# Towards the development of the Supply Chain of Concentrated Solar Power

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**Abstract.** This work focuses on the investigation into the planning of renewable energy power plants in Brazil using the Concentrated Solar Power (CSP) technology. The main aim of the paper is to present an analysis of the planning process that can be used as a basis of the development of a method to assess the Brazilian's local manufacturing and supply chain capabilities in supporting the deployment of the CSP technology. The paper identifies areas in which the concerted efforts should be emphasized. For this, the paper will first discuss the key components of the chosen CSP technology (in this case the parabolic through). The manufacturing processes of these components will subsequently be analyzed and the key enabling technologies will be determined. The demands of electricity will be estimated using the System Advisory Model®, a modelling tool developed by the National Renewable Energy Laboratory (NREL). An assessment method will finally be proposed to identify the potentials of the local Brazilian supply chain, through the readiness evaluation of the key enabling technologies and manufacturing processes.

**Keywords:** Energy Supply Chain, Concentrated Solar Power, Manufacturing Readiness, Supply Chain Readiness, System Advisory Model

## 1. INTRODUCTION

The Concentrated Solar Power (CSP) is a technology used to collect sunlight, increases its concentration using mirrors or lenses, and transforms it into heat. The heat is used to produce steam to power a steam turbine that subsequently generates electricity. Due to the high level of upfront investment required for building CSP plants, the Levelized Cost of Electricity (LCOE) generated by the CSP plants tends to be higher than that of the conventional fossil-fuel plants', especially with the relatively low fossil fuels prices of today and expectedly in the short and medium terms. In order to be successful, the deployment of renewable energy plants using a technology like CSP will always rely on the availability of the suitable policy frameworks and incentives provided by the government. Those policies related to the development of the CSP supply chain and manufacturing capacity will be critically needed especially in the early stages of the deployment, as the expected cost of the technology will be reduced as a result of the maturity of the supply chains. Therefore, it is envisaged that these policies must be founded on a comprehensive analysis of these supply chains, which may include the identification of the CSP value chain, assessment of the needs and evaluation of the ability of the local manufacturing and the end-to-end supply chain to support them.

Literature (e.g. Kearney (2010), Deloitte (2011),

European Solar Thermal Electricity Association (2015), and International Energy Agency (2014)) has widely recognized the fact that countries intended to deploy CSP technology must significantly enhance their supply chains, if necessary, through appropriate applications of incentive policies and regulatory frameworks. However, these policies should be founded on a far-reaching analysis that should fulfil not only the needs of the existing CSP supply chains but also the capacity to develop the local manufacturing. This is the area where efforts should be focused on.

Set out from the identified economic feasibility for deploying the CSP technology in Brazil, this paper aims to present an analysis of the planning process of the CSP plants that acts as a basis for the development of a method to assess the Brazilian's local manufacturing and supply chain capabilities in supporting the deployment of the CSP technology. The assessment should identify the future needs, and assess both the maturity and missing elements of the existing supply chain and the capacity to generate these.

## 2. PREVIOUS WORK

Gereffi et al. (2008) identified the CSP value chain in a study that also evaluated the impacts of CSP in job creation in the USA. In their analysis, the value chain of CSP was described as evolving due to the novelty of the industry (Gereffi et al., 2008). The analysis also punctuated the high level of integration of the value chain. The components used in CSP technology, as well as the key global players and suppliers were identified. Though the study analyzed the potential job creation by identifying the needs in construction and operations, it did not take a closer look into the needs and capacities to manufacture the components locally.

Braun et al. (2011) identified the CSP value chain in the analysis of the innovation trends of the industry. Parallel to that work, Gazzo et al. (2011) conducted their study to identify the capacity of the Middle East and North Africa (MENA) region in developing a local supply chain of CSP components. Their analysis provided an insight into the CSP technology and how the components can be mass manufactured. Servert and Cerrajero (2015) built upon the MENA study and identified the manufacturing supply chains in which Egypt could participate. This analysis was performed through the assessment of the existing CSP supply chains in Egypt and the identification of the potential markets. Retana Herrera (2013) looked into the supply chain opportunities within a Saudi company. The study provided a better understanding of the manufacturing processes involved and the complexity of the technologies, pointing out that the analysis performed was eminently based on the technological analysis performed.

The Energy Sector Management Assistance Program

(2013) identified the need to develop a local CSP supply chain, to support the development of the solar energy plans put in place by the government of India. The study followed a similar path to the one carried out in the MENA region. It started off by performing the SWOT analysis of the related industries and the capacity to develop these components in India; and concluded with the definition of the incentive policies that could lead to the development of the local supply chain.

In the context of Brazil, a recent study by Schaeffer et al. (2014) also identified the global CSP value chain. They pointed out that, so far, Brazil only participated in the first stage as a supplier of raw materials, despite the fact that the country plans to construct three CSP plants. A study by Soria et al. (2015) estimated the technical feasibility of deploying CSP plants and built the case of hybridized CSP-Biomass plants. In this respect, Schlipf et al. (2014) identified some companies and groups that could help deploy the CSP technology in Brazil. The vast majority of these companies are subsidiaries of multinational enterprises with wealth of experience in the solar industry, although some are in fact construction and procurement companies specializing in the infrastructure.

The aforementioned literature has identified that the maximum benefits are gained when local supply chains are developed. However, there seems to be little work that has been done to analyze the supply chain of CSP. Due to the relatively immature technology whose value chain still continues evolving, CSP technology must be characterized at a global level in order to identify all the key players and to analyze the technologies involved. Specific to Brazil, this kind of assessment appears to be lacking.

## 3. RESEARCH METHOD

The ultimate aim of the work described in this paper is to explore an alternative for an assessment of the capability of the local manufacturing and supply chain in Brazil. The assessment should ideally identify future needs of the technology and pinpoint both the maturity and missing elements in the existing supply chain. This is an ongoing work, thus the results reported herein are in progress. Nonetheless, they should lay the foundation that is critical for the next steps in the research project, namely the field study. The step-by-step research process so far consists of three main activities: *understanding the CSP technology*, *defining the value chain* and *estimating the demand*. The *assessment of the local manufacturing and supply chain* completed the steps and set out the future direction of the research. The data have been collected from academic and commercial literature and numerous meetings (small workshop) with the process experts.

## 4. CSP TECHNOLOGY

As mentioned briefly at the beginning of this paper, the basic process used in CSP plants comprises collecting the sunlight using a collector mechanism that concentrates the sunlight on to a receiver. The receiver then uses the concentrated sunlight to heat a heat-transfer fluid, e.g. molten salt. The heat is then used to power a classic thermodynamic cycle of a steam turbine.

CSP plants typically use one of the four sun-collector technologies: Linear Fresnel, Parabolic Trough, Solar Tower and Parabolic Dish. These technologies, in principle, differ in in the way they concentrate the solar rays but for more details on these, readers are advised to refer to Kearney (2010) and the International Energy Agency (2014). The project in this paper uses the parabolic trough.

CSP plants, except parabolic dish plants, have three main components: the solar field, the thermal storage and the power block. The solar field collects sunlight and transforms it into heat. The thermal storage stores the heat to be used when there is no sunlight. The power block transforms the heat into electricity. Figure 1 shows a simplified graphical representation of the parabolic trough.
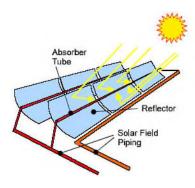
Figure 1: Parabolic Trough

## 5. ESTIMATING THE DEMAND RATE

The estimation of the demand rate is carried out at three levels: the overall electricity (power) demand, the component demand per plant and the overall demand of key components, affected by parameters related to the operation failure rates and construction issues.

### 5.1 Estimation of the component demand per plant

The electricity demand, correlated with the deployment rate of CSP plants, had to be translated into the component demand. Following the method proposed by Soria et al. (2015), a 30 MW parabolic trough plant was chosen as a reference.

The demand rate was estimated using the System Advisory Model (SAM) developed at the National Research Laboratory (NREL). Using the location, plant size (power), thermal storage size and component characteristics as input parameters, the number of loops, plant size (land) and volume of the thermal storage were obtained as the outputs of SAM. The simulation parameters used were obtained from the feasibility study carried out by Soria et al. (2015). These parameters range from geographical location parameters to technical parameters.

The input parameters used to identify the number of parabolic troughs of the plant include: the ultimate through parameters, location parameters, solar field parameters, receiver parameters and power block parameters. These were used by the software to identify the number of loops required to collect the heat to power the steam turbine. Figure 2 shows the output screen of the software.

In the first stage, the number of solar loops indicates the number of solar collector assemblies (SCA) needed for the specified solar field. In this case, the field had 14 loops, each has 8 SCAs; in total of 112 SCAs.

In the second stage, the data extracted were used to estimate the total length of the tubes necessary to pipe the solar field. To do so, the field was divided into two subsections, each with 7 loops. Each loop was divided into 2 sections, composed of 4 SCAs each. The calculations were done, assuming a distance between troughs of 15m and 24m long troughs. The total size calculated was 324.2m x 1,962.4m. Figure 3 shows the sketch of the CSP field.

### 5.2 Estimation of the total component demand

The estimation of the installed capacity and the electricity demand were combined with the estimated component demand, to identify the total component demand. This demand forecast was programmed on a spreadsheet following algorithm:

- Step 1: extract demand curve
- Step 2: extract the installed power at the end of year
- Step 3: identify the number of plants connected to the grid per year (plant demand)
- Step 4: identify the demand of the key components for new plants
- Step 5: identify the demand of the replacement of the key components.

Due to the lack of forecasts for the yearly installed capacity, it was necessary to identify a mathematical expression that described the demand curve. The forecasts for the global deployment of CSP depict a polynomial curve. The expression could have the same degree of freedom as the available data, or it could have less. In latter case, the expression would need to be estimated with the minimum quadratic fitting method. However, as the amount of data available was small, the polynomial expression used was deemed sufficient.
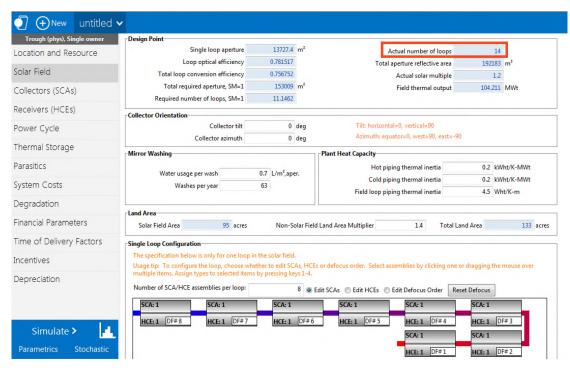
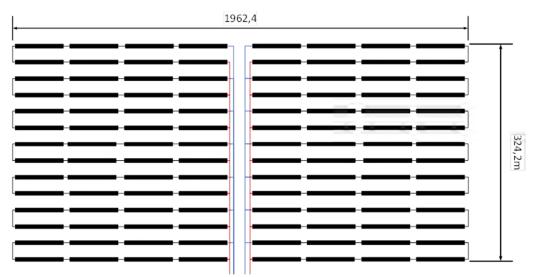Figure 2: Solar field design screen



Figure 3: Solar field schematic

The installed capacity was estimated for the forecast years using the expression that was calculated previously. The expression was valid for the period between the first and the last year. Outside this timespan, the data would need to be extrapolated outside the limits of the equation and so should not be used. However, for 2 or 3 years after the last forecast year, the error margin was small enough to be used in the estimation made.

The number of operating plants at the end of each year was estimated by dividing the installed power at the end of each year by the plant size, which was an external input for this stage. This number was then rounded to the nearest whole number.

The key data to estimate the component demand were the number of plants connected to the grid each year. This was obtained by subtracting the estimated number of plants operating at the end of the previous year, to the number of operating plants being analyzed at the end of the year.

## 6. RESULTS

The previous section showed the forecasts for the CSP plants in Brazil, which led to the identification of four different scenarios (Figure 4) and a reference plant. This reference plant was modelled in SAM, from where the number of loops and volume of the storage was extracted. These parameters were combined with the bill of materials to estimate the component demand per plant.
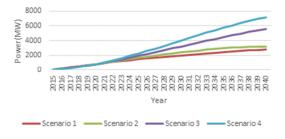


Figure 4: Installed Power

The deployment forecasts were then transformed into yearly forecasts of the operating plants (Figure 5), plants commissioned (Figure 6), and mirror demand (Figure 7). This was combined with the plant component demand and a series of construction and operation parameters to estimate the total demand of key components.
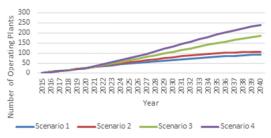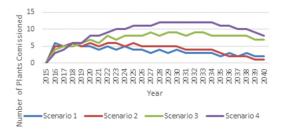


Figure 5: Operating plant at end of year



Figure 6: Plants commissioned

Significant differences can be seen in the demand curves for the four different scenarios. While in Scenario 1 the maximum demand of components occurs during the first five years and reduces later, in Scenario 4, the maximum demand occurs between 2030 and 2035. The demand curve of most components in Scenario 4 follows the typical life-cycle demand of consumer products. As a general trend, all components have similar demand curves, with an exception of the receivers (Figure 8), which have completely different demand curves, due to the high failure rate that makes the substitutional demand increases rapidly as more plants are commissioned.
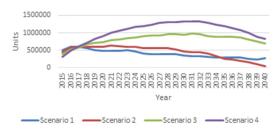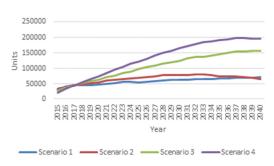


Figure 7: Mirror demand



Figure 8: Receiver demand

## 7. TOWARDS AN ASSESSMENT MODEL

Supply chain includes every company (actor) that has good contact with a product, from manufacturing to logistics. However, in the context of this research, assessing the supply chain is referred to as identifying the manufacturing capability. This was done because the project attempted to develop the national supply capacity, not to create a supply chain for an individual company, and this capability is to manufacture the components, locally.

Identifying a country's potential to build up the national manufacturing capability has been done by conducting the manufacturing readiness assessment (MRA) method (DoD, 2011). This method measures the maturity of the manufacturing capability, and so identifies its state of deployment. MRA has ten levels of readiness (Manufacturing Readiness Level - MRL) from level 1 to level 10; 1 being no degree of maturity, and 10 being totally mature and the manufacturing facility is working at a full production rate. At each level, there is a milestone to be achieved before moving up the next level.

In order to better capture the project requirements, slight modifications to the milestones had to be done, as there was a need to capture the *evolutionary state* (transition) of the existing local supply chains, leading to a definition of the level zero. This level will assess the

capability to develop the component or technology *locally* before starting the full scale production.

Level zero is further divided into 7 sub-levels; each of which identifies the state of development of the sustaining technologies in the country. Sub-level 0.1, for instance, shows the capacity to create a local supply chain is very low, whilst sub-level 0.7 shows a high potential. This assessment also identifies those technologies or areas of technological expertise and experience that will need greater effort or external help. Table 1 shows level 0 and the additional sub-levels to the original MRA (DoD, 2011). The combination gives a total of 11 levels, and 7 sub-levels. Sub-levels 0.1 to 0.7 evaluate the capability to develop an *evolution* of a supply chain, whereas levels 1 to 10, identify the state of development of the existing supply chain.

Table 1: Manufacturing Readiness Levels extension

| Level | Description |
|-------|-------------|
| 0.1 | The country has no technological expertise and experience or capacity to create it. The development of the supply chain will probably rely on foreign investment and players. |
| 0.2 | The country has very low technological expertise and experience or capacity to create it. The development of the supply chain will probably rely on foreign investment and players. |
| 0.3 | The country has some technological expertise and experience or capacity to create it. The development of the supply chain will probably rely on foreign investment and players. |
| 0.4 | The country has a partial technological expertise and experience base or technology creation capacity and will need complementary help to develop the technological expertise and experience in at least half the technologies. |
| 0.5 | The country has a partial technological expertise and experience base or technology creation capacity and will need complementary help. |
| 0.6 | The country has full potential to develop the component, but will need to create technological expertise. |
| 0.7 | The country has full potential to develop the component. |

The assessment method proposed is based on a dual approach. First, potential suppliers of CSP components will need to be identified and for each of the suppliers, assessment will be conducted via a survey using the following algorithms:

- Step 1: Identify potential local suppliers
- Step 2: If local supplier not found, then Go to Step 3 else Go to Step 5
- Step 3: Survey potential local suppliers;
- Step 4: If any supplier has a readiness level over

Level 1, then go to Step 5; else Go to Step 7
- Step 5: For each local supplier, identify potential technological knowledge holders for each component
- Step 6: Survey potential technological knowledge holders
- Step 7: Combine suppliers from Steps 4 and 6.

The second approach is using a survey that is specific for each component and analyzes the local technological readiness. As mentioned before, it identifies the potential or capability to develop a local supply chain by analyzing the expertise that could be sourced locally. To identify this expertise, the survey assesses the key technology areas of the manufacturing and development of the product.

This method does not asses the time, effort or costs of developing the local supply chain. It does, however, provide a measure of the capability of a country to develop the supply chain. As a general consensus, any component whose potential evaluation is above level 0.6 should be sourced locally.

The first survey was developed to assess the *development state of the supply chain of all the components*. This survey is directly related to the manufacturing readiness assessment. It assesses the manufacturing maturity of the manufacturing process of key CSP components, by identifying the components as systems.

The second survey was created to evaluate the *capability to develop a supply chain for all the components*. This second survey is specific for each component, and based on the manufacturing processes and bill of materials. It identifies key areas of technological expertise and experience; and assesses them separately, to identify the degree of development each organization had in each area.

## 8. DISCUSSION AND CONCLUSIONS

The proposed assessment method aims to fill the literature gap. Even though the Brazilian's capacity to develop a local supply chain of components was identified by Schlipf et al. (2014), their analysis was based on the assessment of high level information, such as macro-economic information readily available. Gazzo et al. (2011) demonstrated that the assessment of this capacity is achieved through a complete analysis of the capacity of the manufacturing base to develop the manufacturing processes. They validated this analysis has to be founded of the assessment of information provided by potential players, not only in the analysis of macro-economic information that is readily available. Consequently, the methodology proposed herein, focuses on identifying the capabilities of the country on the supporting technologies.

The assessment, however, does evaluate the capacity

of the innovation mechanisms of the country to help in the development of an emerging industry; which is a path that neither Gazzo et al. (2011) nor the Energy Sector Management Assistance Program (2013) had taken, as they only focused on the industries directly related to the manufacturing processes.

The proposed assessment methodology was, to a large extent, inspired by the based on the manufacturing readiness assessment (MRA) used by the US Department of Defense. This research has extended the MRA by adding a new, level zero aiming at identifying the development capacity of CSP components, whilst the original levels one to ten, focused on the system for which the supply chain was being evaluated. This new level took a deeper look into the technologies that enabled the manufacturing of these components, thus ascertaining whether the expertise was locally available to support the development of the components, systems and manufacturing processes.

The methodology can be used to make local qualitative evaluations of the maturity of manufacturing processes, or to assess the capacity of the local supply chain to provide systems. However, this methodology is suitable for systems that are not a global novelty or at least not completely, but which are being manufactured in other parts of the world. The assessment of completely new systems should rely on the technology readiness assessment methodologies and manufacturing readiness methodologies proposed by NASA and the Department of Defense of United States of America respectively. These same methods should be used to assess global manufacturing maturity and technology maturity evaluations.

The assessment proposed here includes another new element that had not been proposed in previous analyses, the demand estimation algorithm. The results from the algorithm can be used to benchmark the capacity of a country to manufacture CSP key components against the expected demand. The methodology proposed here uses some of these parameters to estimate the demand of components, thus opening a new application of SAM that had not been previously identified in the literature.

Future work will focus on developing the survey instruments, including the hypotheses and conducting the survey to a large number of Brazilian companies.

## ACKNOWLEDGMENT

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