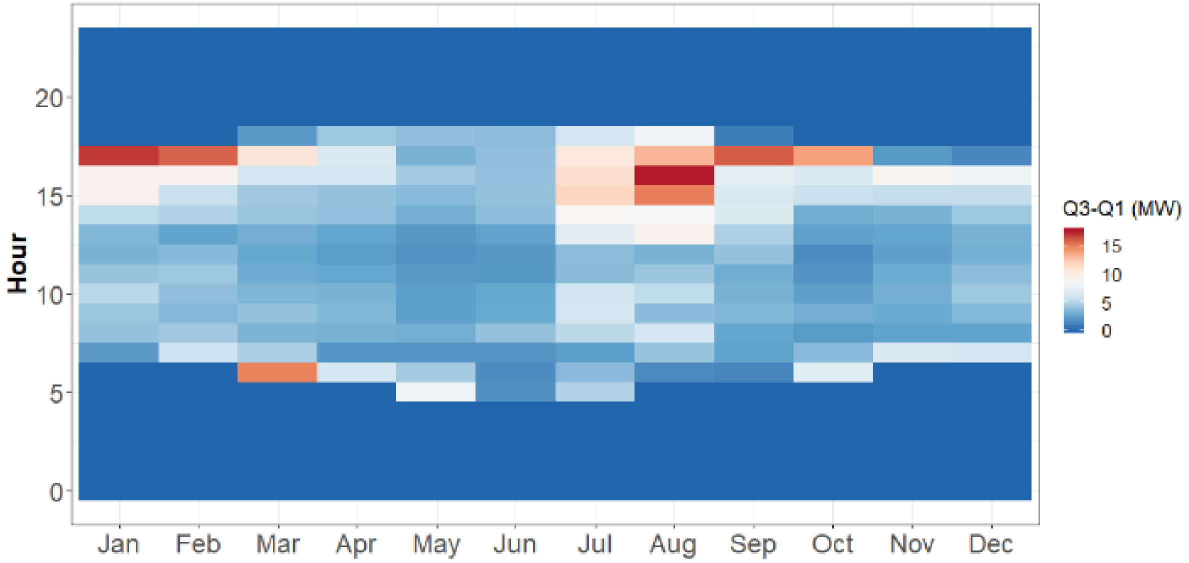

Figure 6. IQR of hour-to-hour variability for Bhadla site

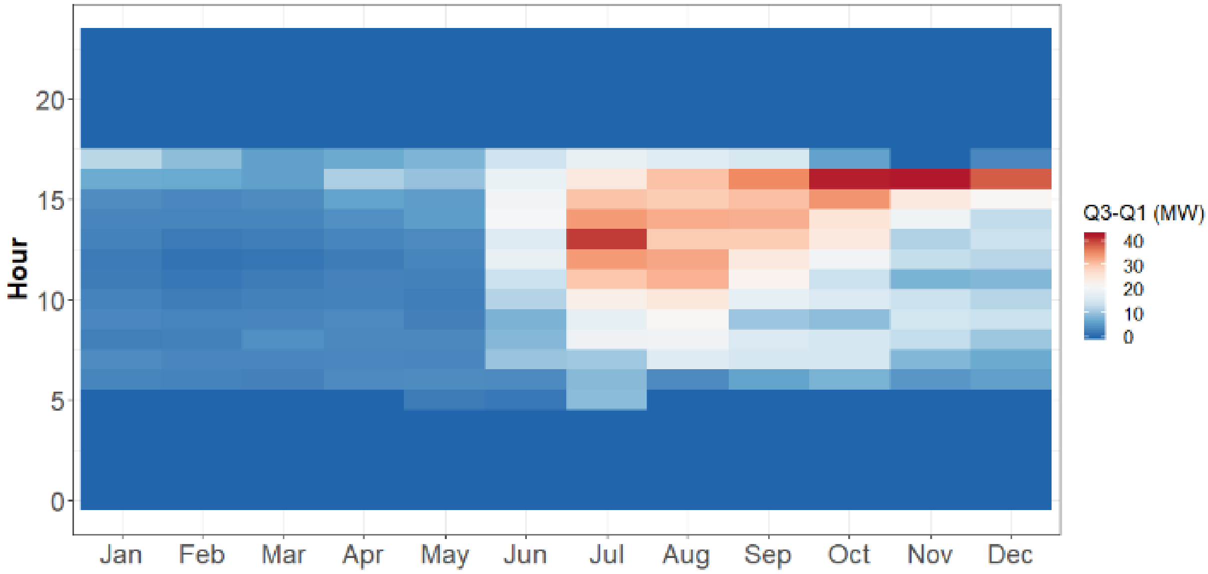

Figure 7. IQR of hour-to-hour variability for NP Kunta site

2.2.2 Interannual Variability in the Same Hour

The absolute variability of the hourly generation can be understood by examining the range of generation variation in each hour across many years. This is represented by interannual variability. For this, we first prepared average monthly generation curves based on 10 years of generation. In Figure 8, these monthly averages overlap the maximum and minimum generation at each hour of all the days in a month, which is represented in the gray envelope in the figure below. TMY average values are also shown for reference.

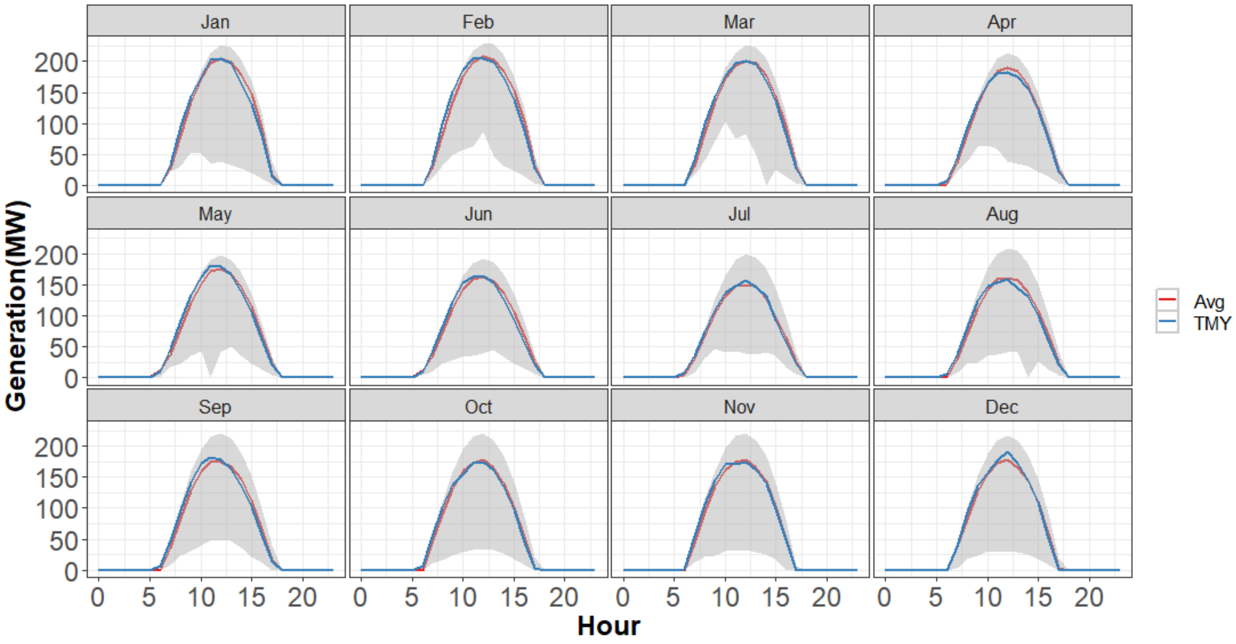

Figure 8. Range of hourly generation variation at NP Kunta site

It can be observed from Figure 8 that average generation is generally very close to the outer maximum value of the gray envelope. This indicates fewer instances of weather changes in different years, leading to average generation in an hour close to maximum value. Further, the difference between the peak value of average generation and the upper edge of the gray envelope is more from July to November, representing slightly more variability during peak generation hours in those months.

Standard deviation, which is a statistical parameter measuring the variation around the mean, was also calculated for each hour of the year. Standard deviation captures the variability in both directions, and it can be observed from Figure 9 that standard deviation is comparatively higher during the afternoon period in October through December.

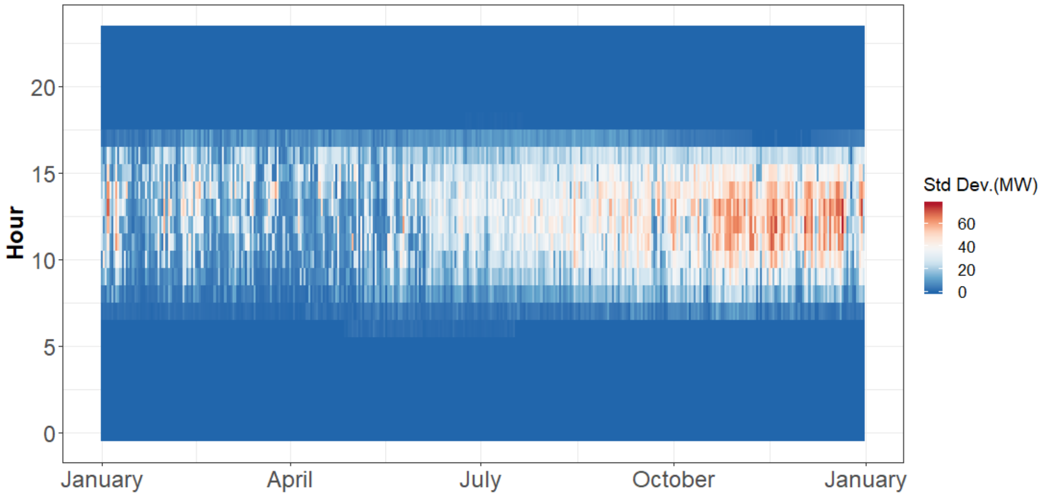

Figure 9. Generation standard deviation at NP Kunta site

We compared the results of NP Kunta with Bhadla solar plant site by calculating the weighted average standard deviation where the mean value was assigned as the weight for each time-period:

$$\sigma_{wt} = \frac{\sum_{i=1}^{N} \sigma \times \mu}{\sum_{i=1}^{N} \mu}$$

Where:

$\sigma_{wt} = weighted\ average\ standard\ deviation\ for\ i_{th}\ time\ period$

$\sigma = standard\ deviation\ for\ i_{th}\ time\ period$

$\mu = mean\ for\ i_{th}\ time\ period$

$N = total\ number\ of\ time\ periods\ in\ each\ month.$

Table 2. Weighted Average Standard Deviation (MW) at NP Kunta and Bhadla

Month	NP Kunta	Bhadla
January	16.55	18.04
February	17.67	23.63
March	14.68	16.09
April	12.62	13.19
May	16.69	8.30
June	22.36	12.55
July	25.49	19.10
August	29.42	26.34
September	30.59	19.40
October	36.24	8.63
November	39.41	9.93
December	36.46	13.36

It can be seen from the Table 2 that the weighted average standard deviation of the Bhadla site is less than NP Kunta site. For Bhadla, weighted average standard deviation is slightly more from January to February and July to September in comparison to other months. On the other hand, NP Kunta has slightly higher weighted average standard deviation from June to December in comparison to other months.

3 Conclusions

The analysis presented in this white paper shows the intertemporal variability of the NP Kunta solar plant site. This paper also demonstrates the use of publicly available resource quality data, which can be utilized by various stakeholders to better understand the variability of any existing or potential RE site in India and possibly increase confidence in decisions or help understand the impacts that can be expected. The two sites analyzed in this show different levels of variability in terms of annual/monthly energy and generation during each time period. The sensitivity towards this variability could be different among different stakeholders which is an area for future work. An analysis with more sites spread across various states would reveal better information regarding the diversity of variability among various sites in India.

References

[1] Chernyakhovskiy, Ilya, Sam Koebrich, Vahan Gevorgian, and Jaquelin Cochran. 2019. *Grid-Friendly Renewable Energy- Solar and Wind Participation in Automatic Generation Control Systems.* NREL/TP-6A20-73866. Golden, CO: NREL. https://www.nrel.gov/docs/fy19osti/73866.pdf.

[2] Tran, J., N. Grue, and S. Cox. 2018. *Renewable Energy Data Explorer User Guide.* NREL/TP-6A20-71532. Golden, CO: NREL/ https://www.nrel.gov/docs/fy18osti/71532.pdf.

[3] "RE Explorer." Accessed on 19th and 21st August 2020.www.re-explorer.org.

[4] Blair, Nate, Nicholas DiOrio, Janine Freeman, Paul Gilman, Steven Janzou, Ty Neises, and Michael Wagner. 2018. *System Advisor Model (SAM) General Description (Version 2017.9.5).* NREL/TP-6A20-70414. Golden, CO: NREL. https://www.nrel.gov/docs/fy18osti/70414.pdf.

[5] NREL. Website of System Advisor Model (SAM) Accessed on 19th and 21st August 2020. https://sam.nrel.gov/.

[6] NREL. "Welcome to the NSRDB." Accessed on 19th and 21st August 2020. https://nsrdb.nrel.gov/.

[7] Palchak, D., J. Cochran, R. Deshmukh, A. Ehlen, S.K. Soonee, S.R. Narasimhan, M. Joshi, B. McBennett, M. Milligan, I. Chernyakhovskiy, P. Sreedharan, and N. Abhyankar. 2017. *Greening the grid: Pathways to Integrate 175 Gigawatts of Renewable Energy into India's Electric Grid, Vol. I—National Study.* National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (Berkeley Lab), Power System Operation Corporation Limited (POSOCO) and U.S. Agency for International Development (USAID). NREL/TP-6A20-68530. https://www.nrel.gov/docs/fy17osti/68530.pdf.

[8] Lopez, Anthony, Galen Maclaurin, Billy Roberts, and Evan Rosenlieb. 2017. *Capturing Inter-Annual Variability of PV Energy Production in South Asia*. NREL/TP-6A20-68955. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy17osti/68955.pdf.

[9] Dobos, A., P. Gilman, and M. Kasberg. 2012. *P50/P90 Analysis for Solar Energy Systems Using the System Advisor Model*. NREL/CP-6A20-54488. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy12osti/54488.pdf.

[10] Wilcox, S., and W. Marion. 2008. *Users Manual for TMY3 Data Sets*. NREL/TP-581-43156. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy08osti/43156.pdf.

[11] Sengupta, Manajit, Aron Habte, Christian Gueymard, Stefan Wilbert, Dave Renné, and Thomas Stoffel. 2017. *Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications: Second Edition*. NREL/TP-5D00-68886. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy18osti/68886.pdf.

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