COLLINSVILLE SOLAR THERMAL PROJECT

YIELD ANALYSIS OF A LINEAR FRESNEL REFLECTOR BASED CSP BY LONG-TERM HISTORIAL DATA

Report 2

ARENA

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The University Of Queensland
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This report is one in a series of seven reports undertaken in relation to the Collinsville Solar Thermal Project. The series of reports included: -

1. Yield forecasting

2. Dispatch forecasting

3. Solar mirror cleaning requirements

4. Optimisation of operational regime

5. Power system assessment

6. Energy economics

7. Fossil fuel boiler integration

Copies of all reports can be found at www.gci.uq.edu.au

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1 Introduction

Energy yield evaluation is essential for secure and competitive financing of a concentrated solar thermal power (CSP) project. Energy yield of a CSP system depends on solar radiation and to a lesser extent, on temperature, humidity, atmospheric pressure and wind speed. Weather events such as passing clouds or storms introduce variability in CSP generation profiles in the short term, whereas large scale weather events such as climate cycles could introduce variability in energy yield for larger or inter-annual time scales. Therefore, energy yield analysis of any proposed CSP project using several years of data is significantly important.

The Collinsville site has only one full year weather dataset, that of 2013. Therefore, this report derives yield results for the proposed CSP system in Collinsville by using the historical datasets of a nearby location of Collinsville (Rockhampton).

2 Literature Review

Australia is the world's ninth largest energy producer; it produces 2.4% of the energy production of the world [Energy in Australia 2012]. At this moment, Australian electricity generation predominantly depends on fossil fuels (i.e., coal and gas). Currently only 12% of Australia's electricity comes from renewable resources. With Mandatory Renewable Energy Target (MRET) it is anticipated that this scenario is likely to change in the near future. A recent study has revealed that CSP could be a significant part of the future energy mix in Australia. It would be technically feasible to integrate 15 GW_e of CSP plants in the Australian electricity network with a modest modification to the transmission system [Australian Solar Institute 2012].

According to the Australian Solar Institute there are a number of sites in Australia where CSP with 1 GW_e size can be deployed [Australian Solar Institute 2012]. Moreover, there are 20 conventional plant locations with sufficient solar resources and required area for CSP deployment. Hybridization of the conventional plant or a new CSP plant in place of aged conventional plant is possible in those locations. With this in consideration, RATCH-Australia in partnership with Transfield Infrastructure Pty Limited has undertaken the preparatory development work of putting a 30 MW_e CSP in the place of an existing out of service 180 MW_e coal fired power plant [RATCH Australia]. The proposed project will use Linear Fresnel Reflector (LFR) technology for super heated steam generation. A sketch of LFR is shown in Fig. 1. The LFR system as shown in Fig. 1 creates a linear focus for a downward facing linear receiver. It has long rows of flat or slightly curved mirrors with a one axis tracking facility. At this moment LFR technology is less popular than the parabolic trough collector (PTC) and power tower (PT). However, LFR offers certain advantages over PTC and PT, including a low cost collector, simplified piping of the receiver that facilitates relatively high temperature operation. Nonetheless, LFR does not use rotating joints at the end of the each collector line, therefore the maintenance cost of this technology is low as compared to PTC.

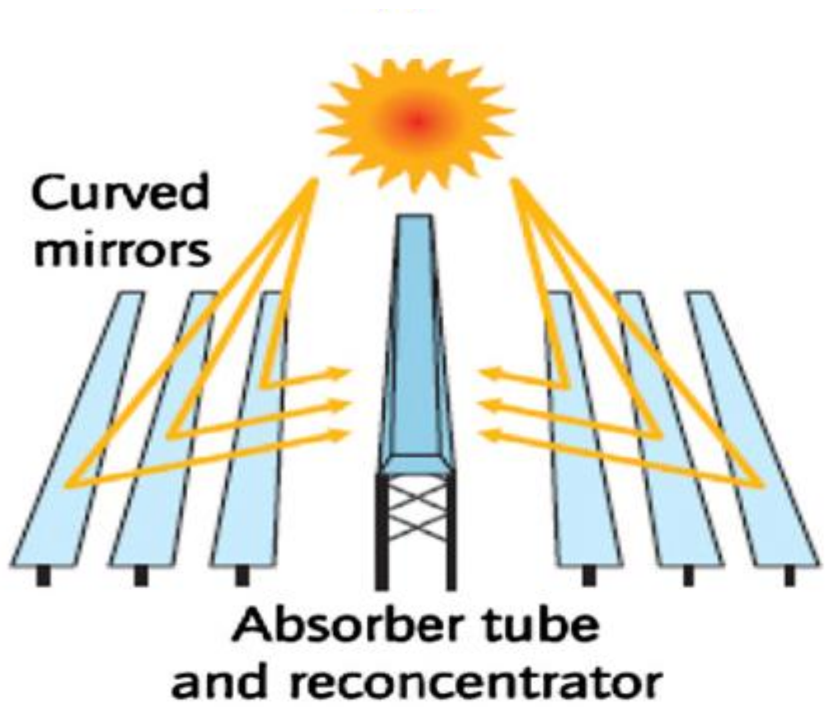


Figure 1. Linear Fresnel Reflector (LFR) technology [Abbas 2012].

Currently LFR technology is being commercialized by several companies. This particular project will use LFR technology commercialized by Novatec Solar. The first Novatec LFR was installed in the demonstration plant at Calasparra, Spain, with a nominal capacity of 1.4 MW_e. A second plant of this technology is now being installed with a nominal capacity of 30 MW_e in Spain [Concentrating Solar Power Technology 2012]. Novatec Solar used low temperature saturated steam for their earlier project, however like other LFR manufacturing companies, developed a superheated system known as Super NOVA with a steam temperature of 500^0 C at 120 bar pressure [Concentrating Solar Power Technology 2012, Abbas 2012]. This superheated LFR system has been used for this study.

3 Methodology

A number of software tools are available for yield analysis i.e., SAM, SOLERGY, SIMULCET and GREENIUS [Dersch 2011]. The Novatec Super NOVA LFR technology model is available in NREL's System Advisor Model (SAM). Therefore, SAM has been used in this work for yield analysis. SAM is an open source software which has been extensively used by design engineers and system planners for performance and financial modelling of CSP, wind and solar PV systems [Gilman 2008].

For a robust estimation of energy yield, SAM requires many years of data. SAM uses files from Typical Meteorological Year (TMY) data format (e.g., TMY2 and TMY3) as an input. The TMY is a dataset containing hourly values of solar radiation and other meteorological data such as wind speed, humidity and atmospheric pressure over a period of one year. A TMY weather file may contain a single year or typical year of data. TMY2 datasets for Rockhampton from 1990-2012 obtained through Exemplary Energy has been used here for yield analysis of the 30 MW_e CSP plant in Collinsville [Exemplary Energy]. The following design point parameters as given in Table 1 are considered for this study.

Furthermore, to express the energy yield with inter-annual climatic variability, P50/P90 analysis has also been conducted here. SAM has an inbuilt capability to conduct P50/P90 analysis. P50/P90 analysis provides the annual output of any renewable system by exceedance probability. Either empirical CDF or CDF calculation for a standard probability distribution is used in SAM for P50/P90 analysis. For both methods, SAM calculates P50 and P90 exceedance probabilities either from standard CDF or a linearly interpolating CDF table. The detailed yield analysis results for the proposed 30 MW_e LFR system using historical weather data sets of Rockhampton are given next.

Table 1. Fixed design point parameters for yield analysis [RATCH Australia]

Item	Specification
Power cycle rating	30 MW_e
Fossil fuel backup	None
Thermal storage	None
Solar multiplier	1.65
Condenser type	Evaporative
Estimated gross conversion factor	0.950478
Design point irradiance	950 W/m^2

4 Results and Discussion

Tables 2-4 show the average daily yield results of the proposed 30 MW_e LFR system in Collinsville using the historical data of a nearby location (Rockhampton). The yield results in these tables allow comparison with:

- the weather model of 2013
- the weather projection years 2007-2012 and
- weather years prior to 2007.

As the weather data for 2013 in Rockhampton is not available, the typical meteorological year data for Rockhampton available on the US Energy Plus website has been considered here as 2013 data [US-DOE 2010]. The simulation results gave an energy output of 52.158 GWh for the studied year. Table 2 shows the average daily yield of the LFR system for 2013. From the simulation results it can be seen that the average daily yield of the LFR system is the highest for November and the lowest for May. From the table it is also observable that for the period of April-July the average daily yields are on the lower side.

Table 2. Average daily yield of Rockhampton in 2013

(GWh)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
2013	0.163	0.143	0.151	0.13	0.100	0.106	0.122	0.13	0.15	0.167	0.171	0.163

Tables 3 and 4 show the average daily yield of the LFR system for the periods 2007-2012 and 2000-2005, respectively. From Tables 3 and 4, it can be seen that during June-July the average daily yield for the LFR system is low compared to the summer months (Nov-Feb.). It has also been observed from Tables 3 and 4 that the average daily yield is high for November and December compared to the other two months of the summer. From the results in Tables 3 and 4 it can be seen that among the studied years, 2010 is the worst year with the lowest average daily yield for almost all the months of the year except January.

Table 3. Average daily yield of Rockhampton 2007-2012

(GWh)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
2007	0.112	0.079	0.14	0.132	0.087	0.040	0.108	0.064	0.139	0.157	0.102	0.099
2008	0.072	0.064	0.127	0.128	0.093	0.065	0.058	0.113	0.11	0.144	0.139	0.157
2009	0.068	0.126	0.176	0.145	0.096	0.123	0.139	0.172	0.187	0.217	0.215	0.172
2010	0.109	0.061	0.081	0.089	0.098	0.064	0.036	0.08	0.063	0.124	0.03	0.067
2011	0.204	0.162	0.087	0.119	0.136	0.098	0.13	0.104	0.196	0.151	0.192	0.107
2012	0.167	0.196	0.128	0.163	0.113	0.059	0.078	0.124	0.181	0.199	0.218	0.234
Monthly	0.122	0.115	0.123	0.129	0.104	0.075	0.092	0.11	0.146	0.166	0.149	0.138

Table 4. Average daily yield of Rockhampton 2000-2005

(GWh)	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
2005	0.163	0.213	0.148	0.118	0.126	0.052	0.099	0.089	0.17	0.14	0.209	0.247
2004	0.166	0.17	0.168	0.135	0.118	0.096	0.09	0.167	0.19	0.21	0.187	0.185
2003	0.179	0.09	0.117	0.115	0.077	0.059	0.078	0.098	0.174	0.147	0.073	0.126
2002	0.156	0.112	0.153	0.112	0.087	0.07	0.093	0.091	0.168	0.193	0.209	0.189
2001	0.219	0.172	0.151	0.106	0.16	0.072	0.128	0.198	0.179	0.234	0.167	0.217
2000	0.147	0.102	0.116	0.112	0.109	0.095	0.09	0.115	0.134	0.162	0.104	0.145
Monthly	0.172	0.144	0.142	0.116	0.113	0.074	0.096	0.128	0.169	0.181	0.158	0.185

An additional yield analysis as compared to 2012 has been conducted to verify the obtained results in Table 3 for the year 2010. Figure 2 shows the monthly energy production of 2010 and 2012 as compared to the monthly thermal power injection to the system. From the results shown in Figure 2 it is evident that monthly thermal energy injections to the LFR system for the year 2010 are lower than that of 2012, which reflected in the monthly electrical energy production of the system.

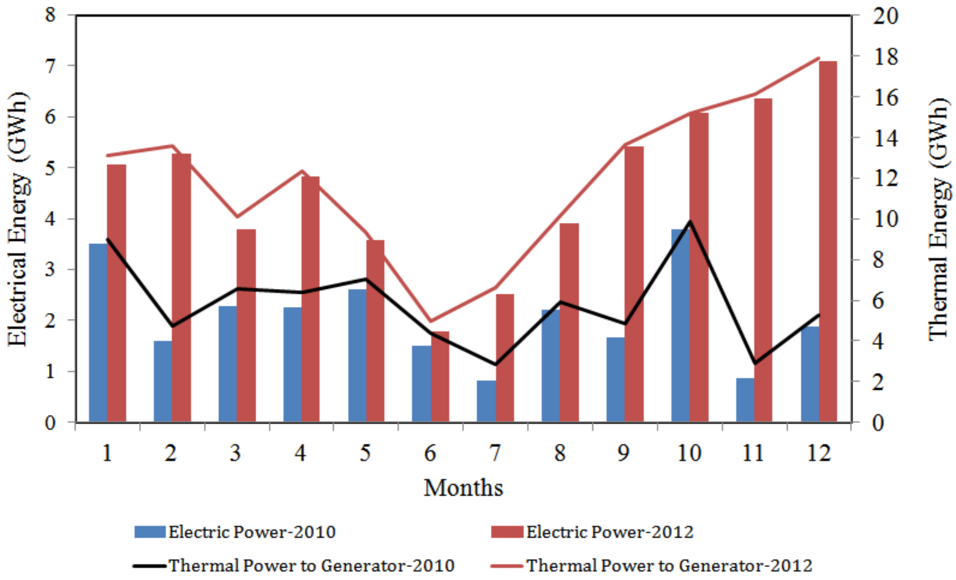


Figure 2. Monthly thermal and electrical power generation for 2010 and 2012.

Figure 3 shows the exceedance probability of energy yield for the 30 MW_e CSP system in Collinsville. For this analysis a total of 13 years datasets for the period of 1999-2012 (excluding 2006) have been used. Solar data for 2006 was discarded from the analysis as SAM had a convergence problem for this year due to a bad data issue. From Figure 3 it can be seen that there is a 50% likelihood that the system's output will be greater than 44.16 GWh per annum. From the figure, it can also be seen that there is a 90% likelihood for the system in Collinsville to generate over 30.88 GWh per annum with a similar weather pattern as Rockhampton.

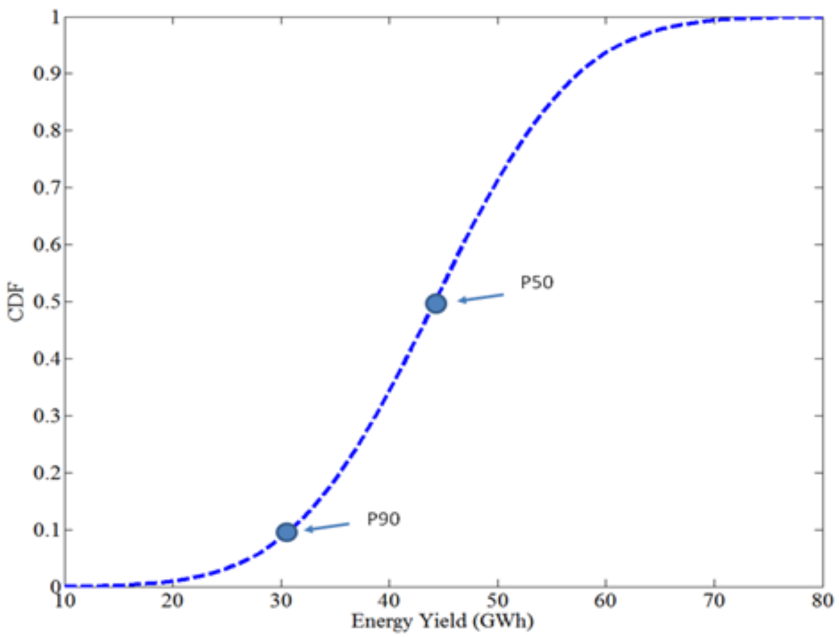
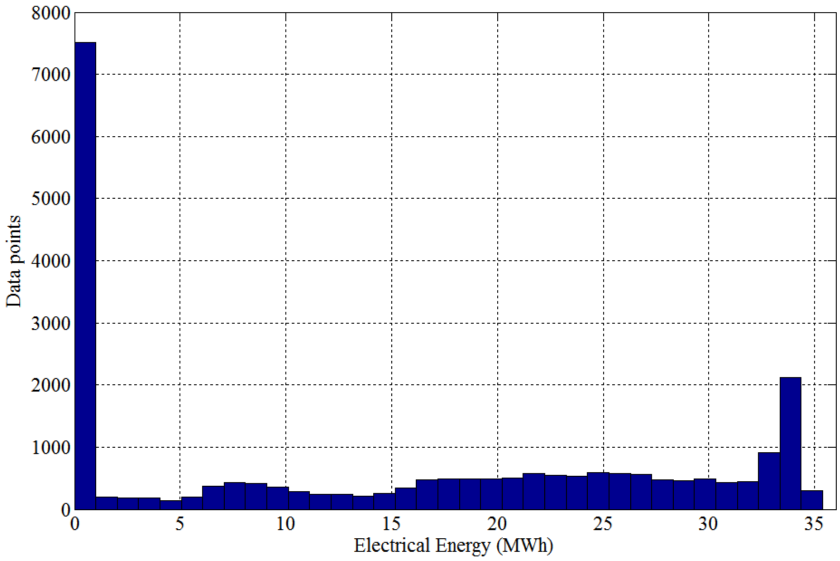
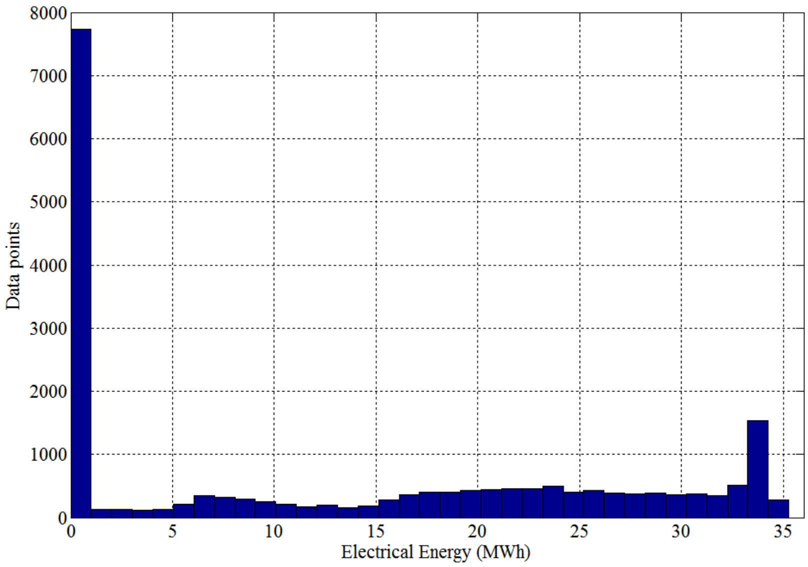


Figure 3. CDF of energy yield for the 30 MW_e CSP system.

Furthermore, Figures 4(a) and (b) show the histograms of hourly electrical energy production for the underlying LFR system for 1999-2005 and 2007-2012 respectively. From the results shown in Figures 4 (a) and (b) it can be seen that for the majority of the time, electrical energy production for the studied LFR system is within 0 to 5 MWh. For 1999 to 2005, 37% of the time the expected electrical energy from LFR system is within 0-5 MWh. From Figure 4 (a) it can be seen that for almost 18% of the time the expected electrical energy from the LFR system will be over 30 MWh. For 2007-2012, 42% of the time the expected electrical energy from the LFR system is within 0-5 MWh. There is a possibility of exceedance of electrical energy over 30 MWh (14.2% of the time the expected electrical energy from LFR will be over 30 MWh).



(a)



(b)

Figure 4. Histogram of electrical energy generation: (a) 1999-2005; (b) 2007-2012.

Figure 5 shows the difference between each years calculated energy to the 13 years mean value. Results in Figure 3 gave the mean value of 44.16 GWh per annum. From Figure 5 it can be seen that most of the years under study experienced a higher deviation from the mean energy yield. From the figure, it can be seen that the system could experience energy output variation as high as 20 GWh per annum from the mean energy yield.

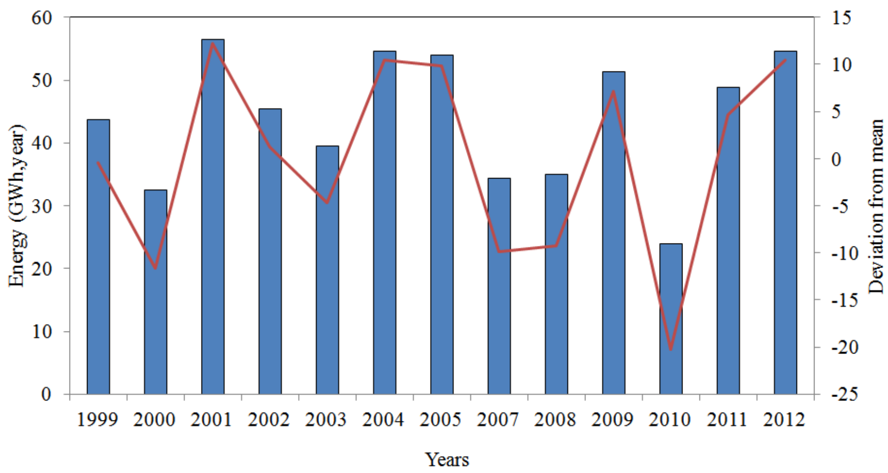


Figure 5. Yearly energy yield and deviations from long term mean values.

Figure 6 shows the percentage difference between the mean energy generation for each month and the worst case scenario (i.e., extreme minimum value) as defined in (1). From the figure it can be seen that the system exhibits higher values for November and December followed by Jun-Sept. From the results in Figure 6 it is worth noting that the ΔE values for January is high for the period of 2007-2012, whereas low for the period of 1999-2005.

$$\Delta E = \frac{E_{mean} - E_{\min}}{E_{mean}} \times 100 \quad (1)$$

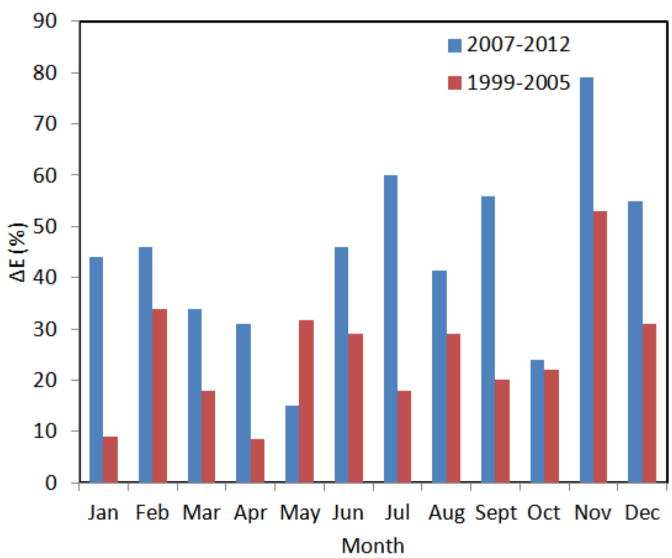


Figure 6. Percentage difference between mean and worst case scenarios.

5 Conclusions

Often the yield analysis of the renewable system has been carried out using a typical meteorological year which excludes the worst case weather events which would represent a realistic long term climate. This analysis might be suitable for a pre-feasibility study, but may not be suitable for gaining PPA or attracting investment. Moreover, using multiple years historical data to model the long term performance of the system presents the performance prediction which accounts for the potential worst case years [Dobos 2012]. Therefore, it is essential to analyse the energy yield of any proposed renewable energy projects by using multiple year datasets.

As the Collinsville site does have only one year data available for the performance prediction of the proposed 30 MW_e CSP plant, this report investigates the performance of the 30MW_e LFR system in Collinsville by using the historical datasets of the nearby location of Rockhampton. This performance prediction of the 30MW_e LFR system would be a good indicator for the technical value of the proposed plant. Furthermore, the yield results obtained by using the historical datasets can further be used to test the effectiveness of the weather model at Collinsville for yield analysis.

6 Further Research

This research does cover the yield analysis of the proposed 30 MW_e CSP plant in Collinsville by using the historical datasets of the nearby location (Rockhampton). In the future, the following research works can be done along this line of research.

1. Significant penetration of non-dispatchable or semi-dispatchable resources such as CSP is likely to introduce more operational time frame variability and forecast uncertainty. From a system operational prospective it is important that such variability and uncertainty do not lead to increasing the system operational cost and decreasing the network security. Therefore, it is important to analyse the ramping events of CSP plant by using large data sets. Further research can be done in this domain for the CSP system in the Collinsville region.
2. Often a CSP system uses thermal energy storage (TES) to make its output dispatchable. Cost benefit analysis based sizing of a storage system is one of the important tasks to be conducted before financial investment. By using large datasets, through cost benefit analysis based sizing of TES system for the CSP plant in Collinsville can be done in the future.
3. RATCH-Australia will develop a 20 MW_e solar PV plant along with the proposed 30 MW_e CSP plant in Collinsville. MW resource assessment for assessing the availability of CSP-PV system can be done for the Collinsville area.
4. It is significantly important to assess the resource availability and understanding of the correlation between generation and load demand of a particular location. Therefore, combined correlation study of CSP-PV resource with load demand for Collinsville can be done in the future.
5. Energy yield analysis of other potential locations for CSP system can be done by considering the sensitivity of the design parameters.

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The Global Change Institute at The University of Queensland, Australia, is an independent source of game-changing research, ideas and advice for addressing the challenges of global change. The Global Change Institute advances discovery, creates solutions and advocates responses that meet the challenges presented by climate change, technological innovation and population change.

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