Concentrating Solar Power (CSP) In Centre Indian Environment

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Abstract: Since the IPCC report 2007established: "it is very likely that global warming nowadays is manmade", it becomes obviously that the emission of CO_2 have to be reduced drastically. The greenhouse gas (GHG) concentration for 2010 was 39% above the preindustrial level. Therefore the warming trend has increased significantly over the last 50 years. Nevertheless, cold-fired power plants are still the basis of electricity production all over the world. In order to work against this trend research and political influence is necessary to avoid the negative impact of the global warming. Based on the history of industrial development the industrialized nations have the responsibility to decrease their individual emissions, as well as supporting developing countries by doing so. The high solar irradiation form 2500kw/m^2/y in some parts of India and the high share of direct radiation concentrated solar power plants (CSP) are an excellent option for as us. It is generally assumed that CSP systems are economic only for locations with direct normal irradiation (DNI) above 1800 kWh/m^2/year (about5 kWh/m^2/day). In the present study, regions of Central India are investigated to install CSP plants by using the accessible measured data of global horizontal irradiation (GHI) from 6metropolises. A computational code changes the measured GHI to DNI and by relating the calculated data, six most capable city area of Central India are nominated as the case study. By applying topographical, radiation and climate logical parameters to SAM software, the electricity capacity of these cities for a typical CSP plant are evaluated. The selected CSP plant is a parabolic trough (PT) power plant with capacity of 50 MW and 4 hour thermal storage. Results show that areas around the cities of Bhopal and Indore have more solar energy prospective to begin CSP plants in Central India.

Key word: **CSP, solar panel, solar power.**

I - INTRODUCTION

1.1 Introduction

Two phenomena nowadays jeopardize people's comfort and way of living: global warming and the fossil fuel resources depletion. Those two events are linked together and trigger, as the main consequence for humans, a need to change their way of consuming, most of all energy, without changing their comfort. More and more countries and organizations turn thus themselves to renewable and greener energies. Almost all the renewable energies that are known today (except for geothermal energy) come from the Sun. Indeed, when reaching the Earth, the sunrays bring four different forms of energy. Latent energy is used to vaporise the water from the sea, which is then transformed into rain and is used in hydropower. Sensible heat is used to heat up fluids, in thermal solar energy as well as in ocean thermal energy. The uneven heating of the Earth creates winds whose kinetic energy is used to run wind turbines and oscillating water columns using wave's energy. Finally, the energy of photons is used in photovoltaic cells, but also by the plants during the photosynthesis, thus creating biomass. Of all those renewable energies, hydropower is the most advanced one, developed to full power in most of the developed countries, and still developing in developing countries. Wind power and photovoltaic are developing quickly, even though they suffer from their unpredictability and variability, which make them difficult to link to the electrical network. Biomass is used in power plants, in complement or not to fossil fuel, but can also be turned directly into fuel for car engines. Ocean thermal energy and waves energy are still at an early stage in the development process as there is a need to find solutions to with stand complex situations as sea storms and icing.

Among all of these renewable energies, concentrated solar power (CSP) is a fast developing technology with great potential. The quantity of solar energy arriving the Earth every day (600 TW) is around ten times superior than the daily global electricity consumption (60 TW) [Krothapalli 2011]. A mirror of about 20 square metres in the desert would be enough to provide the need of one person, day and night, with no CO emission. The potential is thus huge. And the technology to convert the heat into electricity is a proven and well-known one that has been used for years in thermal power plants: Rankine cycles with a steam turbine.

1.2 Energy from the Sun

i. Global Solar Resource

When two atoms of hydrogen fuse into one atom of helium in the Sun core, energy is produced, which is then brought to the surface thanks to radiation and convection. This ensures a production rate of3.85×10^{26}W and a temperature of around 6000K at the surface.

This energy is then radiated through space with electro-magnetic waves travelling at the speed of light. The intensity of the solar radiation decreases with the inverse-square law, given by the following formula:

$$I_{(r)} = \frac{I_{sun}}{4\pi r^2} \quad \text{……… (1.1)}$$

Where I(r) is the intensity received at a distance r from the Sun, in W/m^2 and I is the power at the sun surface in W. The distance between the Sun and the Earth is 1.5x10^{11} meters, as shown on figure 1.1.

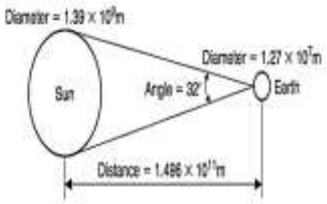

Figure 1.1 Distance between the Sun and the Earth and relation between their diameters [Kalogirou 2009]

At this distance, the global radiation received by the Earth from the Sun is equal to the solar constant, Isc=1367W/m^2. The solar constant is the mean power received from the Sun on a unit area surface perpendicular to the sunrays, outside of the atmosphere. This radiation varies of about 3.4% throughout the year, because of the variation of the distance between the Earth and the Sun.

Outside the atmosphere, the solar radiation can be approximated by the distribution of the radiation of a black body at temperature 5800K, as shown in figure II.2. It gives the irradiance (in W/m) as a function of the wavelength.

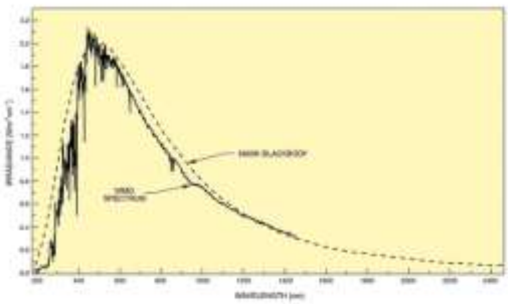

Figure 1.2: Extra terrestrial radiation spectrum and 5800K black body spectrum

This attenuation of the incident radiation can be seen on the following figure, which shows the distribution of the solar radiation that reaches the surface of the Earth, compared to the radiation outside the atmosphere.

Several definitions can then be given.

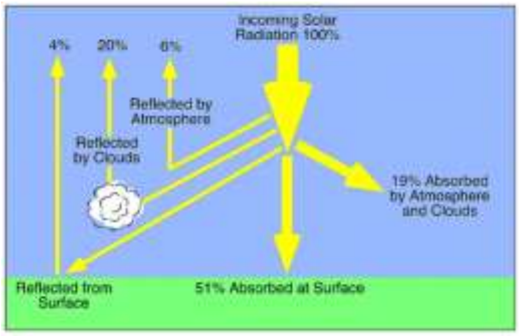

Figure 1.3 Attenuation of the incoming solar radiation

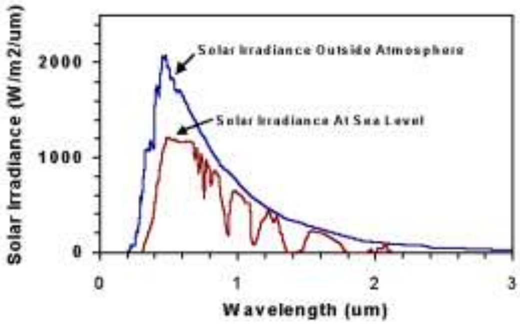

Figure 1.4: Solar radiation spectrum at sea level compared to extra-terrestrial radiation spectrum

The **beam radiation** is the radiation that is incident from the direction of the Sun. It means that it has not been scattered. The beam radiation is the one that is useful in concentrated solar power (CSP). Its intensity depends a lot on the orientation of the surface on which it is collected. This is why the collectors in CSP technology have to be orientated during the day, to maximize the beam radiation that is received.

Those different radiations are linked together by the following equation

$$I_{t,h} = I_b cos\theta_z + I_{d,h} \quad \text{……. (1.2)}$$

Where $I_{t,h}$ is the global radiation on a horizontal surface, I is the diffuse radiation on a horizontal surface, I_b is the beam radiation and θ zd, his the solar zenith angle represented in figure 1.5.

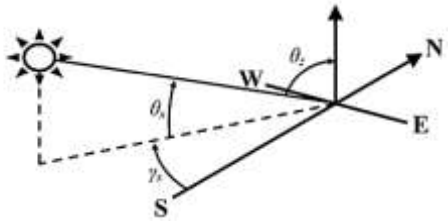

Figure 1.5 Definition of Zenith Angle

Figure 1.6 Direct Normal Irradiation in the World

ii. **Energy balance on a receiver**

Knowing the beam radiation at a specific location, one is able to calculate the energy that can be extracted from the sun in a receiver. This useful energy is the difference between the energy received from the collector and the energy lost because of radiation and convection, as given by the following equation:

$$Q_{useful} = Q_{sun} - Q_{losses} \ldots\ldots (1.3)$$

Where the first term is the useful power in the receiver, the second term is the power received from the Sun via the collector and the third term represents the losses.

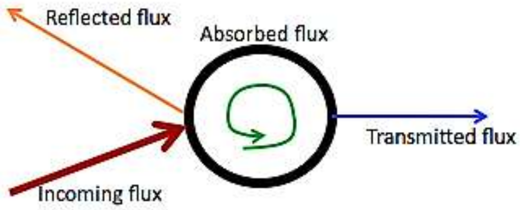

Figure 1.7 Consequence of an incoming radiation on a body

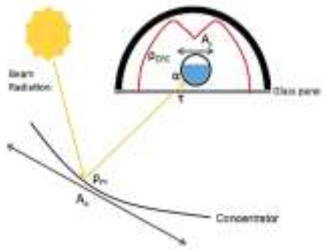

Figure 1.8: Definition of the different parameters used in the equation

To estimate the amount of energy that is received from the sun on the receiver, some definitions need to be given. An incoming radiation on a body can be either reflected, absorbed or transmitted by the body, as represented on figure 1.7.

iii. ***Optical Losses***

The following section describes some optical losses that one must take into account to estimate the amount of energy that is received by the receiver. Those losses are of different kind. Some are due to the geometry of the field, while others are due to the atmosphere and the environment.

It can be explained as follow: the amount of energy that passes through the surface A is the same as the amount of energy that arrives on the surface Ac of the collector (see figure 1.9). It gives:

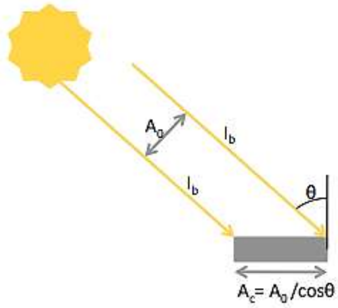

Figure 1.9 The cosine Effect

$$I_b A_0 = I_c A_c = I_c \frac{A_0}{cos\theta} \qquad \ldots\ldots.. (1.7)$$

It is due to the shadow that is created by the collectors all around, thus preventing the direct beam to reach the collector, as illustrated in figure 1.10

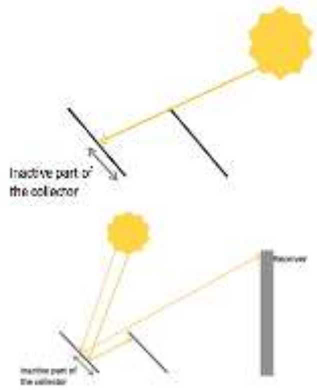

Figure 1.10: Illustration of the shadowing effect (left) and the blocking effect (right)

Blocking is another cause of optical losses on solar fields, mainly where the collectors are close one another and far from the receiver, that is to say on solar tower power plants. Blocking is also due to the geometrical design of the solar field and means that the light cannot be reflected to the receiver because other collectors block the rays, as illustrated in figure 1.10 (right).

Once the light has been reflected, a part of it can be scattered by the atmosphere or by dust in the air. This is called atmospheric attenuation and has an influence on plants where the collectors are placed far from the receiver, most of all in tower power plants.

Tube-End losses are the last losses due to the geometry of the solar field. As the mirror field and the receiver tube are not infinite, parts of the tube are sometimes inactive, while a part of the light is reflected outside the tube, as shown on figure 1.11.

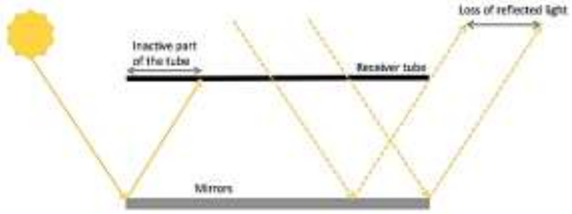

Figure 1.11: Illustration of the tube-end losses

Finally, part of the light that is reflected can miss the receiver, as the spot of reflected light is wider than the receiver itself. This is called **spillage** and has an influence in plants where the receiver is far from the collectors, most of all solar tower plants but also linear Fresnel plants. In linear Fresnel plants, those losses can be reduced using a Compound Parabolic Collector that reflects the light missing the receiver, onto the receiver.

1.3 Concentration technologies

In this section, the different types of concentrated solar power (CSP) plants are described, with their advantages and drawbacks.

Some solar energy collectors do not concentrate the energy that is received from the sun. They are called stationary collectors and are mainly used to heat water for domestic purposes.

One can define the geometric concentration ratio as the ratio of the receiver area to the aperture area, as shown in figure 1.12.

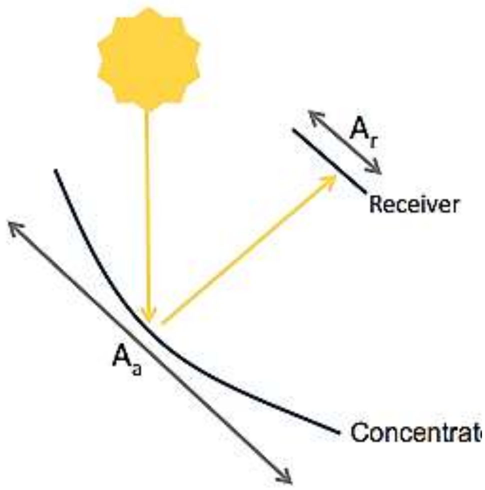

Figure 1.12 Geometric concentration ratio

A non-concentrating collector has a concentration ratio equal to 1. This means that the area of concentration of the radiation is the same as the heat collection area. Most of the non-concentrating collectors are indeed flat, for example, flat plate collectors.

As they do not concentrate the radiation flux from the Sun, those collectors can reach only low temperatures, for example, up to about 120°C. This is perfect for domestic use but not good enough for power production.

Concentrating the radiation flux has thus several advantages. First, when the radiation is concentrated onto a receiver, the heat transfer fluid inside the receiver can reach higher temperatures (up to 2000°C)than with non-concentrating collectors. As a consequence, the thermodynamic efficiency of the cycle is a lot higher.

Then, as the area where the energy is received is smaller than with non-concentrating collectors, the heat losses due to convection, conduction and radiation are lower. The heat losses can be further reduced using vacuum installation inside the casing of the receiver, to decrease convection losses, and selective surface treatment on the receiver tube, to increase the amount of energy that is transmitted to the tube.

This cannot be done on non-concentrating collectors as the heat collection area is larger, and thus the investment is not profitable. Finally, the reflective surfaces (mirrors) are structurally simpler and thus cheaper than flat plate collectors.

Different technologies of solar concentrating collectors exist. All of them have advantages and drawbacks that are studied in this section. Each collector is made of two distinct parts: a concentrator, which reflects the incident solar radiation onto a receiver, thus increasing the energy received; and a receiver in which flows a fluid that extracts the energy from the radiation.

The technologies of collectors can be divided into different types. Some are line focusing, which means that they focus the radiation on a tube with one-axis sun tracking. Those kinds of collectors are parabolic troughs or linear Fresnel collectors. They can reach medium temperatures, between 120°C and450°C.

1.3.1 Parabolic Trough

In the parabolic trough technology, the concentrator is a parabolic dish, which reflects the solar radiation onto a tube that is placed along the focal line of the collector, as can be seen on figure 1.13.

This technology belongs to the linear collectors category. The concentration ratio for parabolic trough collectors is between 30 and 100.During the day, the parabolic dish turns around a horizontal axis, in order to track the Sun and thusreceive the maximum radiation all day long. The reflectors lines can be oriented following a North South axis, thus tracking the sun from East to West, or an East-West axis.

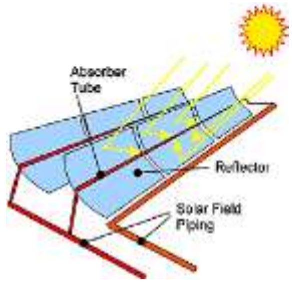

Figure 1.13 Parabolic Trough Technology

The receiver tube is usually made of stainless steel covered with a special coating, with a high absorbance at short wavelengths (visible spectrum) and a low emissivity at long wavelengths (infrared), which means that the radiation received by the tube is mainly absorb, a small part being re-emitted. A glass envelope with a high transmittance then covers the tube, in order to decrease the convection losses.

One advantage of parabolic trough technology is that the parabolic shape ensures a high optical efficiency. However, this shape is difficult to produce, which increases the production costs. The costs are further increased by the structure to maintain the mirrors. Indeed, as the area of mirror is quite large, it increases the wind loading. The structure needs to be stronger than, for example, with linear Fresnel collectors.

1.3.2 Linear Fresnel collector

A linear Fresnel collector is made of several planar or slightly bended mirrors that can be orientated in dependently in order to track the sun and approximate a parabolic concentration on an absorber tube situated above the mirrors, on a tower (about 10 metres high). Figure II.17 represents a linear Fresnel collector.

The mirrors are smaller and simpler than those used in parabolic trough. They can thus be placed closer to the ground. As a consequence, the costs linked to the mirrors and to the structure are reduced compare to the previous technology. However, the mirrors in a Fresnel collector can only approximate a parabolic concentration, and the optical efficiency is thus lower.

As it is a line focusing technology, it needs only a one-axis sun tracking and can only reach medium temperatures (lower than 400°C). The geometric concentration ratio for a linear Fresnel collector is between 25 and 100.The receiver tubes used in this technology are the same as for the parabolic trough technology.

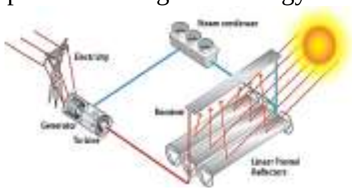

Figure 1.14: Layout of a linear Fresnel collector

1.3.3 Solar Tower

In the solar tower power plant technology, the solar field is made of several thousand planar mirrors called heliostats, individually tracking the sun with a two-axis system and concentrating the radiations on a receiver mounted atop a high tower (more than 100 meters high), as shown on figure 1.15. Heat transfer fluids can be either molten salt of nitrates ($NaNO_3$and KNO_3) or water that is turned into steam. Other heat transfer fluids, such as air, sodium or helium are also currently tested. Then, power is produced usually with a Rankine cycle. Storage is possible with the molten salts.

The geometric concentration ratio for solar tower power plants is between 500 and 800. The sunlight is concentrated between 300 and 1500 times on the receiver, allowing to reach temperatures between 800and 2000°C. Solar tower power plants can thus reach higher rated power than the others technologies.

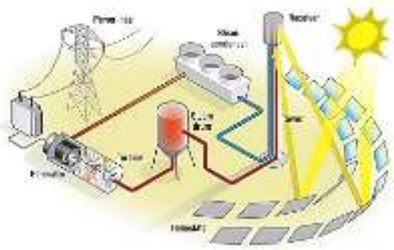

Figure 1.15 Solar Tower Plant Technology

1.3.4 Dish Stirling:

The dish Stirling technology is a point focusing technology as well. However, this is the only technology that is modular, meaning that it can be used either in large power plants, with several dishes, but also as standalone power systems, in remote areas to produce energy for villages or for water pumping.

The dishes are usually between 5 and 15 meters wide. The parabolic dish can be made of one surface, or of several small facets.

Figure 1.16 represents the principle of a dish Stirling system.

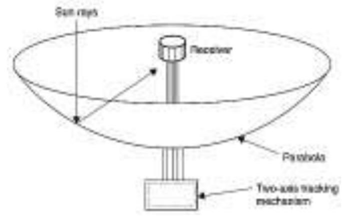

Figure 1.16 Dish Stirling system principle

1.4 Objective of study

Based on the history of industrial development the industrialized nations have the responsibility to decrease their individual emissions, as well as supporting developing countries by doing so.

In the present study, regions of Central India are investigated to install CSP plants by using the accessible measured data of global horizontal irradiation (GHI) from 6 metropolises. A computational code changes the measured GHI to

DNI and by relating the calculated data, six most capable city area of Central India are nominated as the case study.

By applying topographical, radiation and climatological parameters to SAM software, the electricity capacity of these cities for a typical CSP plant are evaluated. The selected CSP plant is a parabolic trough (PT) power plant with capacity of 50 MW and 4 hour thermal storage.

II - LITERATURE REVIEW

Solar energy is one of the most mature technologies to produce electricity from renewable energy. The various studies have been accomplished for the technology some of them are as follows:

"Simulation and optimization of a parabolic trough solar power plant inthe city of Barranquilla by using system advisor model (SAM)" by L.Guzman, A. Henao, R.Vasquez, Energy Procedia 57 (2014) 497 – 506 2013 ISES Solar World Congress

This papers analyses the solar radiation potential in the city of Barranquilla (Colombia), located at 10°59'16" north and 74°47'20" west, for using Concentrated Solar Power technology (CSP) to generate electricity. Due to the lack of meteorological data in coastal areas of Colombia, Daily Integration Approach (DI) was used as the hourly radiation model. The DI model, along with radiation data from NASA-SSE (Surface meteorology and solar energy) were used to map the direct and beam radiation.

"Analysis of CSP plants for the definition of energy policies: The influence on electricity cost of solar multiples, capacity factors and energy storage" by Salvador Izquierdo, Carlos Montan, Cesar Dopazo, Norberto Fueyo

The effect on the cost of electricity from concentrating solar power (CSP) plants of the solar multiple, the capacity factor and the storage capacity is studied. The interplay among these factors can be used to search for a minimal-cost objective that can serve as a technical criterion to guide in the design of economic incentives for CSP plants.

The results provide information to define the optimal operational range as a function of the desired objective. Thus, it is possible to derive a technical criterion for the design of CSP plants which optimizes the solar electricity produced and its generation cost. The methodology is applied to Spain, and the analysis of the results shows that a solar energy production of 37 kWh/m^2/year for tower plants and 66 kWh/m^2/year for parabolic-trough ones define the approximate optimal working conditions for the mean DNI in Spain.

"Modeling and co-simulation of a parabolic trough solar plant for industrial process heat"R. Silva, M. Pérez, A. Fernández-Garcia

In the present paper a tri-dimensional non-linear dynamic thermo hydraulic model of a parabolic trough collector was developed in the high-level a causal object-oriented language Modelica and coupled to a solar industrial process heat plant modeled in TRNSYS. The integration is performed in an innovative co-simulation environment based on the TLK interconnect software connector middleware. A discrete Monte Carlo ray-tracing model was developed in Sol Trace to compute the solar radiation heterogeneous local concentration ratio in the parabolic trough collector absorber outer surface. The obtained results show that the efficiency predicted by the model agrees well with experimental data with a root mean square error of 1.2%. The dynamic performance was validated with experimental data from the Acurex solar field, located at the Plat a form a Solar de Almeria, South-East Spain, and presents a good agreement.

III - METHODOLOGY

The method used in this work starts with the detailed estimation of the irradiation, and then uses models for the technical performance of the plant and the cost structure of the electricity-generation process.

The estimation of the spatial and temporal variation of the irradiance in Central India during one year is in summary as follows:

1. the extra-terrestrial radiation is calculated from first principles from the Sun–Earth relative position;
2. then the clearness index is evaluated at each point using measured meteorological data from a number of stations;
3. the above data are combined to calculate the horizontal irradiation, then this is decomposed in hourly values of diffuse and beam irradiation; and
4. Finally these components are combined, as needed, to compute the irradiance on the tilted surface for the technology considered.

This procedure, which use a GIS structure to get geo-referenced results, is based on Duffie and Beckman (1991), Goswami et al. (1999) and Lorenzo (1994); and it is describe in additional factor in a paper by a number of the current authors (Montanes et al., un published).

Therefore, statistical values (e.g. periodical averages) as of this irradiation are used in this work with the objective of presenting and exemplify the investigation. Of course, more precise or thorough data can be used for the assessment creation when evaluating definite sites. Within this structure, the entirety quantity of solar energy that can be transformed into electricity per unit terrain area for the CSP plants can be articulated as

$$SE = E\eta_c\eta_t\eta_m \qquad \text{.............} (3.1)$$

Where
SE= Solar Energy , E = Irradiation
η_c = Collecting Efficiency,
η_m= Maintenance Efficiency
η_t = Transformation Efficiency

Table 3.1 Assessment Parameters used for CSP technical limit

	Units	Parabolic Trough
Optical Efficiency, η_{opt}	%	75
Convection Coefficient (U)	W/m²K	2
Absorber Temperature (T_A)	K	653
Geometric factor (Fg)	–	π/C
Concentrating Factor (C)	–	82

To convert available GHI data into hourly database, a computational code according to the previously mentioned methodology in literature is employed. This methodology is based on the clearness index (K_T), which is the ratio between daily radiation in a horizontal surface and the extra-terrestrial radiation. The selected procedure is also used by Larraín et al. and is described essentially by Duffie and Beckmann to precede the calculations.

IV - RECOURSE ASSESSMENT FOR CSPP

4.1 Land Recourse Assessment

Using numerous criteria such as ground structure, water bodies, slope, shifting sand, protected and/or restricted areas, forest, and agricultural covered areas allows for the detection of land resources, which would permit the placement of concentrating solar collector fields.

For collecting these data sets from the “Department of Land Resources” are used, which finally all combined in order to yield a map of usable areas. Some of the used criteria can be seen as optional. For instance, tourist areas or agricultural areas cannot be transformed into potential sites for CSP plants. Other information like slope of the terrain or water availability can be understood as compulsory criteria. For example if the slope of the terrain is greater than 2.1% the placement of a CSP plant will be, considering the state of the current technologies, impossible. Table4.1 shows the compulsive and the optional criteria an area must fulfil for being considered as a possible construction site for a CSP plant

In this work, all criteria, whether compulsive or optional, are used for evaluating the capability of an area. As shown in table 4.1 it can be notice that the criterion can be concise into five main topics. Furthermore a minimum direct irradiation as well as the existing grid system is discussed as possible site exclusion criteria.

4.1 Slope:

The digital elevation map shown in figure 4.1 presents the slope of the terrain. As it was mentioned previously a slope of more than 2.1% excludes a site for installation of a CSP plant. The digital elevation model from ISRO is used for determination of the slope.

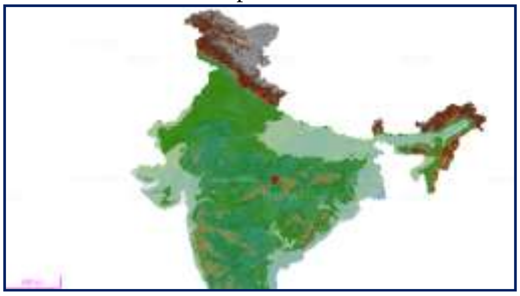

Figure 4.1 Digital Elevation Map

Table 4.1 Exclusion Criteria for CSP Plants

Exclusion Criteria for CSP Plants	compulsive	optional
Slope of Terrain		
> 2,1 %	x	
Land Cover		
Sea	x	
Inland Water	x	
Forest		x
Swamp	x	
Agriculture		x
Rice Culture		x
Hydrology		
Permanent Inland Water	x	
Non-Permanent Inland Water		x
Regularly Flooded Area		x
Geomorphology		
Shifting Sand, Dunes	x	
Security Zone for Shifting Sands 10 km		x
Salt Pans		x
Glaciers	x	
Security Zone for Glaciers		x
Land Use		
Settlement		x
Airport		x
Oil or Gas Fields		x
Mine, Quarry		x
Desalination Plant		x
Protected Area, Restricted Area		x

The figure 4.1 highlights a slope of greater than 2.1% in bright red. Smaller slopes are displayed in different tones from green, which shows flat terrain to dark green, which stands for a slope of 2.1%.

4.2 Land cover

The information about the land cover is extracted from the land cover characterization (GLCC) database provided by ISRO BHUVAN. Figure 4.2 and 4.3 displays the 9 classes of land use for the central India region.

Figure 4.2 Land Use and Land Covers

Figure 4.3 The 10 classes for Land Covers

4.3 Hydrology

Data sets for rivers, lakes etc. are also extracted. Map 4.4 and 4.5 shows the most significant hydrological features in the central India region. Small rivers are not taken into account simply because of the fact that shifting a plant site of a maximum of 500 meters in any direction is consider as suitable. Large rivers, however, mostly near the sea-confluence are taken into account. As a final point the areas prone to flooding are displayed in the satellite image.

4.4 Geomorphologic features

Figure 4.4 The Hydrology of the Central India

Region

Figure 4.5 The Hydrology of the Jabalpur Region

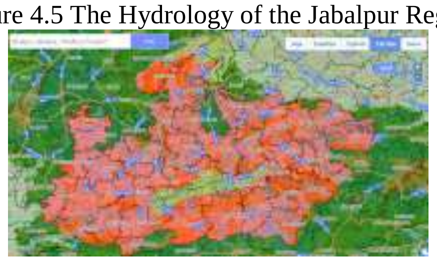

Figure 4.6 Geomorphology for central INDIA

Figure 4.6 gives an impression of the geomorphology characteristic in the central India region. The soils are basically of two types Red laterite and Shallow & Medium Black Soil. Both are in abandon in the region. The dark red and light red colour in the map shows both of them respectively.

4.5 Protected areas

According to the definition published by the World Conservation Union (WCU) a protected area is: "An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed though legal or other effective means.". Areas, which meet the universal guidelines contained in this definition, can be seen as eliminated areas for CSP plants and presented in figure 4.7

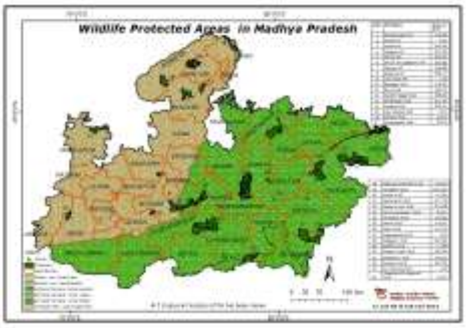

Figure 4.7 Wildlife protected areas of Madhya Pradesh

4.6 Industry and Population

Figure 4.8 displays data about industry and highly populated places. This map also includes mines, quarry airports and desalination plants.

4.7 Technical potential

The data sets explained previously are used to develop maps showing possible restricted areas for concentrated solar power plants based respectively on land configuration. Another powerful criterion is the yearly average of direct normal irradiance at a certain location for each month. This is displayed in the following map (source NREL INDIA)

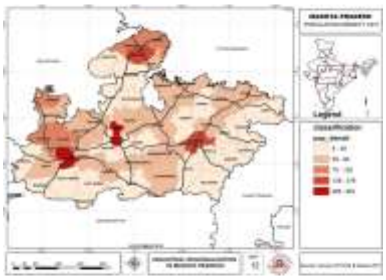

Figure 4.8 Industry and highly populated places

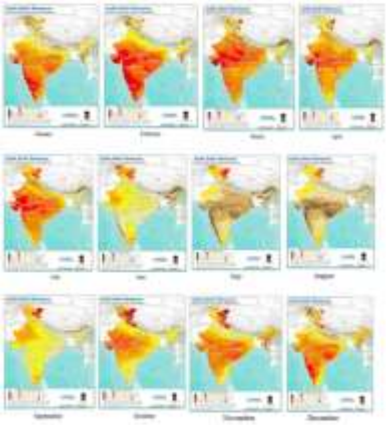

Figure 4.9 The Direct Normal Solar radiations for a year

A site is considered to have a technical potential for a CSP plant when the yearly average direct irradiation is at least 2000 kWh/m^2/year. In central India it is about 3000 kWh/m^2/year so it is well suited for CSP. Taking into consideration economical factors, CSP first start to become feasible with a higher irradiation. However, the 2000 kwh/m^2/year represents a suitable value for operating a CSP plant.

4.8 High voltage Grid

In order to supply the electrical energy produced by a CSPP plant a connection point to the transmission grid must be within a certain distance. This DESERTEC scenario includes high voltage direct current transmission lines. In this work only the actual existing high voltage and extra high voltage grid systems are taken into consideration. The transmission grid not only consists of high voltage lines, but also of transformers, switchgear and other electrical equipment.

If power plants must be connected to high voltage grids over a long distance enormous investment costs must be taken into account. But not only equipment like cables, transformers and switchyards are expensive: the transmission losses over long distances in AC grid systems have to be taken into consideration.

With the idea to minimize the connection costs and minimizing the transmission losses, the distance from the power plant to the existing high voltage Grid in central India has to be very short. In case of central India the grid system is so rich and this cost can be saved, therefore the existing high voltage grid like it is presented in figure 4.10 gives another possibility of excluding possible areas for erecting concentrated solar power plants.

Figure 4.10 (a, b) Grid System of India

V - RESULT & ANALYSIS

5.1 Solar Energy Potential Assessment

One of the purposes of this study is valuation of solar energy potential for numerous areas of Central India to form CSP plant; hence, some cities in diverse locations of Central India are nominated. These municipalities with their coordinates are as

Table 5.1 Selected Cities for Study with their Longitude and Latitude

City	Latitudes	Longitude
Indore	22.7195687	75.8577258
Jabalpur	23.18146	79.9864071
Bhopal	23.2599333	77.412615
Nagpur	21.1458004	79.0881546
Raipur	21.2513844	81.6296413

In order to investigate solar radiation of these cities, average GHI is resolute according to calculated data for era of 10 years. The mean GHI values per square meter per month for the chosen cities are revealed in Figure5.1. This figure depicted that almost in all considered cities; the mean GHI is more than 1600 kWh/m^{2,} which is the minimum required value for CSP plant.

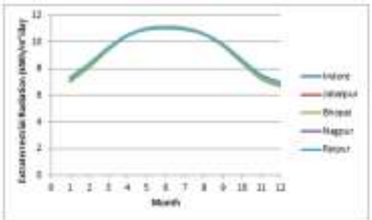

Figure 5.1 Comparison of Extra-terrestrial Radiation of all the considered cities

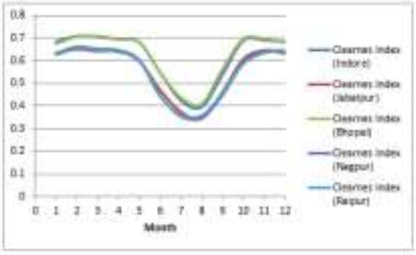

Figure 5.2 Comparison of Clearness Index of all the considered cities

Figure 5.3 Comparison of average monthly Solar Insolation of all the considered cities

Figure 5.1 shows the Comparison of Extra-terrestrial Radiation of all the considered cities. It is depicted from the figure that there are not any significant changes in the extra-terrestrial radiation in between all the cities. It is due to the fact that the extra-terrestrial radiation is completely depends on the latitude and longitude of any place. All these places are near about and got the same amount of extra-terrestrial radiation.

Figure 5.2 shows the clearness index which is the ratio of solar insolation at the earth surface to the extra-terrestrial radiation on the atmospheric surface. Atmospheric parameters reduce solar irradiation and as a result they vary significantly in the amount of their property. Enduring gases such as ozone and oxygen impact attenuation belongings along with the rates of changeable gases between which the water vapor has the most important action. It is depicted from the figure that Bhopal and Indore has same but more clearness ratio than the other three cities.

Figure 5.3 shows the comparison of average monthly Solar Insolation of all the considered cities. The average monthly solar insolation is more in the month of May to June compare than the July to October. The solar insolation varies from minimum of1842.94 kWh/m^2/year to the 2069.24 kWh/m^2/year. Both the values are more that 1600 kWh/m^2/year which is the minimum required value for CSP plant operating condition.

In this outline, the entire quantity of solar energy that can be transformed into electricity per unit terrain area in CSP plants can be articulated as (Equation 3.2)

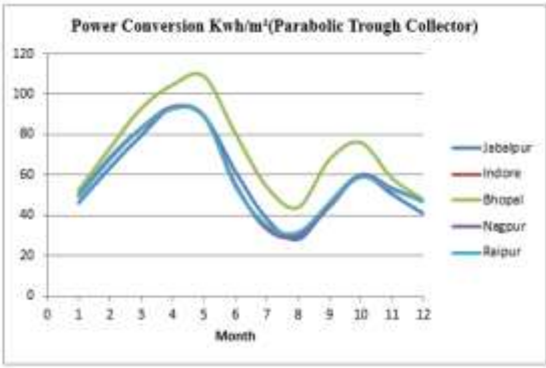

Figure 5.4 transformed solar energy into electricity when using parabolic trough collector

Table 5.2 solar energy that can be transformed into electricity per unit terrain area in CSP plants

	JBP		Indore		Bhopal		Nagpur		Raipur	
	Parabolic trough plants (kwh/m²)	Tower plants (kwh/m²)	Parabolic trough plants (kwh/m²)	Tower plants (kwh/m²)	Parabolic trough plants (kwh/m²)	Tower plants (kwh/m²)	Parabolic trough plants (kwh/m²)	Tower plants (kwh/m²)	Parabolic trough plants (kwh/m²)	Tower plants (kwh/m²)
Jan	46.25	23.725	49.991	25.037	52.189	25.808	49.991	25.037	49.311	24.738
Feb	65.77	29.894	68.786	31.658	73.148	33.102	68.798	31.658	67.478	31.198
Mar	79.09	35.559	83.343	36.851	92.798	40.195	83.343	36.851	82.698	36.623
Apr	93.43	40.511	93.859	40.862	104.44	44.426	93.859	40.862	92.588	40.232
May	89.09	39.018	89.301	39.093	108.81	45.980	89.301	39.093	89.091	39.018
Jun	61.83	29.270	55.460	27.007	80.313	35.833	55.460	27.007	54.186	26.555
Jul	38.41	20.963	33.439	19.208	53.972	26.456	33.439	19.208	34.952	19.742
Aug	28.10	17.330	29.838	17.942	45.720	22.855	29.838	17.942	31.355	18.477
Sep	46.19	23.709	44.462	23.089	67.372	31.185	44.462	23.089	45.759	23.557
Oct	59.86	28.541	60.080	28.617	75.812	34.576	60.080	28.617	58.787	28.161
Nov	50.36	25.247	53.587	26.242	58.189	27.927	53.387	26.242	52.517	25.998
Dec	40.87	21.836	47.011	23.993	47.450	24.147	47.011	23.993	47.011	23.993

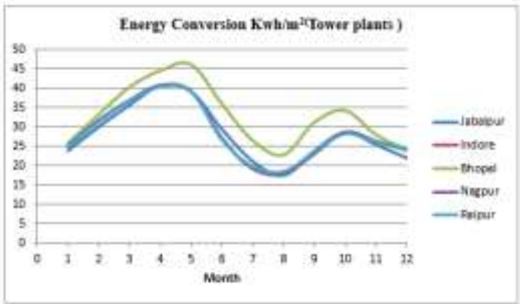

Figure 5.5 Transformed solar energy into electricity when using tower Plants

It is depicted from figure 5.4 and 5.5 that the Energy conversion is more in Bhopal while the other cities have the almost same values.

5.2 CSP Plant Performance Assessment

The investigation of a parabolic trough power plant performance is conducted by using National Renewable Energy Laboratory's (NREL) SAM software. Parabolic trough solar power plant is the extensively used solar technology approximately in all region of the world. This segment shows the selection of parameters and input essentials necessary by a design using SAM. The temperature and wind speed data were obtained from meteorological stations. It was assumed that a geographical surface for setting up the plant is accessible.

SAM syndicates an hourly simulation model with presentation, price and economics models to compute energy output, energy expenses and money flows.

The designated parabolic trough power plant has a capability of 50 MW and 4 hour thermal storage. Supplementary design characteristics are shown in Tables 5.3 and 5.4.

- Heat transfer fluid: The available commercial heat transfer fluids are depicted in table 5.5. As depicted in table 5.5 the most favorable heat transfer fluid is VP-1 which is a synthetic fluid having the desirable properties.
- Type of collector: There are 3 types of collectors are available:

1. Luz system
2. Euro Trough
3. Solargenix

Among all of these we considered Euro trough collectors. Due to the fact that it is cheap, Easy installable, has rigid structure, High optical performance, and less specific weigh compare than other two.

- Type of receiver: The performance of the collector is extremely subjective to the receiver; then it is essential to choose the kind of receiver cautiously. Only some companies construct solar receivers used for parabolic troughs (Schott ,Siemens, HUIJIN, Archimede Solar). The comparison has been done among the both companies for manufacture of CSP solar plants: Siemens and Schott. The differences amongst these manufacturer's commodities are negligible, they are shown in table 5.6.

As per the Table 5.6 depicts the property we have been chosen Schott PTR 70 for the analysis.

- Storage System: In this work we uses thermal storage in array to keep away from solar reliance and assure demand requirements when is requisite. VP-1 is considered as storage media which is synthetic oil that is the similar used for collectors of the solar field.

Table 5.5 Commercial heat-transfer fluids (HTF)

HTF	Application T(°C)	Properties
Synthetic oils (aromatic HC's)e.g. VP-1	13to 395	Flammable
Mineral oils (paraffinic HC's)	-10 to 300	Flammable
Silicone oils	-40 to400	Expensive Flammable
Nitrate salts e.g. HITEC XL	220 to 500	Freezing point≥120°C Highest stability

Table 5.3 Description of parabolic trough collectors nominated for simulating the power plant

Sr. No.	Parameters	Value
1	Collector type	Solargenix SGX-1
2	Aperture width	5m
3	Length of collector assembly	144m
4	Reflective aperture area per SCA	817 m²
5	Length of single module	12m
6	Mirror reflectivity	0.935
7	Number of modules per assembly	12

Table 5.4 Design characteristics of the proposed parabolic trough power plant

Sr. No.	Parameters	Value
1	Receiver Type	Schott PTR 70 2008
2	Total plant capacity	[illegible]
3	Total land area	[illegible] acres
4	Absorber tube outer diameter	0.07 m
5	Condenser type	Air Cooled
6	Absorber material type	304 L
7	Design loop outlet temperature	390°C
8	Design loop inlet temperature	293°C

Table 5.5 Design characteristics of Collectors and Solar Field for parabolic trough power plant

Sr. No.	Parameters	Value
1	Total field reflector area	287584 m²
2	Number of loops	30
3	Single loop aperture	6536 m²
4	Solar multiple	1.5

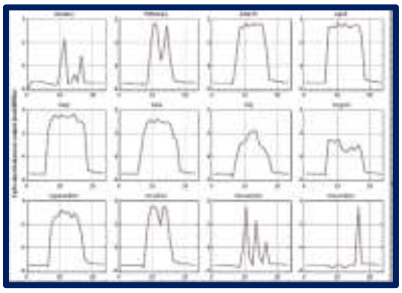

Figure 5.6 Net Cycle Electrical Power Input

Table 5.6 Design characteristics of Reciever

Characteristic	Schott PTR 70	Siemens UVAC 2010
Absorptivity	≥95%	≥96%
Transmissivity	≥96%	≥96.5%
Emissivity	≤10% at 400°C	≤9% at 400°C

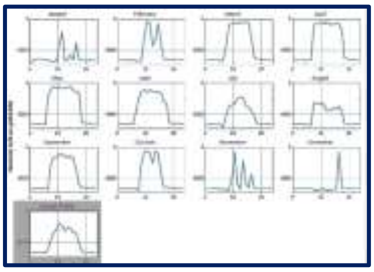

Figure 5.7 Electricity To /From Grid

This plant can produce 34768.316 MWh of energy every year. Extreme production is gained during the month March – June (as shown in figure

5.6 and 5.7) because those months are the hottest and there is more availability of solar radiation.

CONCLUSION

There is lot of opportunity of solar power generation in India. In solar power generation field CSP is the one of the most suitable technology that can be acquired by the India in era of self-dependency in the field of energy sector. In India almost 9 CSP projects are in working and producing power but the shortcoming is that no one is in central India region.

The pre-feasibility study for the central India region for the establishment of a parabolic trough power plant is employed in this dissertation work. By using the measured GHI data for 5 cities of central India, Bhopal and Indore are selected with higher solar potential.

Simulation is completed for a 50 MW parabolic trough power plant with 4 hour thermal storage with the help of SAM software. Outputs show that:

- The site of Bhopal and Indore area has the maximum prospective to produce electricity
- The huge dry land around these areas as presented in the solar GIS plot is the key benefit of the above sites.
- Consumption of Fossil fuel can diminish substantial in these areas

There is neither thermal energy storage nor thermal energy transportation possibility. The energy is directly converted into electricity.

Future Scope

The pre-feasibility study for the central India region for the establishment of a parabolic trough power plant is employed in this dissertation work. By using the measured GHI data for only 5 cities of central India, Bhopal and Indore are selected with higher solar potential. As per the future aspects this study can be enlarge on the whole country which will more beneficial to solve the problem of energy crises through solar energy.

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