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Techno-Economic Parametric Assessment of CSP Power Generations Technologies in India

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Abstract

India lies in the sunniest regions of the world and has a high potential for solar energy for power generation, given that both technology routes for conversion of solar radiation into heat and electricity. One of the technologies, Concentrating Solar Power (CSP) uses direct sunlight, concentrating it to the focus of solar thermal concentrating systems where the light is absorbed by some material surface to produce high temperatures. The CSP can also be used for centralized level with high power requirement. The current work focuses on the parameters required for the commissioning of the Concentrating Solar Power plants in India. Various parameters which were relevant to this technology are identified from the literature review and by discussion with experts. To evaluate those identified parameters and to know the perceptions of key players in this area a survey was conducted. Total of thirty nine relevant parameters are considered and categorized under two aspects, *viz* technical and economical aspects. The main purpose of the research is to determine how the judgment level for different parameters, varies among different groups. The results of this study may be useful for the decision and policy makers of CSP technologies.

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Keywords: Solar Energy; Concentrating Solar Power; Techno-Economic Parameters; India

1. Introduction

Solar energy technologies have the potential to play a significant role in the world's energy future. The theoretical solar energy potential on the Earth's surface (land and ocean) has been estimated at 3.9×10^{6} EJ/yr [1]. This amount of energy is sufficient to meet all energy demand of the world. The solar energy falling from the Sun can be

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harnessed into two forms i.e. heating purpose or electricity generation purpose. Heating purpose can include active and passive heating of buildings, solar water heating systems, drying of biomass etc. For generating of electricity, mainly two ways are used, the first one being direct conversion of solar radiation into electricity (via photovoltaic panels) and the other one as indirect conversion in which solar radiation is concentrated to heat up the fluid stream which runs conventional thermal power plant cycles [2]. Solar thermal power technologies are distinguished by the way they focus sunlight. These systems are classified as line focus, which includes Parabolic trough and Linear Fresnel collectors, or point (or area) focus, which includes Central receivers, Parabolic dishes and Scheffler systems.

Direct electricity from the solar energy can be generated by Solar Photovoltaic (PV) which is proven and tested technology [3]. Megawatt Plants using PV technologies have already been in operation all over the world since past few decades. Though the cost associated with this technology is high but the technology is well-known and reliable [4]. In India, during 1999 to 2006 the use of PV for power production began by the later part. [5]. The Jawaharlal Nehru National Solar Mission (JNNSM), one of the eight National Missions under National Action Plan on Climate Change, which was launched on 11th January 2009 with funding of USD 930 million, is an ambitious mission to make India a global leader in solar energy generating 20,000 MW of solar power by 2022. Three guidelines for project implementation under JNNSM have been issued. A total of 1236.48 MW capacity of solar grid power has been allocated by January 2013. This allocation is purely grid connected while off grid power is only 107.80 MW [6, 7]. Fig. 1 shows the growth of on-grid solar power generation in India.

The growth in CSP technologies though started early in nineties but its progress didn't gain momentum due to the decreasing cost of PV technologies. Another reason for the same is poor political and financial support by governments all over the world. In India, CSP met similar fate, it was planned to set up a 35 MW solar power plant based on CSP in Mathania, Rajasthan way back in 1994, but the project was postponed due to lack of sufficient bidders and contractors. Now, with the onset of JNNSM the scenario has changed. There is a rapid development in the field of CSP and the potential aspect of further growth appears to be extremely bright [8]. CSP generation systems are emerging as the key players among the other power generation technologies [9]. From 2010 to 2012, many CSP projects are introduced in India. The Mathania solar power plant has been selected again with increased capacity, by the government of Rajasthan. The project configuration of 140 MW Integrated Solar Combined Cycle Power Plant involves a 35 MW solar power generating system (which was proposed in 1994) and 105 MW conventional power component [10].

Few of the CSP projects are operational & under construction. As of December 2012, a little more than 3 MW of CSP generations has been achieved. Under phase I of JNNSM, many of CSP plants which are under construction are supposed to be commissioned by March 2013 [11]. The current status of CSP plants in India are shown in Table 1.

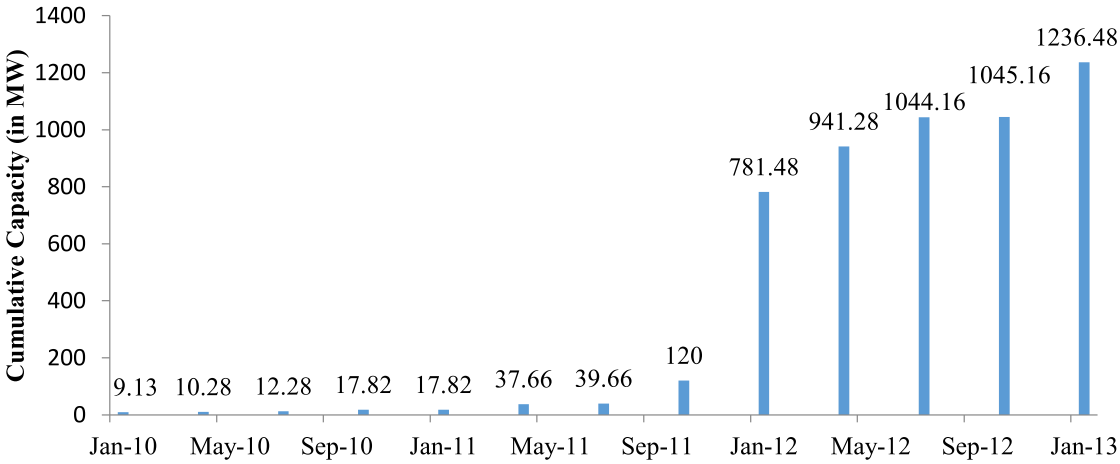

Fig. 1. Growth of on-grid Solar Power in India (PV) [6, 7]

Table 1 Current status of CSP in India (as of March 2013) [10,12-14]

State	Project Name	Size (MW)	Location	Technology (Status)
Rajasthan	ACME Project	10	Bikaner	Power Tower (First Stage Completed 2.5MW)[1]
	Sun Technique Energy Pvt Ltd (Reliance Power) Project	100	Bikaner	Solar Tower (Power block)[2]
	Lanco Infratech Ltd Project	100	Jaisalmer	Parabolic Trough[2]
	KVK Energy Ventures Pvt Ltd Project	100	Jaisalmer	Parabolic Trough[2]
	Godawari Power & Ispat Ltd Project	50	Jaisalmer	Parabolic Trough[2]
	Corporate Ispat Alloys Ltd Project	50	Jaisalmer	Parabolic Trough[2]
	Mahindra Solar One Plant	10	Jodhpur	Parabolic Trough[3]
	Bap Solar Power Plant	10	Jodhpur	Parabolic Dish Sterling[3]
	NTPC Pilot Project	15	Baran	Parabolic Trough[3]
	Solar hybrid power plant	140	Mathania	Parabolic trough (35 MW)[2]
Andhra Pradesh	Sunborne Energy Project	50	-	Parabolic Trough[3]
	Megha Engineering & Infrastructures Ltd Project	50	Hyderabad	Parabolic Trough[2]
Gujarat	Thermal Power Project	25	Kutch	Parabolic Trough with Thermal Storage[3]
	Aurum Renewable Energy	20	Porbandar	Concentrating Linear Fresnel Reflectors[2]
Haryana	Ministry of New & Renewable Energy (MNRE) along with Indian Institute of Technology, Bombay	1	Gwal Pahari	Parabolic Trough & Linear Fresnel reflectors[1]

The capacity installed for CSP in India is quite low as compared to PV, which has current status of 1236.48 MW (as shown in Fig. 1). This disparity is due to the various factors like maintenance of panels, grid connectivity, ease of commissioning of PV systems etc. which ultimately leads to growth of PV sector. Easy availability of water supply, which is the key factor for CSP plants for both cleaning of mirrors and running the turbines, is scarce in arid regions like western Rajasthan and Kutch region of Gujarat. Despite this, the large numbers of CSP plants are under construction in these areas. The main reason behind this is high solar insolation in these regions. The power plants with collective capacity of 585 MW are under construction in Rajasthan, out of which only 2.5 MW has been operational since December 2012. An operational plant in Gwal Pahari, Haryana is solely for research and development purpose of MNRE. In Andhra Pradesh around 100 MW and in Gujarat 45 MW of CSP plants are under construction, as shown in Table 1. It is expected that CSP will gain momentum in near future. And further, there is need to review technical and economical parameters for CSP especially in Indian context.

2. Review of techno-economic assessment

Techno-economic assessment for various solar power generation technologies has been attempted by various researchers. A pre-feasibility study for CSP is done by Cameron and Crompton [15] for Australia. It shows that the size of the plant is key determining factor, followed by location and cost. Similar kind of study has been performed for Iran [16], USA [17] etc. A research by National Renewable Energy Laboratories (NREL) shows that large scale deployment of CSP plants with careful land and water usage would have ecological impacts in USA[18]. One of the key works in the field of CSP is done by Vogel and Kalb [19], which discussed the technical and cost factor for commissioning of solar thermal based power plants. Assessment report on parabolic trough and solar tower by Sargent and Lundy [20] shows that in a long run condition CSP will prove to be main source of power generation technology.

For India, World Institute of Sustainable Energy (WISE) [21] and CSP Today [12], performed the technical

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[1] Operational
[2] Under construction (JNNSM)
[3] Under construction (non JNNSM)

assessment for a few states and compared the supplier's cost for the commissioning of solar power projects. The study depicts that in India states like Rajasthan, Gujarat and Andhra Pradesh have vast potential for CSP technologies. It also discusses the barriers and policies for the CSP Technologies. A research paper by Purohit and Purohit [22] presented the technical assessment where a comparative study has been done for various Indian locations for commissioning of CSP plants in comparison with existing solar thermal power plants of Spain, ANDASOL-1 and PS-10. Patil [23] presented the cost analysis of utility scale CSP technologies in India considering material and labour charges as per Public Works Department rate of Rajasthan. A research paper by Sharma et al. discusses the solar policies and barriers for India [24, 25]. For countries like India, a roadmap for successful implementation of CSP has prepared by International Energy Agency (IEA) [26]. Ramachandra et al. [27] has consider technical parameters like location and weather in their study. While economical assessment comparison of various technologies on the basis of direct cost and operational costs are performed by various researchers [21, 28-29].

3. Research Methodology

3.1. Selection of Parameters

For CSP technologies, various factors like land requirement, water supply, solar angle, solar multiple etc were identified from literature. These parameters were then categorized into two categories *viz*. economical parameters and technical parameters. Initially seventy six parameters were identified from literature review consisting of journal papers, technical reports, books etc. After extensive discussion with the experts, few of the parameters were combined together based on their similarity and finally thirty nine parameters have been taken for the survey design. Table 2 presents identified parameters and their descriptions, where 'C' represents economical parameters and 'T' represents technical parameters.

Table 2 Parameters Classified

Economical Parameter No	Parameter	Technical Parameter No	Parameter
C1	Direct Investment Cost	T1	Location
C2	Indirect Cost	T2	Capacity Utilization Factor of Plant
C3	Operation and Maintenance Cost	T3	Tracking
C4	Insurance Cost	T4	Solar Multiple value
C5	Loan Interest Rate	T5	Need of Lightning arrest for CSP
C6	Payback Period	T6	Annual Efficiency of the plant
C7	Consideration of Inflation Rate	T7	Solar Field
C8	Net Salvage Value	T8	Operating Temperatures
C9	Power Purchase Agreement	T9	Solar resource assessment
C10	Auxiliary Cost	T10	Access to roads
C11	Taxes	T11	Washes/Cleanliness of Mirrors
C12	Government Subsidies	T12	Area of Collector and absorber
C13	Land Cost	T13	Grid Connectivity
C14	REC Mechanism	T14	Hours of Full load operations
		T15	Impact of local climate
		T16	Local O&M support
		T17	Type of CSP technologies
		T18	Thermal Storage
		T19	Heat Transfer Fluid (HTF)
		T20	Easy availability of Water
		T21	Losses in CSP
		T22	Mirror/Heliostat properties
		T23	Materials used
		T24	Module mounting structure
		T25	Need of Fire Alarm systems

3.2. Survey Design

Since majority of the criteria were technical and the evaluation of these criteria was planned to be identified through a survey. Questionnaire was designed for evaluation of different parameters. Structured questionnaires were prepared, tested, validated, modified and opinion was collected from 70 experts through web base survey. The experts were identified from groups such as educators, professionals (which includes policy maker, manufacturers, engineers etc), and researchers. The few respondents like NGO's and individuals working in this area were classified into miscellaneous category since their percentage is quite less. The experts were asked to assign importance of the parameters on a 10 point qualitative linear scale. The 10 point was given for Very High (VH) importance level, which had highest level of parameter judgment by the respondent. Similarly 8 point was given for High (H) which shows dominance of the judgment, 6 point for Medium level (M), which shows compromising level of judgment, 4 point for Low (L), which shows lower level of judgment and 2 points for Very Low (VL) level, which shows peripheral level of judgment for the given parameter.

3.3. Computation of Weightage

Weighted average values have been computed for importance of parameters on 10 point scale. The weighted average value are calculated by the formula shown in Eq. (1).

$$Weightage = \frac{\sum_{i}^{j} W_j N_j}{N} \tag{1}$$

Where W_j indicates the importance of j^{th} parameter (on assigned scale) by the numbers of respondents, N_j for the parameter and N are the total number of respondent [30]. The assigned weightage for various groups identified for the present problem are computed using Microsoft Excel. The computed weightage for the thirty nine parameters are categorized according to different groups. The average values in two different groups of parameters *viz* economical and technical for CSP are also calculated. The weightage thus obtained from the survey is then normalized for the given scale, as given in Table 3.

4. Results and Discussion

As discussed in previous section, 70 suitable responses were obtained from the survey. The respondents were classified according to their field of expertise. For the survey, the percentage contribution of the experts for professional, researchers, educator and miscellaneous are 39%, 34%, 17% and 10 % respectively.

The analysis of normalized performance of parameters is further classified according to respondent's field of expertise. The weightage analysis of parameters gives the preference given by experts. The higher value of normalized weight represents the highest preference by the experts and vice versa. The expert preference wise classification for economical parameters and technical parameters for CSP is shown on graphical radar in Fig. 2 and Fig. 3 respectively.

The analysis of weightage indicates the importance level of the selected parameters for CSP based electricity generation plant. In overall scenario of economical criteria, direct investment cost (0.0308) is given the highest priority followed by payback period (0.0282) and power purchase agreement (0.0273). It is also observed that inflation rate (0.0208), net salvage value (0.0189) and insurance cost (0.0187) have lowest importance level. When the results are categorized by the respondents groups, it is observed that Professionals, Researchers and Educators have given highest priority to direct investment cost over the other parameters. For the second place professionals preferred power purchases agreement while researchers preferred the need of government subsidies.

Table 3 Normalization of the responses

Parameters	Professional	Researcher	Educator	Miscellaneous	Overall
C1	0.0304	0.0304	0.0313	0.0330	0.0308
C2	0.0232	0.0248	0.0232	0.0224	0.0237
C3	0.0216	0.0230	0.0226	0.0181	0.0220
C4	0.0185	0.0183	0.0197	0.0181	0.0187
C5	0.0260	0.0236	0.0209	0.0256	0.0243
C6	0.0289	0.0263	0.0290	0.0309	0.0282
C7	0.0201	0.0204	0.0226	0.0224	0.0208
C8	0.0181	0.0207	0.0174	0.0192	0.0189
C9	0.0294	0.0254	0.0261	0.0277	0.0273
C10	0.0235	0.0236	0.0226	0.0224	0.0233
C11	0.0214	0.0222	0.0209	0.0170	0.0212
C12	0.0245	0.0275	0.0284	0.0330	0.0270
C13	0.0224	0.0245	0.0203	0.0256	0.0231
C14	0.0248	0.0262	0.0261	0.0287	0.0260
T1	0.0312	0.0331	0.0290	0.0298	0.0313
T2	0.0299	0.0301	0.0273	0.0298	0.0295
T3	0.0263	0.0263	0.0250	0.0298	0.0264
T4	0.0253	0.0292	0.0267	0.0256	0.0269
T5	0.0260	0.0260	0.0261	0.0213	0.0256
T6	0.0289	0.0263	0.0290	0.0277	0.0279
T7	0.0271	0.0254	0.0261	0.0266	0.0263
T8	0.0273	0.0257	0.0267	0.0245	0.0264
T9	0.0294	0.0292	0.0307	0.0277	0.0294
T10	0.0216	0.0213	0.0226	0.0202	0.0215
T11	0.0271	0.0236	0.0267	0.0256	0.0257
T12	0.0266	0.0269	0.0290	0.0287	0.0273
T13	0.0286	0.0260	0.0284	0.0330	0.0281
T14	0.0271	0.0266	0.0273	0.0266	0.0269
T15	0.0272	0.0238	0.0255	0.0234	0.0252
T16	0.0239	0.0238	0.0238	0.0202	0.0234
T17	0.0304	0.0310	0.0296	0.0319	0.0306
T18	0.0263	0.0307	0.0273	0.0287	0.0282
T19	0.0263	0.0269	0.0284	0.0266	0.0269
T20	0.0266	0.0254	0.0267	0.0266	0.0262
T21	0.0258	0.0254	0.0255	0.0256	0.0256
T22	0.0268	0.0269	0.0261	0.0256	0.0266
T23	0.0268	0.0278	0.0284	0.0224	0.0270
T24	0.0242	0.0245	0.0232	0.0266	0.0244
T25	0.0206	0.0210	0.0238	0.0213	0.0214

In overall case of technical parameters, Location (0.0313) has got highest preference followed by the type of CSP technology used (0.306). The CUF (0.0295), solar resource assessment (0.0294) and thermal storage (0.0282) are given higher preference than other parameters. Same trend is followed in the preference of professionals and researchers. Location is preferred commonly by professionals (0.312) and researchers (0.0331). The parameters like module mounting structure (0.0244), local O&M support (0.0234) and access to road (0.0215) are less preferred.

The need of fire alarm system (0.0214) is unanimously least preferred by all the respondents. It is also observed that educators preferred solar resource assessment (0.0307) more than location of the site (0.0290). However, annual efficiency (0.0290) and preference to the site (0.0290) got the same preference level.

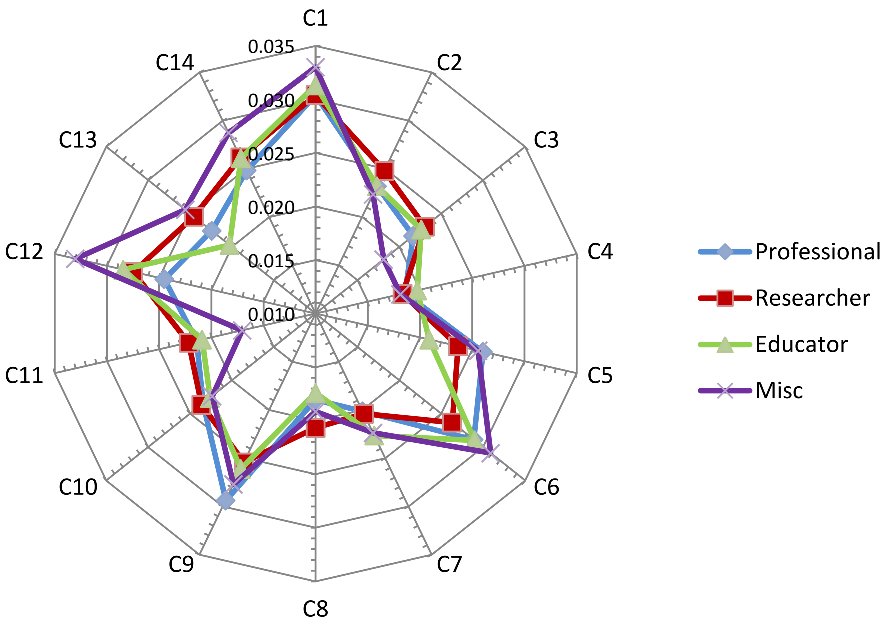

Fig. 2. Economical parameters preferences

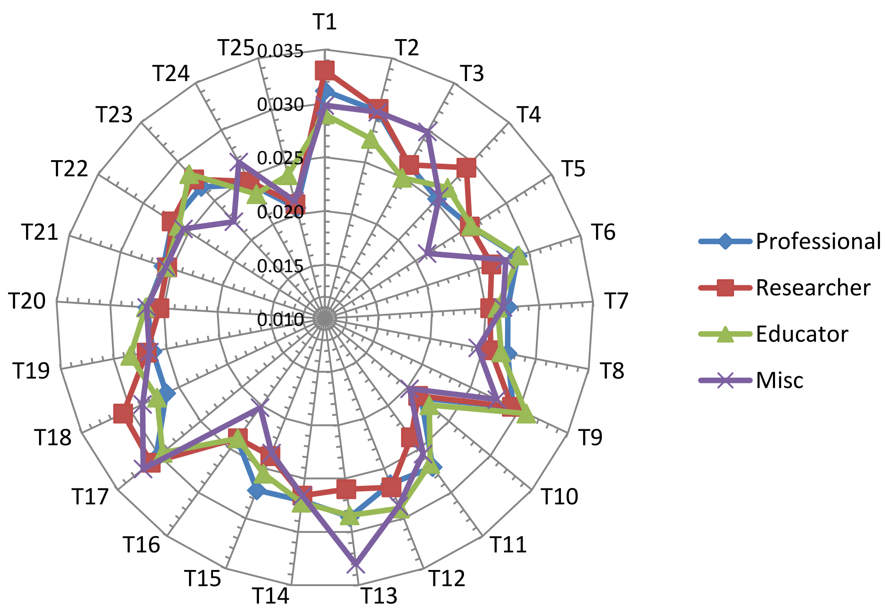

Fig. 3. Technical parameters preferences

5. Conclusion

The Jawaharlal Nehru national solar mission targets for 20,000 MW of solar power generation by the year 2022.

So far, around 1236.48 MW of solar power generation capacity has been achieved, majority of which is PV. In order to promote CSP technologies a boost is required from the government, policy makers and decision makers etc. [31] The parabolic trough technology has proven to be commercially successful in developed countries. The same technology may also be implemented in the Indian subcontinent.

The current work discussed the parameters required for commissioning of CSP plants in India. The key parameters were identified using literature review and in discussion with experts. A survey was conducted to evaluate various identified parameters. It was observed from the analysis of the responses received that the economical parameter like direct investment cost were highly preferred by the respondents (professionals, researchers and educators) while in the case of technical parameters, location of the site had given the highest preference by professionals and researchers. Educators preferred solar resource assessment of the site over other parameters. The insurance cost and need of fire alarm system were least preferred parameters in economical and technical criteria, respectively. The results of this study may be useful for the decision makers and policy makers in CSP technologies in India. Future research work on CSP should address this study.

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References

[1] Arvizu D, Balaya P, Cabeza L, Hollands T, Jäger-Waldau A, Kondo M. Direct solar energy. *IPCC special report on renewable energy sources and climate change mitigation.* Cambridge University Press, Cambridge, UK and New York, USA. 2011.

[2] Feierabend L. Thermal Model Development and Simulation of Cavity-Type Solar Central Receiver Systems. MS Dissertation, University of Winconsin, Madison, 2009

[3] Bosetti V, Catenacci M, Fiorese G and Verdolini E. The Future Prospects of PV and CSP Solar Technologies. FEEM (Fondazione Eni Enrico Mattei), Review of Environment, Energy and Economics (Re3). 2012

[4] Suneel D. *Solar PV Power – A Global Perspective,* TERI Press, New Delhi, India; 2011.

[5] Pillai IR, Banerjee R. Renewable energy in India: Status and potential, *Energy 2009;* 34: 970–980.

[6] Ministry of New and Renewable Energy (MNRE). JNNSM current status. Available online < http://mnre.gov.in> [Accessed 25.11.2012]

[7] Akshay Urja . *Ministry of New and Renewable Energy* Govt of India; 2009, 2(5): 20–23.

[8] Sukhatme SP. *Solar energy: principles of thermal collection and storage*, McGraw-Hill, New Delhi, India; 1996.

[9] Mills D. Advances in solar thermal electricity technology. *Solar Energy, 2004;* 76(1-3): 19-31

[10] Rajasthan Energy Department, Govt. of Raj. <http://www.rajenergy.com/mathania.htm> [Accessed 10.12.2012]

[11] Indian Renewable Energy Development Agency Ltd. (IREDA) guidelines. Available online, <http://cii.in/WebCMS/Upload> accessed 24.9.12]

[12] CSP Today 2008 India < http://www.csptoday.com/india/>[Accessed 12.08.2012]

[13] Gujarat Energy Development Agency (GEDA) Gujarat, India, Online article: <http://geda.gujarat.gov.in/media/Solar_Power_PLants_at_a_Glance.pdf> [Accessed 15.12.2012]

[14] Beetz B. Work underway on India's first CSP plant. PV-Magazine. Online Article <http://www.pv-magazine.com/news/details/beitrag/work-underway-on-indias-first-csp-plant>[Accessed 14.1.13]

[15] Cameron P and Crompton G, Solar Power Plant Pre-feasibility Study, *Report by Parsons Brinckerhoff ,* Australia, 2008.

[16] Nezammahalleh H, Farhadi F and Tanhaemami M. Conceptual design & techno-economic assessment of integrated solar combined cycle system with DSG technology, *Solar Energy,*2010; 84(9): 1696-1705.

[17] Fthenakis V, Mason JE and Zweibel K. The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US, *Energy Policy,*2009; 37(2): 387-399.

[18] Drury E, Margolis R, Denholm P, Goodrich AC, Heath G, Mai T, and Tegen S. Chapter 10 - Solar Energy Technologies, *Renewable Electricity Futures Study*, National Renewable Energy Laboratory, 2012; 2; 10.1 - 10.60.

[19] Vogel, W. and Kalb, H. *Large-Scale Solar Thermal Power: Technologies, Costs and Development*, Wiley VCH, Weinheim, Germany, 2010.

[20] Sargent & Lundy LLC Consulting Group. *Assessment of parabolic trough and power tower solar technology cost and performance forecasts.* Subcontractor Report, Chicago, IL, USA. 2003. <http://www.nrel.gov/csp/pdfs/34440.pdf> [Accessed 10.10.2012]

[21] Achieving 12% Green Electricity by 2017. *Report by World Inst. of Sustainable Energy*, Pune, India, 2011.

[22] Purohit I, and Purohit P. Techno-economic evaluation of concentrating solar power generation in India, *Energy Policy,* 2010; 38: 3015-3029.

[23] Patil V. Utility-Scale Concentrated Solar Thermal Power for India: Technologies, Development and Costs. *First degree Off-campus Thesis*, BITS Pilani, Rajasthan, India. 2012.

[24] Solar handbook: Bridge to India, Final Report. <http://bridgetoindia.com/our-reports/the-india-solar-handbook> [accessed 8.11.2012]

[25] Sharma NK, Tiwari PK, and Sood YR. Solar energy in India: Strategies, policies, perspectives and future potential, *Renewable and Sustainable Energy Reviews,* 2012; 16: 933-941.

[26] International Energy Agency (IEA) CSP Roadmap, IEA, Paris, France, 2010 < http://www.iea.org/publications/freepublications/publication/csp_roadmap.pdf> [accessed 21.09.12].

[27] Ramachandra T V, Jain R, and Gautham K. Hotspots of solar potential in India, *Renewable and Sustainable Energy Reviews*, 2011; 15(6): 3178-3186.

[28] Beerbaum S and Weinrebe G. Solar thermal power generation in India – a techno - economic analysis, *Renewable Energy,* 2000; 21:153-174.

[29] Ummadisingu A and Soni MS Concentrating solar power–Technology, potential and policy in India, *Renewable and Sustainable Energy Reviews,* 2011; 15(9): 5169-5175.

[30] Pohekar SD, Kumar D, and Ramachandran M. Dissemination of cooking energy alternatives in India - a review, *Renewable and Sustainable Energy Reviews,* 2005; 9: 379-393.

[31] Tripathy AK. Three decades of Renewable. *Akshay Urja Magazine,* MNRE India, 2012; January: 10-13.