CSP IN BRAZIL

PERSPECTIVES FOR INDUSTRIAL DEVELOPMENT

PROJETO Energia Heliotérmica

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A study produced by the project DKTI-CSP (German Climate Technology Initiative on Concentrating Solar Power), which is managed by the Ministry of Science, Technology and Innovation (MCTI) and the Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The project focusses on the promotion of climate technologies, in particular Concentrating Solar Power. Its objective is to ensure that required conditions to implement and disseminate Concentrating Solar Power are established in Brazil.

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CONTENT

1 INTRODUCTION

Solar thermal power plants for electrical energy production have been built worldwide for several years, with main focus on Southern Europe, North and South Africa and the United States.

The key components of these plants are independent of the used technology: A system of mirrors is used to concentrate the direct irradiation from the sun on a receiver. Inside the receiver system a medium is heated up and transferred to a power block. There, the heat is used to produce steam, which is used in a steam turbine to produce electricity. Using the sun as a renewable energy source, CSP plants are delivering reliable and eco-friendly electricity.

The possibility to implement a thermal storage system is one of the key advantages of CSP plants. Based on the plant setup the storage system could be integrated in each of the big-scale commercially available CSP technologies, shown in Figure 1.

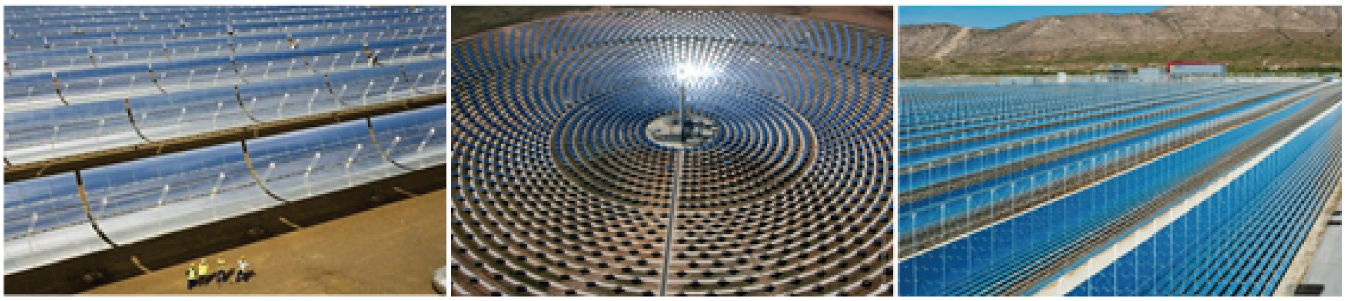

Figure 1: Considered CSP Technologies (from left to right): Parabolic Trough (PT), Solar Tower (ST) and Linear Fresnel (LF)

Energy storage systems have an essential role in every electrical system. Due to the fact that electrical energy must be consumed when it is produced, every energy system needs reliable and flexible energy generation units. Such energy generation units are directly controlled by an operator and called "dispatchable" energy generation units. Additional energy storage systems support the electrical grid by providing the possibility to shift energy over the time. With an increased share of non-dispatchable energy generation units (like wind farms or hydro plants without reservoir) the importance of storage systems rises.

Worldwide, about half of the CSP plants in operation and nearly all CSP plants that are under construction are equipped with a thermal storage system. These figures show that thermal storage systems are an important key feature of the CSP technology. In comparison with other renewable energy generation units, the ability to integrate a storage system is a huge advantage of the CSP plant. For the further development and to ensure the success of the technology, thermal storage systems have a crucial role, providing the ability to supply energy when it is demanded. In order to solve the current demand in Brazil for energy generation units including the possibility to store energy, CSP could be one part of the solution.

Brazil offers a huge potential for the CSP technology. The solar resource, the so called "direct normal irradiation" achieves very good values that are comparable to other emerging CSP markets. Furthermore, these values are achieved in regions that are close to the equator, resulting in very constant optical conditions for the plant operation during a day. Besides the solar resource, Brazil offers a developed industry with a high potential for new and innovative solutions.

Compared to other renewable generation units, the CSP plant consist of several different components. Most of these components needed for the implementation of the plant do not need a highly specific industry. Often only slight adoptions on already existing production lines are necessary to manufacture the different components, resulting in a high local share of the investment in the plant.

Along the value chain of the CSP plant several industrial sectors are active. Besides the classical power plant industry also companies active in the steel and glass industry, chemical and petrochemical companies and of course construction companies are active. As the CSP technology was rising worldwide during the last years, quality standards and automatic production methods are established along the whole value chain.

Main objective of the report is to create a basic understanding of the value chain and the necessary components of the CSP technology. Based on experiences of other countries and the estimated development of the local share, the assumed behavior for the local share of the CSP industry within Brazil is presented.

2 VALUE CHAIN ANALYSIS

To estimate the impact of CSP plants on the local economy, first the value chain of a typical CSP plant project over its whole life cycle is shown in this chapter.

Of course, the main value of the plant is created during the construction phase of the plant. During plant operation (typically around 25 years) additional value is created by operation and maintenance of the plant. The development phase of the plant creates additional value.

The commercial development of the CSP technology is connected with two countries. The United States started the development in the 80s and early 90s, driven by the oil crisis. In 2005 new plants were built in Spain, with a big increase in 2010-2012 in parallel to the increase of renewable energies in Europe. Both developments show some key points and key lessons in the development of the CSP industry and are considered in detail in this chapter.

2.1 VALUE CHAIN FOR DIFFERENT CSP TECHNOLOGIES

In the following chapters, an overview for the value chain is presented. A general overview of the value chain with the key industrial sectors is presented. Afterwards, a detailed analysis of the key components and necessary raw materials is presented.

2.1.1 General overview of the value chain

The general value chain of the CSP plant could be divided into several phases during the development and construction phase. In Figure 2 these phases are shown.

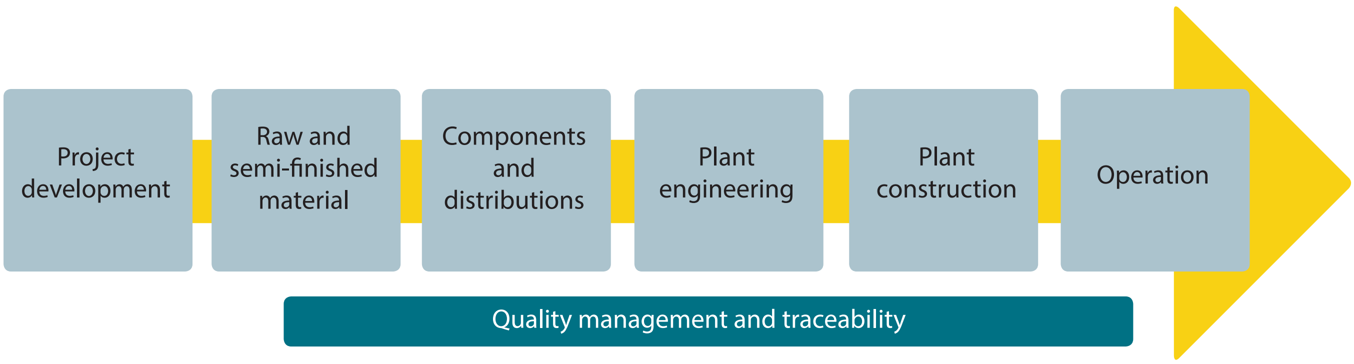

Figure 2: Different phases along the development phase of a CSP plant

The development is very similar to the typical development of a power plant or bigger facilities in the process industry. Besides the owner of the plant there are several key players active:

- *Project development company*: The project manager and the project development company is responsible for the coordination of all preliminary works, permits, environmental analysis, pre-engineering and the negotiations with the EPC ("Engineering, procurement, construction").
- *EPC-company*: The EPC -company is responsible for the engineering and construction of the power plant. All component manufacturers are chosen by the EPC.
- *Component manufactures*: Several components for the solar field are manufactured by different companies. Either as complete product (e.g. heat exchangers), as manufacturer under license

(e.g. support structure) or even as sub supplier for specific parts (e.g. steel tube for absorber tubes).
- *Financial and technical advisors*: Besides the project development, several other advisory companies are active along the value chain during all project steps.
- *Logistics and construction companies*: For the preparation of the infrastructure and the site of the CSP plant construction companies are required. During the construction phase of the plant a lot of raw and semi-finished material and prefabricated components must be delivered to the side, requiring companies with local experience.
- *Operation and Maintenance (O&M)*: After the construction and commissioning phase of the plant, the regular operation of the plant starts. The O&M-company is responsible for the daily operation, regular inspections and maintenance.

The different phases are detailed within the following paragraphs.

Project development

The first phase of a CSP project is the project development. The decision-making process begins with technical and economic feasibility studies, the site selection, and financing opportunities, which provide the basic scope of the project. After drawing up a first draft incorporating these basic decisions, the conceptual engineering of the project starts with a proposal for the technical specifications. Once the conceptual design is established, the permission process and contract negotiations start. These phases are closely interlinked with the financing of the whole project. In current projects, engineering experts specializing in power plant projects offer all the services needed for the project development. Due to the fact that feasibility studies, the permission process, and public decision-making processes take a lot of time, especially for the first plants, this phase is time critical.

Materials

The second phase of the CSP core value chain involves the selection and gathering of the raw materials and further transformed materials. While some materials are provided by the world market, others are supplied locally, depending on costs and logistical aspects. Quantitatively, concrete, steel and glass are the materials most needed for a CSP plant. Other materials like chemicals for the heat transfer fluid or the insulation materials are necessary. For a 50 MW reference plant, for example, about 10’000 tons of concrete, 10’000 – 15’000 tons of steel, and 6’000 tons of glass are required. Concrete and steel could often be provided by local suppliers, depending not only on the raw material quality but also on the local market price compared to the world market [1].

Components

The CSP plant consists of several key components produced independently. For each component, several specific industrial sectors are necessary. The considered components are:
- **Solar field**: Including the mirrors and the related support structure. For parabolic trough and Linear Fresnel systems, also the tracker system with the cabling is considered. For solar tower systems, the heliostats and the cabling are regarded. The solar receivers are not part of this component and included in the following component.
- **Solar receiver**: For line focusing systems (parabolic trough, Linear Fresnel) the receiver tubes are considered in this component. For solar tower systems, the whole solar tower including the absorber at the top of the tower is considered.
- **Thermal storage**: All components necessary for the thermal storage system are included within this component. As current state-of-the-art for long term storage systems, a 2-Tank molten salt system is considered, directly or indirectly

integrated, based on the used technology and the HTF (heat transfer fluid). As main components, the solar salt, storage tanks, heat exchangers (if necessary) and the molten salt pumps are considered.

- **Heat transfer fluid system**: Based on the used HTF-system, different raw materials and production capacities are necessary. For direct steam generating systems, the requirements are similar to the conventional industry (e.g. pressurized vessels and piping, feed water tanks). If a thermal-oil is used as HTF, the material itself (synthetic thermal oil) must be produced, with the obligation to offer a high thermal stability. Also the related equipment like the piping, storage vessels and the pumps must be applicable for the use with the hot thermal-oil over a long time horizon.
- **Power block**: Main part of the power block is the water-steam cycle, usually driven by a heat exchanger, transferring the heat from the solar field to the water-steam cycle. For technologies with direct steam generation, this heat exchanger is not necessary. The steam is used to drive a steam turbine. All necessary auxiliary equipment (called "Balance of Plant") is also included.

Plant engineering and construction

The fourth and fifth phase of the value chain involves the plant engineering & construction. This is performed by the engineering, procurement, and construction (EPC) contractor. The EPC contractor is responsible for the whole plant construction. He often represents also the project manager. Main task of the project manager is to coordinate all partners. The EPC selects all the suppliers and awards most of the jobs to subcontractors. Sometimes, even before the contracting entity chooses the final EPC, candidates have already chosen certain component suppliers due to logistical, time-sharing, or political motivations. Most experienced EPC have a fixed basis of component suppliers that are involved in nearly all projects.

EPC contractors are usually subsidiary companies of industrial groups and can resort to building companies and engineering consultants in their own company group. The civil works for the total plant are also often closely connected to the EPC contractor, as many companies have their own subsidiaries or joint ventures to undertake these tasks. Large infrastructure companies for buildings, power plants, and other infrastructure projects provide the basic services for civil works. For these civil works, and for the assembly and installation of the collectors, a large number of low skilled workers are required on the construction site.

Operation

The sixth phase, operation, includes the operation and maintenance (O&M) of the plant for up to 25-30 years. This is often performed by local sub-contractors. Currently, about 30 people are necessary for the operation and 10 people for the maintenance of a 50 MW CSP plant. The tasks for operation and maintenance can be split into four different groups: Plant administration, operation and control, technical inspection of the power block and the solar field operation and maintenance [1].

Quality management and traceability

With the further development of the CSP technology and the increased installed capacity, new topics like structured quality control of each component or the traceability of components from the supplier and the sub-supplier gain in importance. Besides the thermal or optical performance of each component, also the long term stability of the different components is an essential part of the quality control.

Especially for components with a high value for the performance of the plant (like solar receivers or parts of the power block) it is important for the operational company of the plant, to trace these companies. In case of a failure, the supplier must be able to offer sufficient and precise information about the productions process for the component, including all sub-suppliers. This traceability of the component is well known to other industry sectors (like the automotive sector).

Summary:

- The value chain of a CSP plant could be divided into three main phases: project development, construction of the plant and operation and maintenance of the plant.
- Especially in the construction phase several different industrial sectors are active along the value chain.
- The CSP plant itself consists of several different components.

2.1.2 Industrial view on the value chain

The scheme shown in Figure 2 is divided in the relevant industrial components for every CSP plant: the HTF-system, the solar field, power block and thermal storage system. For each component the mainly involved industry section are given with Figure 3. This overview of the value chain for all relevant components is similar for every CSP technology.

Especially for the production of the different components of the CSP plant, special production processes or adapted production methods are necessary. Nevertheless the main know-how and equipment of already existing facilities could (and must be) used in order to be competitive.

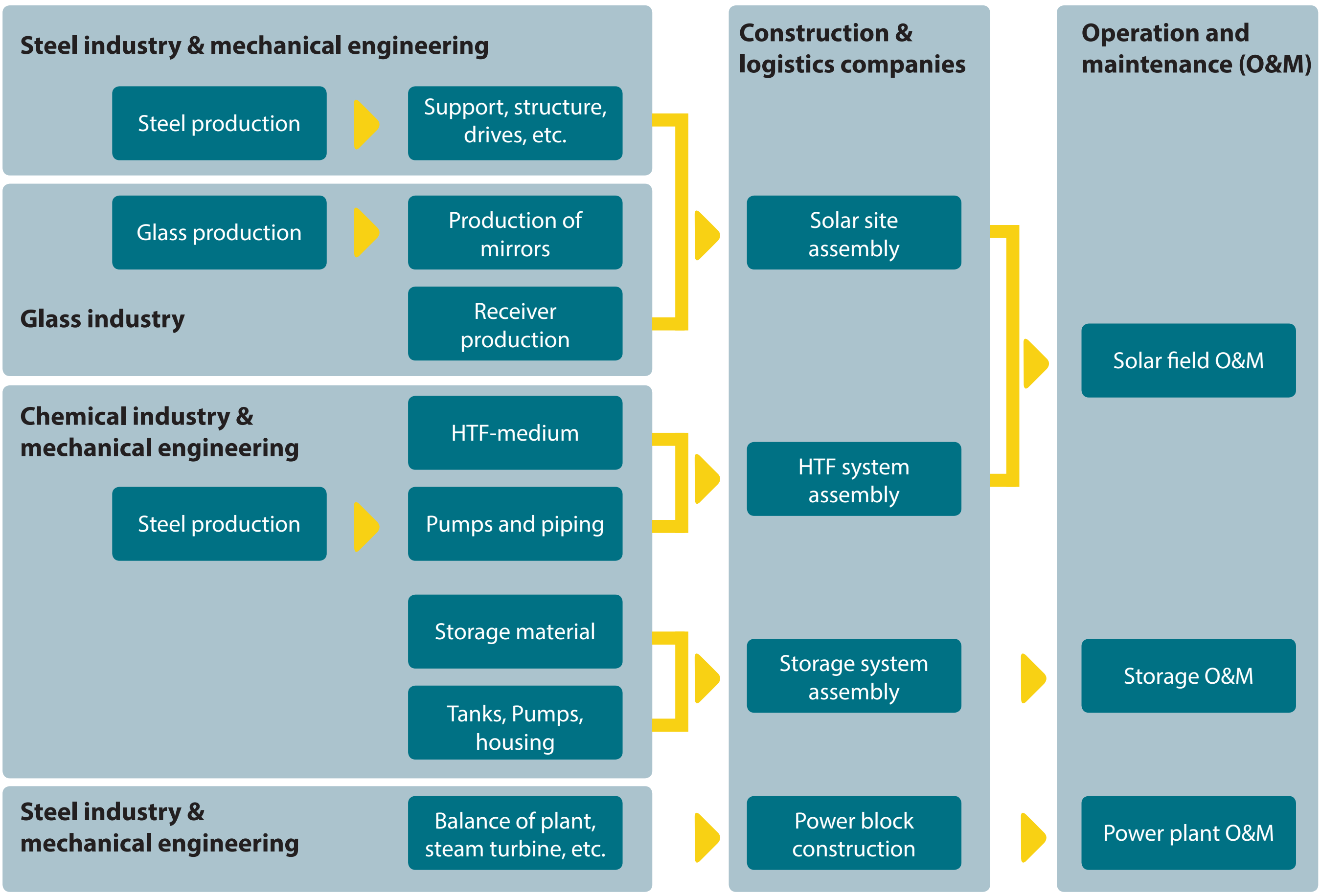

Figure 3: Overview of all industrial components related to the CSP plant

Mechanical Engineering companies and companies from the steel industry are the main players producing the components for the CSP plant, especially regarding the power block. Companies from the glass industry and the chemical industry are involved in specific components of the plant (e.g. the solar field). With the construction of the plant at the site, companies active in the logistics and construction sector are active.

Besides the production companies, also several service, engineering and consulting companies are active along the value chain of the CSP plant, shown in Figure 4.

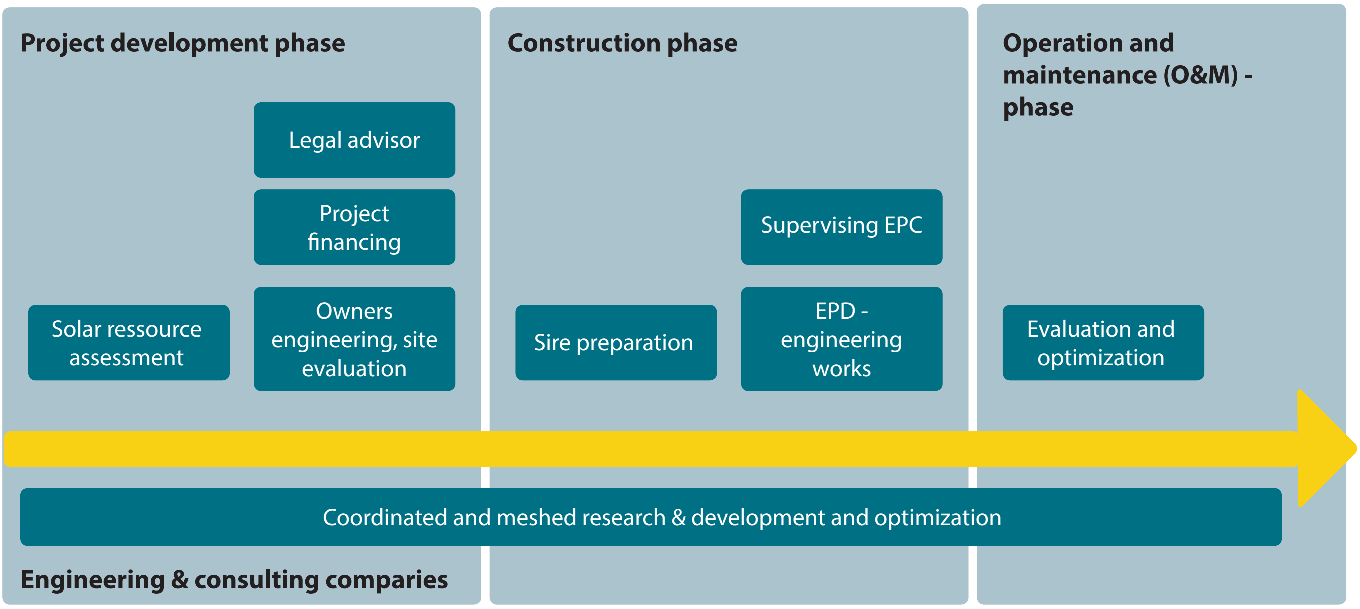

Figure 4: Overview of all engineering services related to the CSP plant

During the development of the project, engineering companies are providing the first data about the solar resource and the boundary conditions. Several consultants active in the different sectors (legal, financing, technical) are active in the contract management of the plant. During the construction phase, engineering and supervising works are necessary. With the operation phase, a continuously monitoring and optimization of the plant should be performed, in order to improve the operation of the plant and gain experience for new plants.

2.1.3 Special items for different technologies

Each CSP technology consists of several special items, influencing the value chain. Within this chapter the main components influencing the value chain are described.

Solar field

For all types of CSP plants mirrors are needed that are mounted on a steel support structure. Based on the used technology, the principal design of the support structure differs. With Figure 5 the different designs of heliostats (for solar tower), solar collector element (SCE, parabolic trough) and primary reflector module (Linear Fresnel) are shown.

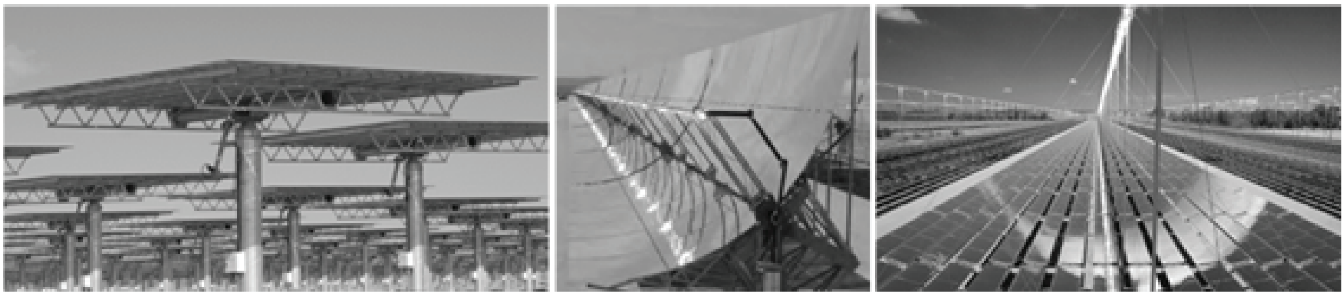
Figure 5: Solar field components: Heliostats (left), SCE (middle) and primary reflector module (right)

Common to all three solar reflectors is the simple construction. A steel support structure is used to hold the mirrors and to provide the tracking possibility. The mirrors are mounted on this structure. The steel support structure is designed in a very easy but robust way in order to provide the necessary stability of the system against wind load and to enable a local assembly nearby the side.

For parabolic trough systems, the mirrors must be bended and further processed in order to allow the assembly at the site. This additional bending process must be included into the value chain for the mirror production, shown in Figure 6.

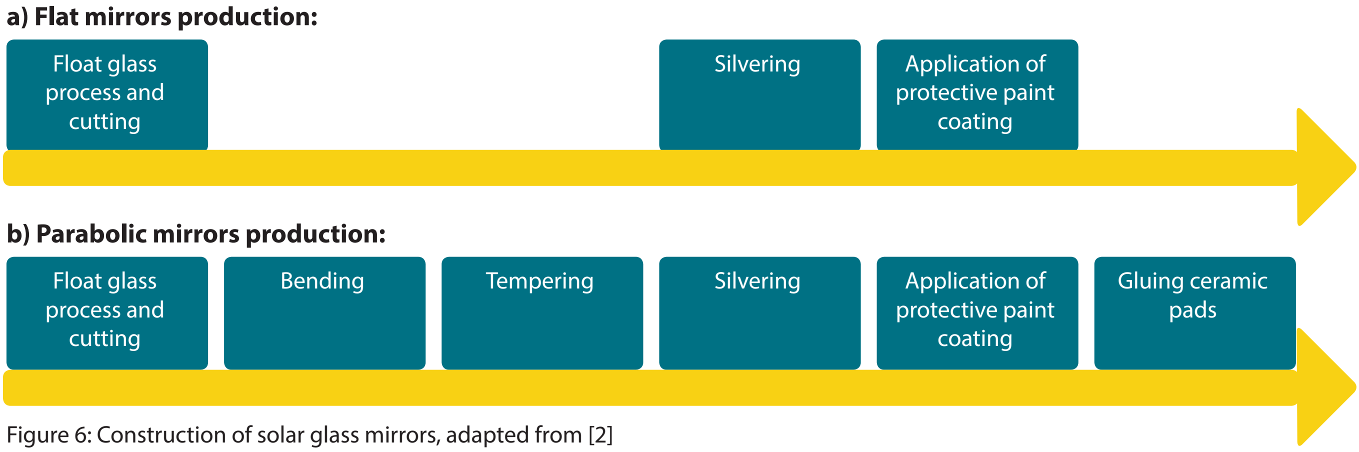

Figure 6: Construction of solar glass mirrors, adapted from [2]

Especially for the bending process, high demands on the accuracy are necessary, in order to guarantee a high optical efficiency. No matter which technology is used, the reflectivity of the mirrors must always be very high. Big market players like *Flabeg* or Saint-Gobain offer mirrors with a reflectivity of more than 94% with a thickness of 2 mm and 93% with a thickness of 4 mm [3]. The bending process and especially the accuracy of the bending, is a critical process step and has a high influence on the optical efficiency of the whole solar collector element. A better optical efficiency has a direct influence on the electricity yield of the plant and is therefore resulting in lower electricity production costs.

The current state of the art CSP plant uses mirrors with the following sizes [3]:

- *Parabolic trough*:
  - Dimensions: up to 2030x2010 mm
  - Thickness: 4 mm
  - Exemplary demand (*Andasol*, Spain): Around 574’050 m^2 surface area necessary for a 50 MW plant with 8 h storage (thermal oil and molten salt storage), resulting in more than 210’000 mirrors.
- *Solar tower*:
  - Dimensions: up to 2000x2250 mm
  - Thickness: 3-4 mm

- Exemplary demand (*Crescend Dunes*, USA): Around 1’209’341 m² surface area necessary for a 110 MW plant with 10 h storage (direct molten salt), resulting in more than 365’800 mirrors.

• *Linear Fresnel:*
  - Dimensions (Novatec): 5350x750 mm
  - Exemplary demand (*Puerto Errado II*, Spain): Around 302’000 m² surface area, necessary for a 30 MW plant without storage (direct steam generation), resulting in more than 75’000 mirrors.

The high reflectivity for the CSP mirrors could only be achieved by using highly pure or “white” glass. This type of glass is also used for PV-cells. The main resource to manufacture this glass is low iron sand, either as natural resource or as iron-reduced industrial sand produced with special equipment. Based on [4] such sand resources could be available in the south of Brazil. An overview of the production sites is given within Figure 7.

1. Bofete
2. Rio Claro
3. Analândia
4. Descalvado
5. São Simão
6. Araquari
7. Imbituba
8. Jaguaruna
9. Campo Largo
10. Viamão
11. São Gonçalo do Rio Abaixo
12. Itaquitinga

Figure 7: Location of industrial sand mines in Brazil [5]

The steel support structure necessary for the SCE consists of different parts, mostly made of common galvanized steel. There are also some developments using recycled aluminum. Based on the developed SCE technology, different designs of the support structure are possible. Nevertheless the basic material necessary could be manufactured in the steel industry. For a typical SCE like the Skal-ET 150, manufactured by *Flagsol*, the torque box and the support arms for the mirrors are made of square tubes, equal angles, profiles and plates.

The main part of the SCE is formed by the torque box, providing the basis of the whole solar collector and the connection to the foundations. The cantilever arms holding the mirrors are connected with this torque box, as well as the support elements for the solar receiver tube. The whole support structure is mounted on the side with a so called “assembly rig”, exemplary shown within Figure 8. The overall manufacturing process could be arranged along an automatically assembly line [6].

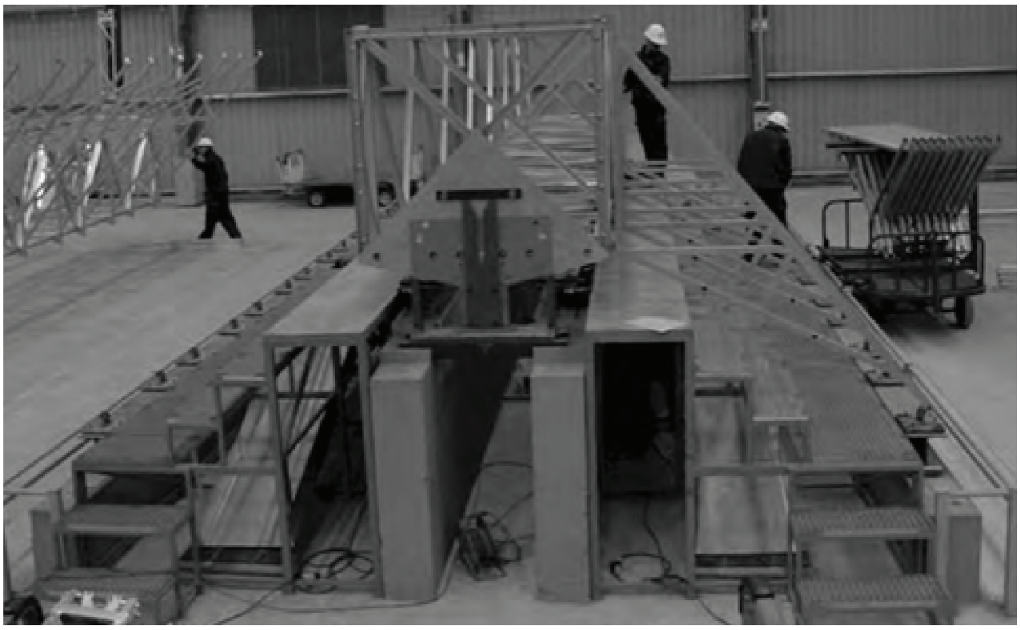

Figure 8: Exemplary assembly rig for a SCE (here *Flagsol*) [6]

For Heliostats (necessary for solar towers) automatic assembly systems have been constructed and used in the last years for a solar tower project in the US. For the Linear Fresnel system of the German company *Novatec* an own automatic production center was created, allowing an automated production of the mirrors and the support structure at the side.

The assembly lines use technologies and components similar to the automotive industry and are scalable to the project size. It is suitable to establish the assembly lines close to the project site to utilize local labor and minimize transportation cost. Logistical and transport advantages are a by-product of establishing manufacturing factories in target market regions close to the solar field. Special transport frames ensure that reflector components are delivered to the assembly site undamaged, meaning only slight adaption to local logistic companies.

Heat exchanger

In the CSP plant several heat exchangers are necessary, to transfer the heat from the HTF to the thermal storage system or the power block. Based on the used process several heat exchangers with different challenges are necessary:

- *Thermal-oil as HTF and molten salt as storage material*: For this very common CSP system, two different heat exchanger groups are necessary. One heat exchanger train transfers the heat between the thermal oil and the molten salt The heat exchanger group for the heat transfer between molten salt and HTF consist of several shell and tube heat exchangers connected in series. The used steel alloys have to be resistant against the molten salt and the HTF. Furthermore the equipment has to withstand low pressures in the range of 20 bar at temperatures up to 400 °C. The second heat exchanger group is the steam generator, transferring heat from the thermal oil into the water-steam cycle producing super-heated steam. Here, pressures of up to 100 bar and temperatures up to 400 °C have to be handled.
- *Molten salt as HTF and storage material*: For this CSP system, often used in solar towers, only one heat exchanger group is necessary, transferring the heat from the molten salt to the water-steam cycle. By using molten salts as heat transfer

medium higher temperatures can be achieved resulting in more efficient power plant cycle. The used solar salt consists of a mixture of sodium nitrate and potassium nitrate. Due to the chemical and physical characteristics of the solar salt mixtures, special measures have to be considered in the design of the molten salt heat exchangers like trace heating or special draining concepts to avoid freezing of molten salt, abrasion, corrosion or aging of molten salt in contact with oxygen. As molten salt based systems are also used as heat transfer medium in the chemical industry, too, often specific knowledge and products are already available. For example, molten salts are used in the production of melamine, alumina and aluminum and for the purification of sodium hydroxide (caustic soda).
- *Air as HTF and solid storage material*: For this CSP system, implemented at the solar tower in Jülich, only one heat exchanger group is necessary, transferring the heat from the air to the water-steam cycle. This heat exchanger is similar to heat recovery steam generators used in the conventional power plant business.

Thermal storage

Based on the used technology, the value chain for the thermal storage system differs. In general, the storage vessels and the auxiliary systems are similar to industrial applications and needs. Therefore these components could be produced locally with minor adaptations of already existing manufacturing processes.

For the storage material itself, the availability of the raw material is important for the local content:
- *Solar salt*: The solar salt consists of a mixture of potassium nitrate and sodium nitrate. Both raw materials are only available at certain places, like Chile or China. The market is dominated by a few players. The raw material prices are very high, resulting in high prices for the storage system itself. For "state-of-the art" molten salt systems, the storage material is representing around half of the total value.
- *Solid material*: Based on the used storage technology, the storage material is locally available. Especially storage systems based on rock or sand are easily locally available. Ceramic based systems have a special structure, e.q. honeycomb, requiring special manufacturing processes. These processes are similar to indus trial applications necessary like regenerative thermal oxidizers (RTO) or exhaust air treatment.

Based on the market framework in Brazil, only CSP plants with thermal storage are applicable and might be realized in a sensible way. Therefore, this part of the CSP value chain is one key element for the further development of the technology in Brazil. It must be emphasized that experienced local companies are able to enter this sector very easy and can develop own storage developments for the specific Brazilian needs.

Key challenge of the molten-salt storage is the solar salt itself. There are only a few companies worldwide able to deliver the necessary nitrate salts. The market is dominated by the company *SQM* (Chile).

Conclusion:

- Different components of the CSP plant have different requirements on the local industry.
- The mounting structure for the mirrors requires only basic steel construction skills and should be produced near the CSP plant.
- Especially the bending of the bending of the mirrors and the heat exchangers requires experienced manufacturers and are crucial features for the performance of the plant.
- The storage system is the key element for Brazilian CSP projects and local companies should be encouraged to develop storage systems for the Brazilian needs.

2.2 DEVELOPMENT IN OTHER COUNTRIES

Within this chapter the exemplary development of the CSP industry in two selected countries is described. With Spain and the United States of America, the both currently leading countries related to installed capacity and industrial capacities were chosen.

2.2.1 Spain

The development of the CSP plants in Europe is strongly connected to the development in Spain. As only the countries in the south of Europe offer a good solar irradiation, a big amount of commercial plants has been realized within the past years. Among them, only pilot or demonstration plants have been built in the other European countries so far (e.g. Germany, Italy and France).

2.2.1.1 Generation mix

Traditionally the electrical energy production in Spain has been depending highly on fossil energy sources, like in most European countries. As the following graph of the past two decades Figure 9 shows, usually more than one half of the annual electricity has been produced by combusting fossil fuels.

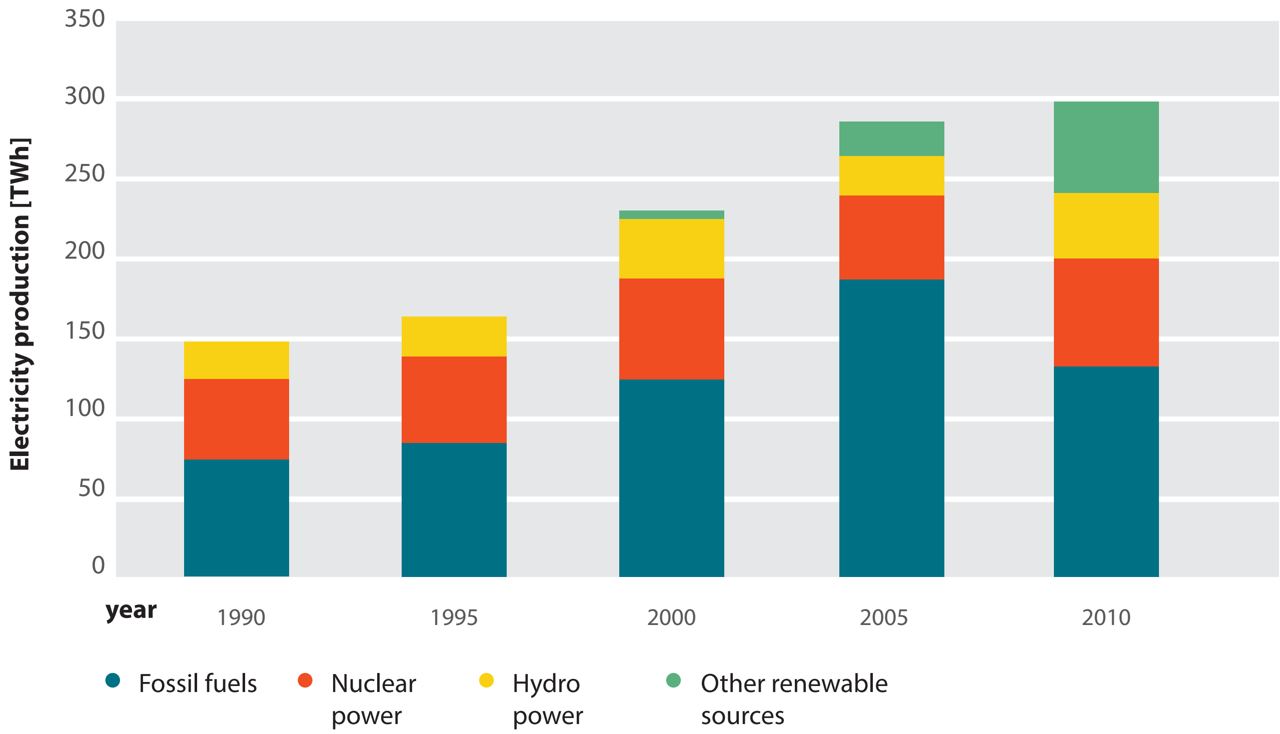

Figure 9: Electricity Production in Spain by Source, 1990 to 2010, based on [7]

But recently the environmental awareness has caused a change of thinking in the electricity production of many countries: Because the combustion of fuels is releasing CO_2, alternative energy sources are needed.

Another aspect is that almost all of the fossil fuels (except part of the coal) have to be imported from other countries, causing a high dependency. Looking for alternatives to fossil fuels would also reduce this dependency.

One option is to use nuclear power instead. Spain's nuclear power plants supply currently about 20% of Spain's electricity. As the Figure 9 has shown, their production has remained almost unchanged for the last 25 years. All of them were built in the 1980s and there has been no new construction of nuclear power plants since then, because of the risks involved in this technology. The government wants to run the existing plants until their licenses expire (in 2020/2021) as a bridge technology until renewable energies can cover the demand.

Spain started to use renewable energies on a large scale, when they built dams with hydroelectric power plants in the 1960s with capacities from 200 to 1,000 MW. Until the late 1990s hydro power was the only renewable energy source notably used.

But Spain has favorable conditions for the use of solar and wind power as well. After Spain started to subsidize renewable energies in 1997, many wind and photovoltaic power plants have been built. But a high share of wind and photovoltaic in the generating capacity can cause problems, due to their lack of controllability. Because of that it is necessary to always have some power plants with controlling capabilities, e.g. CSP with storages. Nevertheless, the possibility to use a limited share of additional conventional firing with natural gas (under 15%) allows Spanish CSP plants an operation without additional storage. In Spain, nearly half of the installed CSP capacity is equipped with a thermal storage system.

The first power plant using CSP was built much later, in 2007, after subsidies also for solar thermal power plants were guaranteed in 2002.

Summary:

- Traditional Spanish energy mix has a high share of fossil fuels; Spain has to import most of its fossil fuels.
- Environmental awareness: Need for alternative in electricity production without CO_2.
- Nuclear power is considered as bridge technology, until renewable energies are developed.
- Increase in share of renewable energies in Spain due to high subsidies.

2.2.1.2 Development of CSP

In 2013 2.2 GW of operating CSP was installed in Spain. Worldwide 2.9 GW of CSP was installed at the same time. So in total 76% of the world's CSP plants were located in Spain.

The graph in Figure 10 shows the development of the installed CSP capacity in Spain. From 2007 until 2012 the capacity increased extensively, with a slower increase in 2013.

There are several reasons for the steep rise of CSP in Spain [8]:

- Large solar irradiation
- High subsidies for CSP (described in detail in chapter 2.2.1.3)
- Support for research on CSP since the 1970s

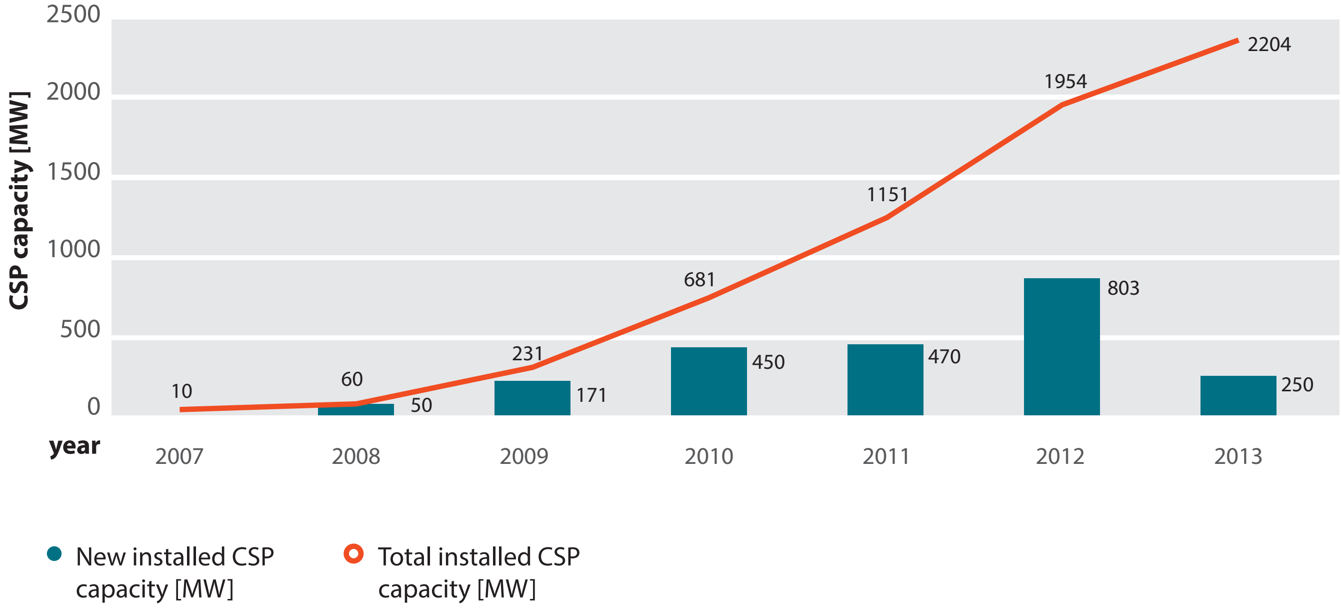

Figure 10: Development of installed CSP capacity in Spain, 2007 to 2013, based on [9]

The following Figure 11 shows the average direct normal irradiation (DNI) in Spain and the location of the operating CSP plants.

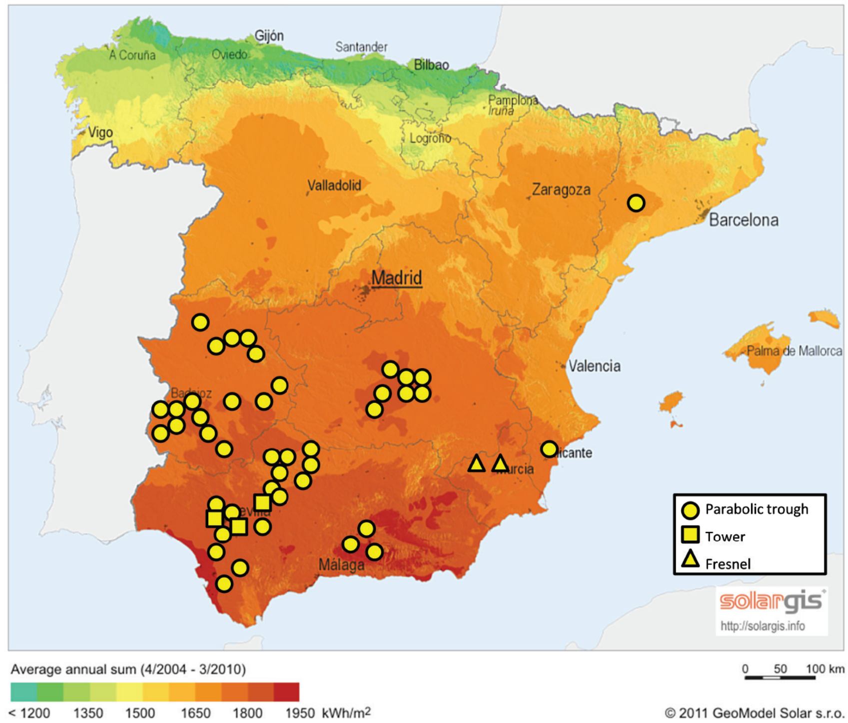

Figure 11: Average direct normal irradiation in Spain with location of operating CSP plants, based on [9] and [10]

The graph shows that the CSP plants are located in areas with high DNI and almost only parabolic trough technology is used.

Because subsidies are limited to power plants with an installed capacity less than 50 MW all CSP plants have a capacity less or equal to 50 MW, even though larger CSP plants are feasible and maybe more cost effective.

The following Figure 12 shows the global CSP capacity in 01/2014 by status:

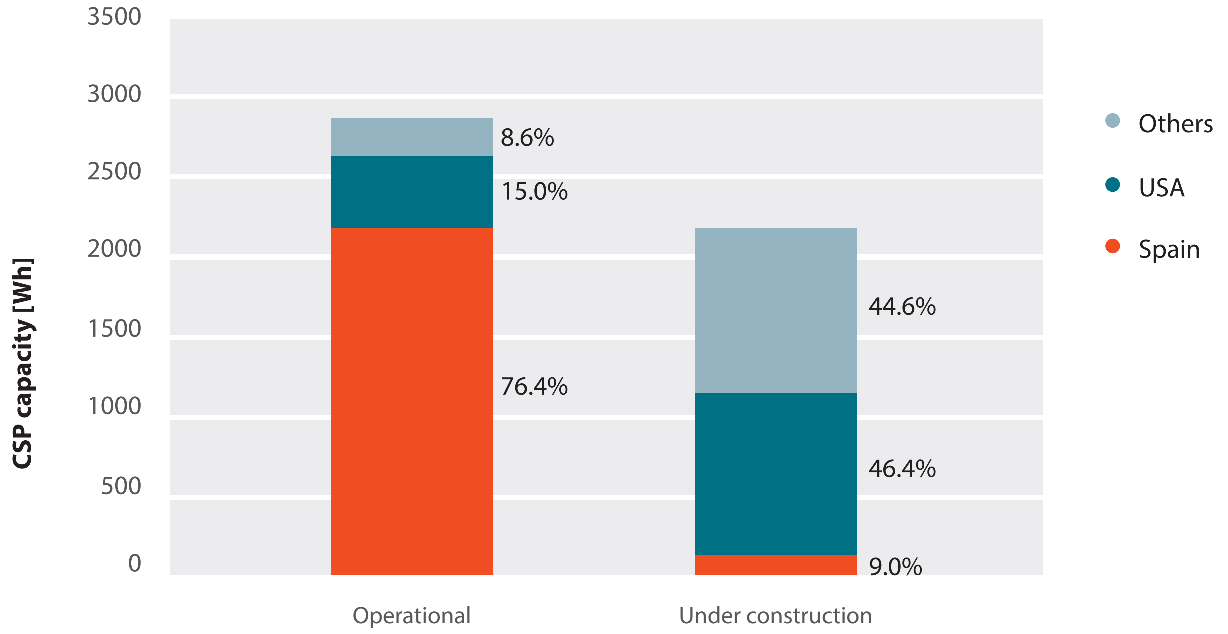

Figure 12: Global CSP Capacity in 01/2014 by status

While 76% of the operating CSP plants are located in Spain, only 9% of the CSP plants under construction are located there. The reason for this severe decrease is a change in the legal framework as described in the next chapter.

Summary:

- Outstanding start of CSP in Spain due to high subsidies.
- Limitation of benefits to plants < 50 MW prevented larger CSP plants.
- In 2013 almost 80% of the world's operating CSP plants were located in Spain.
- But very few new CSP plants in planning or building stage.

2.2.1.3 Legal framework

Spain started to have a law on renewable energies (RE) already in 1980 and introduced with the General Electricity Law in 1997 a special price scheme for RE. This was only possible because of the liberalization of the electricity market. In 1998 premiums paid to RE additionally to the market price were defined, but CSP was not yet mentioned. The following Table 1 shows the most important Spanish laws and regulations between 1980 and 2001 concerning RE. All mentioned laws are online available via the *Boletín Oficial del Estado*(BOE) the official gazette of the government of Spain, or via *Comisión Nacional de Energía* (CNE) the national energy commission.

Table 1: Laws and regulations between 1980 and 2001

Law	Date	Content
Royal Decree (RD) 82/1980	1980/12	- Support of renewable energies
General Electricity Law 54/1997	1997/11	- Liberalization of energy sector - Introduction of special scheme for RE plants < 50 MW: Right of incorporation in grid and premium additionally to market price - Aim: 12% renewable energy sources (of total primary energy consumption) by 2010
RD 2818/1998	1998/12	- Definition of premium to market price for each RE technology depending on annual average tariff (=reference tariff) - Replaced by RD 436/2004

In 2002 a premium for CSP was introduced for the first time. And in the following years up to 2007 the feed-in tariffs for different RE technologies were developed and adapted. Since 2004 the generator was allowed to choose between two options:

a) Sale to distributor at a fixed regulated price

b) Sale on free market at market price and receiving an additional premium plus an incentive for market participation

The following Table 2 gives an overview on the laws and regulations between 2002 and 2008 setting the feed-in tariff for CSP:

Table 2: Laws and regulations between 2002 and 2008

Law	Date	Content
RD 841/2002	2002/09	- Premium for CSP (100 kW - 50 MW capacity): 12.0 c€/kWh
RD 436/2004	2004/03	- Choice between two options: a) First 25 years 300%, then 200% of reference tariff b) market price + first 250% then 200% + 10% incentive of reference tariff - revision of tariffs, when CSP capacity > 200 MW and in 2006
Renewable Energy Plan 2005-2010	2005	- Aim: 500 MW CSP by 2010
RD 661/2007	2007/05	a) First 25 years: 26.9 c€/kWh, then: 21.5 c€/kWh b) Free market premium: First 25 years: 25.4 c€/kWh, afterwards: 20.3 c€/kWh
Spanish Strategy on Climate Change and Clean Energy 2007- 2012 -2020	2007	- Aim: 32% renewable energy (gross electricity consumption) by 2012 - 37% renewable energy (gross electricity consumption) by 2020

CSP reacts slower to changes in the legal framework than many other renewable technologies, e.g. photovoltaic, because the planning and the construction needs more time, as each CSP plant is unique.

But generally the expansion of renewable energies was overwhelmingly rapid. Because of that the amount of annual subsidies to be paid increased enormously from 2009 on. The positive effect of a high share of renewable energies became overshadowed by giant expenses, undermining the already weak Spanish economy. In order to constrain the risks of an uncontrollable increase, various regulations have been taken into action since 2009, shown in the following Table 3.

Table 3: Laws and regulations between 2009 and 2013

Law	Date	Content
n.a.	2009/11	- Limitation on annual growth of CSP (< 500 MW/yr)
RD 6/2009	2009/04	- Pre-registration necessary to receive feed-in-tariffs - Financial guarantee necessary as deposit: 100 €/kW (CSP)
RD 14/2010	2010/12	- Additional fee of 50 €/MWh for electricity sold to the grid
RD 1614/2010	2010/12	- Limitation of energy entitled for subsidies, depending on technology and storage capacity of CSP plant
RD 1/2012	2012/01	- No subsidies for new RE plants - Subsidies for running and already authorized plants not affected
Law 15/2012	2012/12	- 7% tax on all electricity generation
RDL 2/2013	2013/02	- No change from option b) to a) allowed - Premium in option b) cut to 0 c€/kWh
Minister of Energy, José Manuel Soria	2013/07	- No subsidies to RE plants - Instead: 7.5% return for RE plants

Up to 2012 the high feed-in tariff from 2007 was still granted, but many additional fees were charged and the electricity subsidized was restricted as shown above.

Many companies had invested in CSP in Spain after being promised high revenues through the feed-in tariff. Constant changes to the legal framework left investors confused and caused finally a decrease in CSP installations.

In January 2012 new power plants were excluded from receiving benefits and in July 2013 even the subsidies for existing power plants were cut. Since then several companies have sued the Spanish government for changes in their laws [11].

Summary:

- Liberalization of electricity market in 1997 opened doors for renewable energies.
- High feed-in tariffs in the beginning.
- Later many limitations and changes of subsidies due to uncontrollable expenses.
- In 2013 severe reduction of benefits, even retroactive.

Based on the development in Spain, three key lessons could be formulated:

» **The amount of subsidies granted should be carefully chosen.**

» **Limits for the plant size should be technical or economical based.**

» **Investors need security.**

2.2.1.4 Economical impact

The economical impact of CSP in Spain is particularly interesting, because the rise of CSP occurred, while the Spanish economy fell. The following graph (Figure 13) shows the contribution of CSP to the Gross Domestic Product (GDP) of Spain in the years 2006 to 2012:

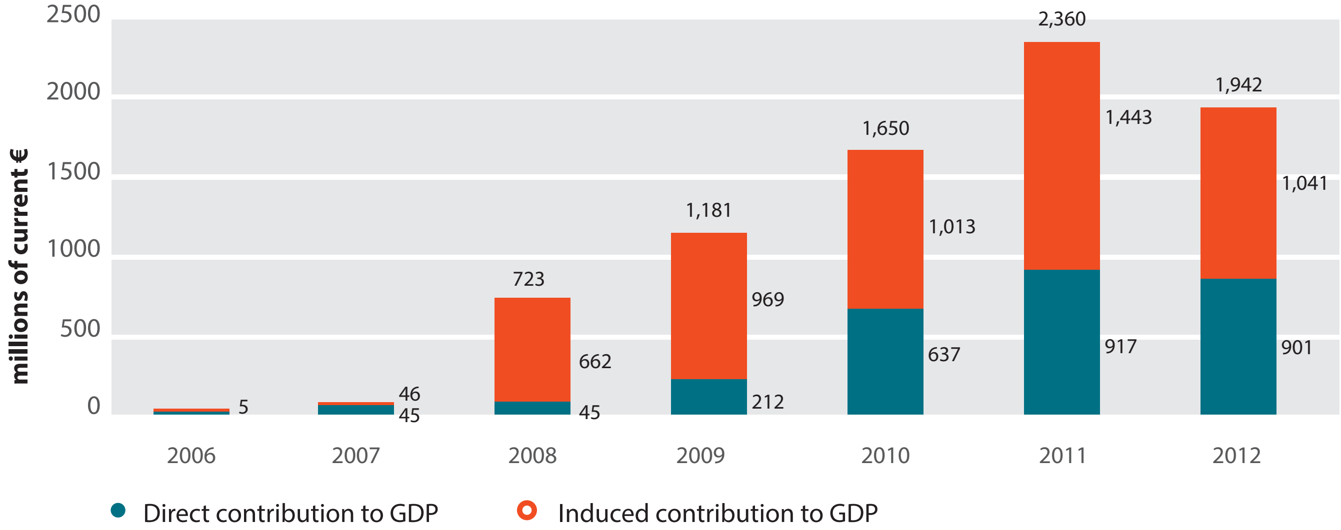

Figure 13: Contribution of CSP to GDP in 2006 to 2012, based on [12]

The direct contribution to the GDP includes all activities of companies which provide specific goods/services to the CSP industry, while the induced contribution shows the additional impact on the rest of the economy derived from the bandwagon effect [8]. The contribution of CSP to the Spanish GDP rose from 0.001% in 2006 up to 0.23% in 2011.

From 2007 on the unemployment rate in Spain has steadily increased up to over 27% in 2013. At the same time the CSP sector employed a growing share of people, with up to 34'000 people in 2011. The number of employees by CSP and the unemployment rate in Spain is shown in the following Figure 14:

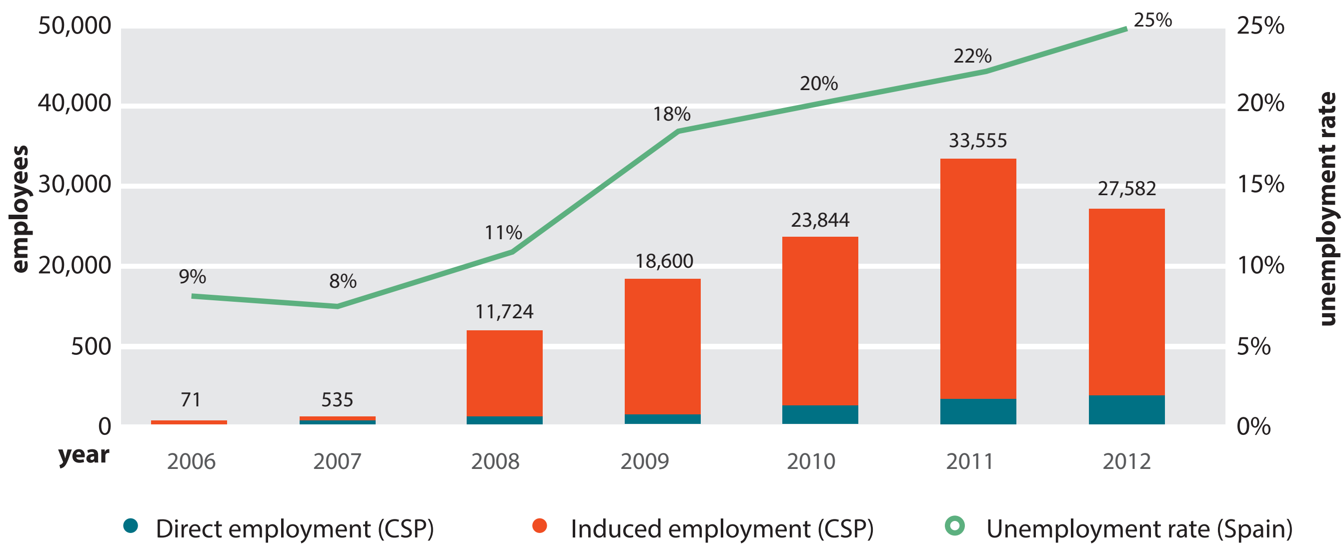

Figure 14: Employment through CSP in 2006 to 2012, based on [12]

Direct employment includes all jobs directly related to constructing and operating the CSP plant, while induced employment also includes jobs derived from the bandwagon effect on the rest of the economy [8].

The CSP sector employed people during an economically difficult time in Spain. Most jobs were created in areas and industries highly affected by the economic crisis.

But critical voices say, that the money used to subsidize renewable energies, could have created much more jobs, if it would have been spent on something else [13].

Figure 15 shows the distribution of jobs between the construction and the operation period. When analyzing the figure, it is important to mention, that in the years shown many plants were still under construction, while few were already operating. When looking only at one exemplary 50 MW CSP plant, about 2'200 jobs are available during contract and construction period, while during operation period only about 50 jobs are available, which equals 98% to 2% respectively [8]. A CSP plant needs generally a lot of people for constructing, but few for operating and maintaining it. One big advantage of CSP is that most of the jobs are close to the construction site, providing local jobs.

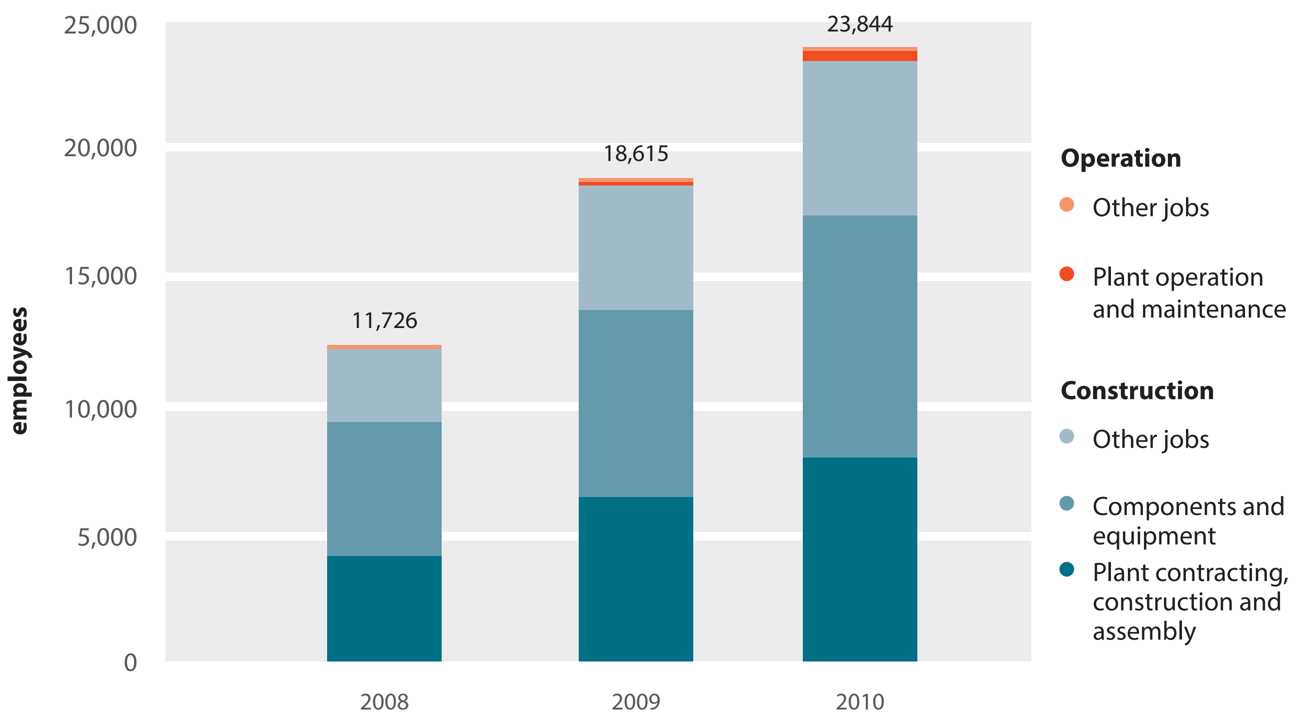

Figure 15: Employment through CSP by sector in 2008 to 2010, based on [8]

When looking at the economical impact of CSP in Spain it is also important to look at the local content, therefore the percentage of investment which remains in Spain. Because Spain has been using mainly fossil fired thermal power plants, they have great knowledge n leading thermal power plants. Figure 16 shows the development of the local content in the CSP industry for CSP plants with and without a thermal storage from 2008 to 2010:

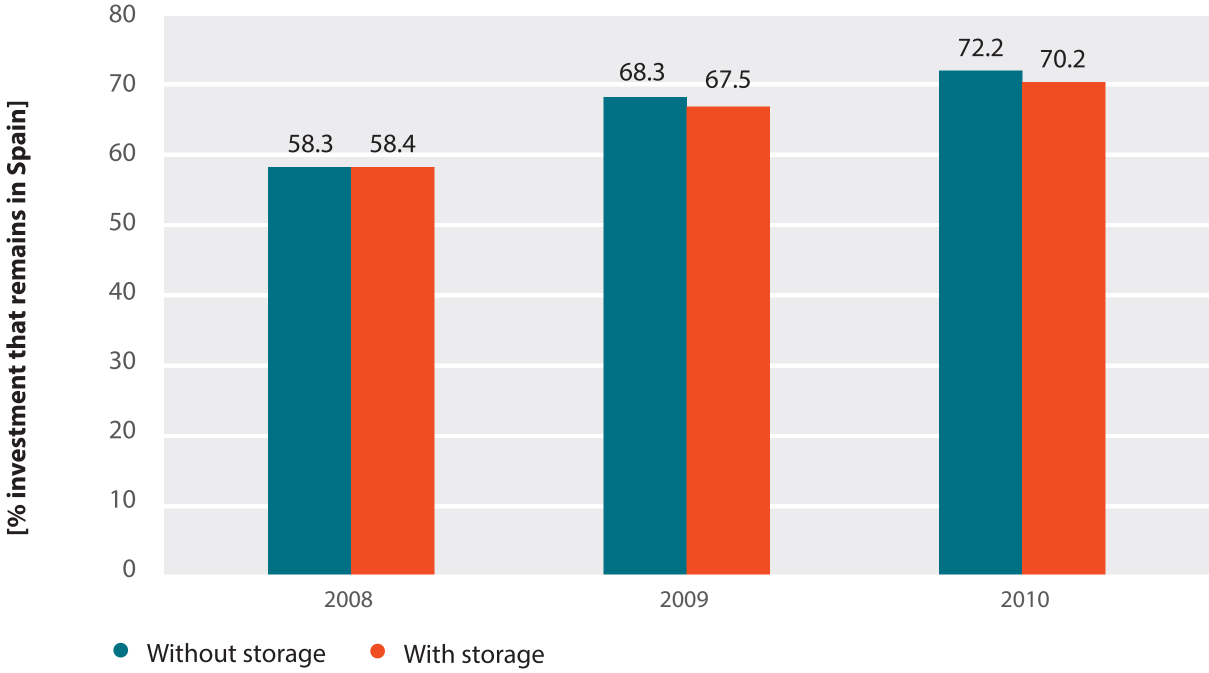

Figure 16: Local content of CSP from 2008 to 2010, based on [8]

While in 2008 only little more than one half of the investment remained in Spain, was it in 2010 almost three quarter. The following graph (Figure 17) shows the distribution of local content by sector for CSP plants with storage:

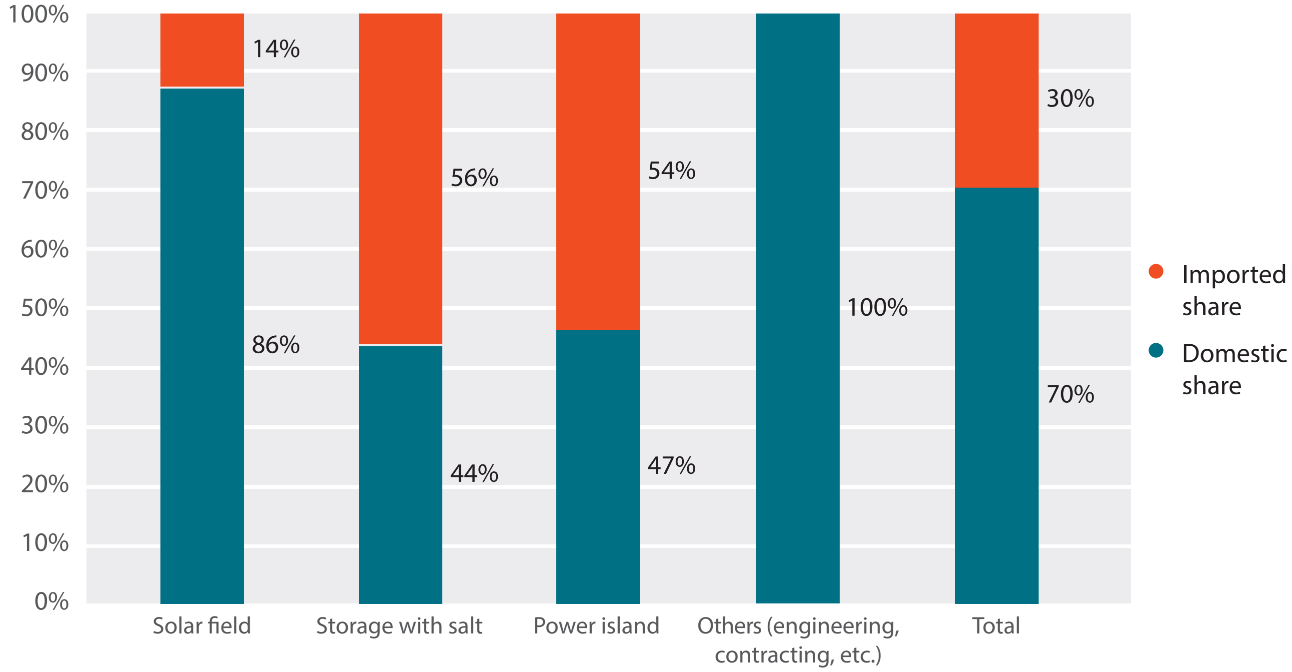

Figure 17: Itemized percentage of investment which remains in Spain for CSP with storage (2010), based on [8]

Even though the solar field as a whole is an item unique to CSP, Spain has acquired great knowledge and therefore a high local content on it. One reason could be that some of the knowledge, e.g. to produce mirrors, can be taken from related industries, like the automotive industry. Also there has been generally a high investment in research, development and innovation (R, D&I) for the CSP industry for a long time horizon.

Many positive impacts on the economy by CSP have been described in this chapter so far. On the downside it is necessary to mention the subsidies paid for renewable energies, which are shown in Figure 18:

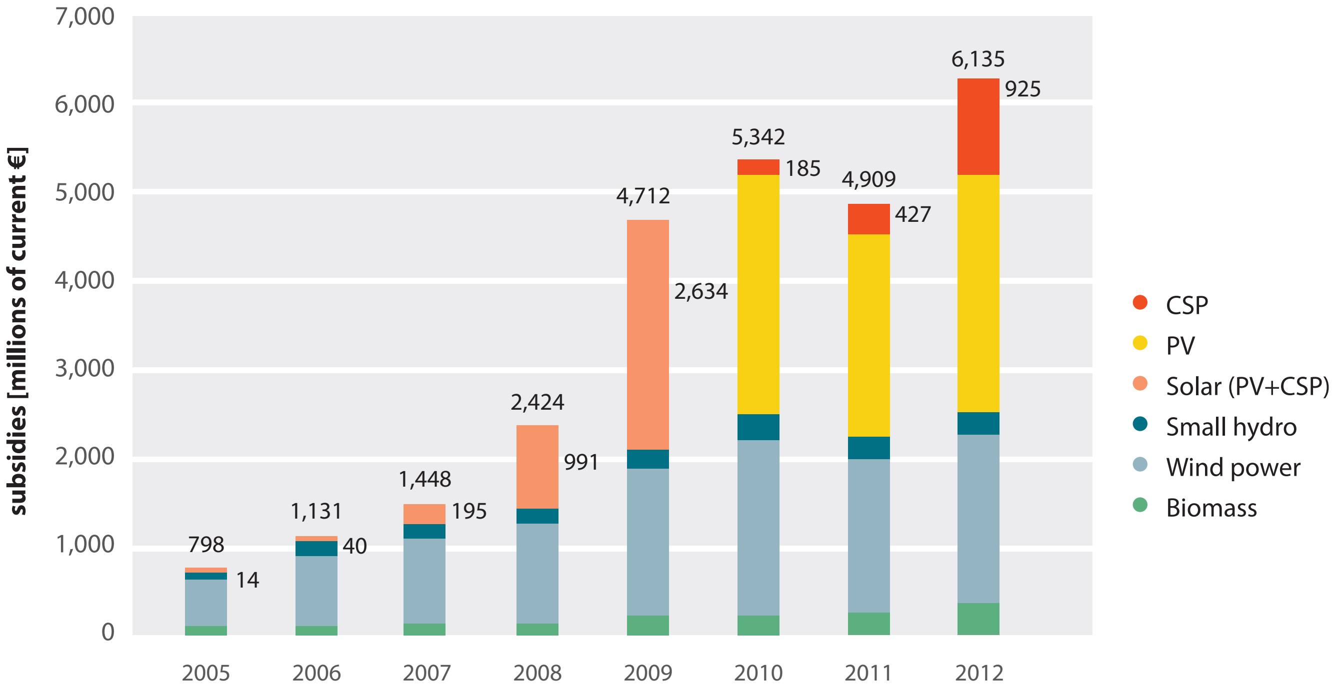

Figure 18: Annual subsidies paid to renewable energies in 2005 to 2012, based on [12]

Since 2008 the annual amount of subsidies to be paid has more than doubled, diminishing the positive effect of contribution to the GDP. The large amount of money to subsidize the feed-in tariff was the reason to cut the benefits for renewable energies.

Summary:

- High contribution of CSP to GDP of Spain, even during parts of the economic crisis.
- Many jobs in CSP sector during times of general high unemployment.
- High local content of about 70% due to long experience with thermal power plants, industrial process flows and investment in R, D&I for CSP.
- But large expenses due to subsidies encumbered the economy.

2.2.2 USA

The USA started to have CSP plants already in the 1980s. After these early plants there was a long gap without any new CSP installations. In 2006 there was the first CSP plant of a new generation built with many more to follow since then.

Figure 19 shows the annual installations of CSP plants between 1984 and 2013 in the USA and additionally plants under construction and under development by technology.

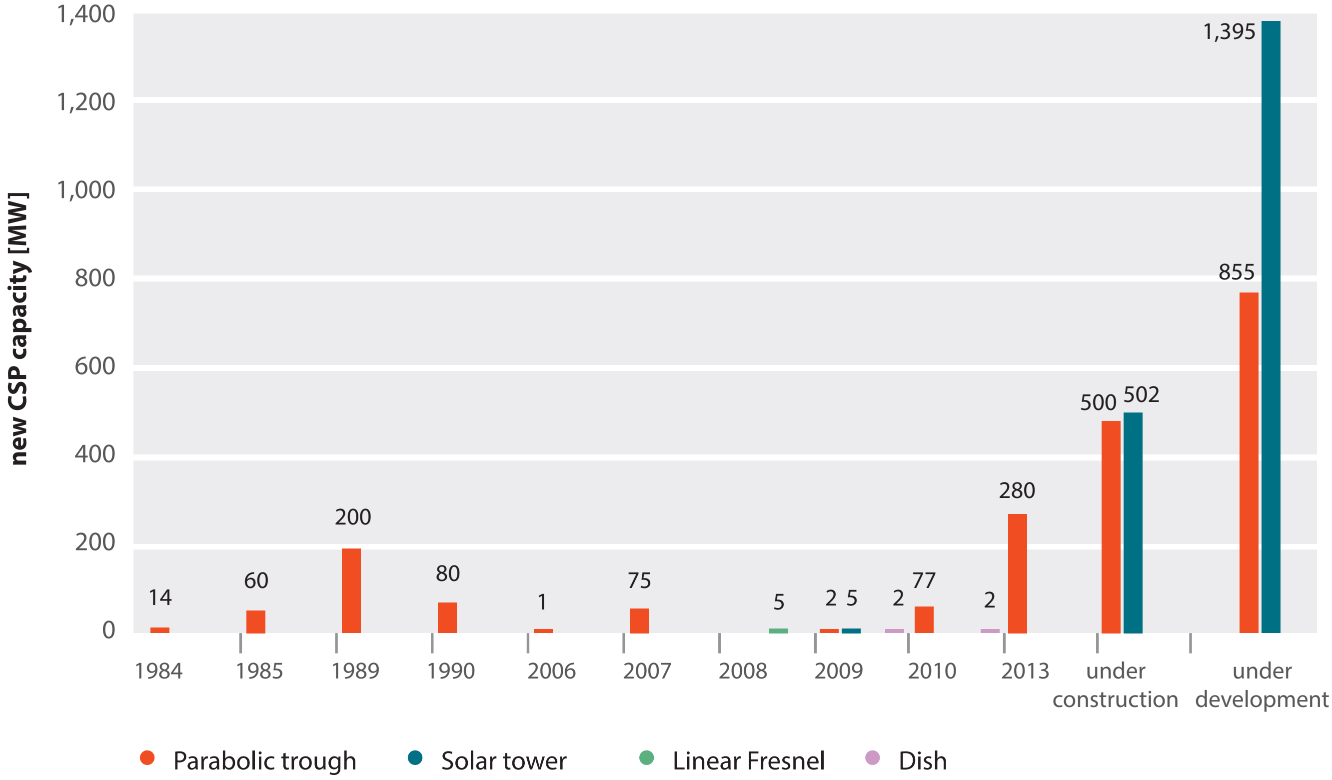

Figure 19: Annually new installations of CSP capacity in USA, 1984 to 2017

In the years not shown in the graph there were no new installations of CSP plants in the USA. In the next chapters the first period of CSP plants will be described and later the recent developments.

2.2.2.1 History of CSP Plants (1980-2000)

Between 1970 and 1980 the world market price of oil doubled. The increase in the price of oil was caused by the OPEC cartel (energy crisis). In this situation the development of alternative energy solutions became more attractive in the US and in Europe. As a result of extensive research and development started in USA and in Europe (especially in Germany and Spain) on large scaled concentrated solar power plants.

In 1978, Congress passed the Public Utility Regulatory Policy Act (PURPA). It established the right of independent power producers to interconnect with the local utility distribution system. PURPA allowed large utility scale of PV and other solar electricity systems. This legislation required utilities to buy electric power from private "qualifying facilities" at an avoided cost rate.

The company Luz International Ltd. was founded in 1979. Luz entered a power purchase agreement with Southern California (SCE) acc. PURPA for a period of 30 years (1983). Based on this PPA the company Luz started with the design and erection of nine CSP plants in the Mojave Desert based on the parabolic trough technology.

The operation of the first Solar Energy Generating System (SEGS I) started in 1984 with an electrical power of 13.8 MW. The SEGS IX started operation in 1990 with an electrical power of 80 MW. The total installed electrical capacity of the facilities of SEGS 1 – SEGS 9 is 354 MW.

In 1991 *Luz International Ltd*. went bankrupt. The facilities are still in operation under the responsibility of the operating companies.

2.2.2.2 SEGS 1 – 9

The essential component of a SEGS plant is the field of parabolic-trough collectors, aligned north to south. Their basic element is the solar collector assembly module (SCA), with its own parabolic collector, sun-tracking and local control system. The collector is a glass reflector which focuses the solar radiation directly onto a receiving metal tube, enclosed in a vacuum with a glass envelope. Thermal oil (mineral based or synthetic) is circulating as heat transfer fluid (HTF) within this heat collecting element (HCE). Superheated steam is generated in a steam generator to drive a common steam turbine. Working temperatures are about 300 °C to 400 °C for all SEGS plants. To ensure superheated steam the legislation allows a supplemental fossil firing up to 25% of the annual thermal heat which is installed in SEGS 2 – SEGS 9. Instead of a supplementary firing SEGS 1 had a two tank thermal storage system to store the hot HTF. The storage capacity was designed for 3 hours of operation, but was later demolished in a fire and has not been rebuilt.

All plants SEGS 1 – SEGS 9 were commissioned 1984 – 1990 with the technical data, shown in Table 4:

Table 4: Technical data of SEGS projects

Plant	Year	Capacity [MWe]	Aperture area [m²]	Temperature [°C]	Pressure [bar]	HTF
SEGS 1	1984	13.8	83'000	307	40	Thermal Oil
SEGS 2	1985	30	190'000	316	40	Thermal Oil
SEGS 3	1985	30	230'000	349	40	Thermal Oil
SEGS 4	1989	30	230'000	349	40	Thermal Oil
SEGS 5	1989	30	250'000	349	40	Thermal Oil
SEGS 6	1989	30	188'000	390	100	Thermal Oil
SEGS 7	1989	30	194'000	390	100	Thermal Oil
SEGS 8	1989	80	464'000	390	100	Thermal Oil
SEGS 9	1990	80	484'000	390	100	Thermal Oil

All projects SEGS 1 – SEGS 9 have been developed and installed by *Luz International Ltd*. The parabolic-trough was developed by *Luz International Ltd.* (Type LS-1 – LS-3). The HCE was delivered by *Solel* (Israel). The steam turbine was manufactured by *Mitsubishi Heavy Industries* (MHI), but is based on *General Electric* (GE, USA).

Delivery and manufacturing of the main components is given in Table 5:

Table 5: Overview of suppliers of SEGS projects

Plant	SCE	HCE	Turbine
SEGS 1	LS-1 Luz (USA)	*Not known*	Mitsubishi Heavy Industries (MHI), Japan
SEGS 2	LS-1 Luz (USA)	*Not known*	Mitsubishi Heavy Industries (MHI), Japan
SEGS 3	LS-2 Luz (USA)	Solel UVAC (Israel)	Mitsubishi Heavy Industries (MHI), Japan
SEGS 4	LS-2 Luz (USA)	Solel UVAC (Israel)	Mitsubishi Heavy Industries (MHI), Japan
SEGS 5	LS-2 Luz (USA)	Solel UVAC (Israel)	Mitsubishi Heavy Industries (MHI), Japan
SEGS 6	LS-2 Luz (USA)	Solel UVAC (Israel)	Mitsubishi Heavy Industries (MHI), Japan
SEGS 7	LS-2 Luz (USA)	Solel UVAC (Israel)	Mitsubishi Heavy Industries (MHI), Japan
SEGS 8	LS-3 Luz (USA)	Solel UVAC (Israel)	Mitsubishi Heavy Industries (MHI), Japan
SEGS 9	LS-3 Luz (USA)	Solel UVAC (Israel)	Mitsubishi Heavy Industries (MHI), Japan

Table 6 shows the supplier of various components of SEGS 7 in detail:

Table 6: Supplier of components of SEGS 7

Component	Company
Mirrors	Flabeg (former Pilkington), Germany/USA
Receiver	Solel, Israel
Parabolic Trough	Luz, USA
Control System	Emerson, USA
Pumps	Sulzer, Swiss
Turbine	Mitsubishi Heavy Industries, Japan

2.2.2.3 Solar tower

In the beginning of the 1980 a solar tower was designed and erected by the *Institute Development of Energy* (DoE) with an electrical power of 10 MW, named "Solar One"[1]. The installation of Solar One began 1981. Between 1982 and 1986 Solar One was in operation. In 1995 the plant was converted to a molten salt storage technology and started operation in 1996 as Solar Two. Solar Two was decommissioned in 1999.

Later the Tower was used as an Air Cherenkov Telescope by the University of California until 2008. In 2009 the plant was demolished. The site was leveled and returned to vacant land by SCE.

Solar One's method of collecting energy was based on concentrating the sun's energy onto a common focal point to produce heat to run a steam turbine generator. It had hundreds of large mirrors or heliostats assembled that tracked the sun, reflecting the solar energy onto a tower where a black receiver absorbed the heat. High-temperature HTF was used to carry the energy to a boiler on the ground where the steam was used to spin a turbine like in conventional thermal power plants. A thermal storage system installed parallel to the turbine where hot HTF was stored in a tank, filled with gravel and sand.

In 1995 Solar One was converted into Solar Two by adding a second ring of 108 larger heliostats around the existing field of heliostats of Solar One. Instead of thermal oil Solar Two used molten salt as HTF and

[1] The names „Solar One" and „Solar Two" for the solar towers should not be confused with two solar dish power plants which were announced recently and a parabolic trough power plant in Nevada from 2007.

as a storage medium. This allowed the turbine to run up to 3 hours after sunset.

Technical Data (Table 7) and key supplier (Table 8) of Solar One and Solar Two:

Table 7: Technical Data of Solar One and Solar Two

Plant	Capacity [MWe]	Number of heliostats	Area of one heliostat	Aperture area [m^2]	Medium	Turbine temperature [°C]	Turbine pressure [bar]	Storage temperature [°C]
Solar One	10	1'818	40	72'650	water/ steam	510	100	304
Solar Two	10	1'920	40	82'750	molten salt	512	68	565

Table 8: Supplier of components of Solar One and Solar Two

Component	Supplier	
	Solar One	Solar Two
Receiver	*Not known*	Rockwell International (USA)
Steam generator	*Not necessary* (Direct steam)	ABB Lummus Global (USA)
Turbine	GE (USA)	GE (USA)
Storage system	Rocketdyne (USA)	
Heliostats	ARCO Solar (USA)	
Tracking system	ATS, Advanced Thermal System (USA)	

Summary:

- Driven by the oil crisis in the early 80s, the US started to build the first commercial CSP plants.
- Full commercial plants were built.
- Nearly all components were manufactured by US based companies, influencing the whole CSP industry.
- After drop of energy prices in the 90s, no commercial plants were built.

2.2.2.4 Recent development (since 2000)

In 2004 the company *BrightSource* (Luz II) was founded taking-up the technology of Luz International (key personnel of Luz).

From 2006 until 2010 several small CSP plants (1.16 MW – 5 MW) were built using various technologies. In 2007 a 75 MW parabolic trough CSP plant started producing electricity. Of particular interest is the time since 2013 with several CSP projects with a CSP capacity of 100 MW and larger, using parabolic trough or solar tower technology. The operational CSP plants since 2006 and the plants under construction are shown in the table below:

Table 9: CSP projects in the USA since 2006

Power Plant	Location	Installed Capacity [MW]	Operational since	Technology
Saguaro Power Plant	Red Rock	1.16	2006	Parabolic trough
Nevada Solar One	Boulder City	75.00	2007	Parabolic trough
Kimberlina Solar Thermal Power Plant	Bakersfield	5.00	2008	Linear Fresnel
Sierra Sun Tower	Lancaster	5.00	2009	Solar tower
Holaniku at Keahole Point	Keahole Point, Hawaii	2.00	2009	Parabolic trough
Colorado Integrated Solar Project	Palisade	2.00	2010	Parabolic trough
Martin Next Generation Solar Energy Center	Indiantown	75.00	2010	Parabolic trough
Maricopa Solar Project	Peoria	1.50	2010	Dish
Solana Generating Station	Phoenix	280.00	2013	Parabolic trough
Ivanpah Solar Electric Generating Station	Primm	392.00	In operation (2013-2014)	Solar tower
Crescent Dunes Solar Energy Project	Tonopah	110.00	Under construction	Solar tower
Abenogoa Mojave Solar Project	Harper Dry Lake	250.00	Under construction	Parabolic trough
Genesis Solar Energy Project	Blythe	250.00	Under construction	Parabolic trough

In 2012 leading CSP companies (*Abengoa, BrightSource Energy and Torresol*) formed the "Concentrating Solar Power Alliance" (CSPA). Up to now other companies (*Cone Drive, Lointek and Wilson Solarpower*) have joined the alliance. Their aim is to bring increased awareness of CSP and to advance the industry's value proposition.

2.2.2.5 Legal framework

In 2000 Senate Bill 1345 directed the energy commission to develop and administer a grant program to support the purchase and installation of solar energy and selected small distributed generation systems. Funding for the program had to be renewed annually by the legislature. The state's budget crisis ended the program in 2006. In September 2000 the legislature adopted the Reliable Electricity Service Investments Act (RESIA) as the result of the legislation (Assembly Bill 995, Senate Bill 1194).

The laws concerning renewable energies and the financial incentives available in the USA are a very complex system with federal, state and local applicability.

Table 10: Overview of incentives in the USA, based on [14]

Incentive	Description	Federal	Total amount
Corporate Tax Incentives	e.g. tax credits, deductions and exemptions for companies installing renewable energies on corporate tax	Y	42
Grant Programs	Usually competitive, designed to lower the installation costs or to pay for R&D	Y	52
Industry Recruitment/Support	Usually temporary support of industries in their early years, with sunset provision	Y	39
Loan Programs	Low/no interest loans, rates and terms vary by program	Y	206
Performance-Based Incentives	= feed-in tariff, money paid for electricity fed into the grid	N	78
Personal Tax Incentives	e.g. tax credits, deductions and exemptions for companies installing renewable energies on personal tax	Y	44
Property Tax incentives	e.g. tax credits, deductions and exemptions for companies installing renewable energies on property tax	N	81
Rebate Programs	Refund, usually for small-scale applications	N	551
Sales Tax Incentives	e.g. tax credits, deductions and exemptions for purchase of a renewable energy system on sales tax, usually for small-scale applications	N	47

So other than Spain, the USA does not have performance-based incentives (=feed-in tariffs) by the federal government. There are some performance-based incentives by state governments and various incentives regarding tax reductions. But in the USA the main incentives for CSP plants are loan programs with good conditions.

Especially the "Section 1705 Loan Program" from 2009 has been used for several recent CSP plants, e.g. Solana, Crescent Dunes, Abengoa Mojave and Genesis Solar [15]. It was designed for projects larger than $ 25 million starting construction before September 30, 2011 and with a repayment period of 30 years [16].

Summary:

- Since 2006 many new CSP plants in operation and under construction using different CSP technologies and capacities (450 MW operating + 1,000 MW under construction).
- All necessary components could be manufactured locally.
- Main incentive in the USA: Federal loan guarantees.

2.3 CASE STUDY: SOLAR RECEIVERS

Solar absorber tubes (or heat collector elements) are one of the most critical parts of line focusing CSP plants (parabolic trough and Linear Fresnel) because of their huge importance for the thermal efficiency and therefore for the electrical output of the plant. There are only a few companies around the world that are able to produce these components, and only two companies (*Schott Solar CSP and Solel Solar Systems*) with a longer track record.

The receiver, shown in Figure 20, itself consists of several subcomponents, like the steel tube with the special coating, the glass tube and the bulk at the end of the receiver tube. The quality requirements on the solar receivers are quite high as already mentioned, resulting in also high requirements on the sub-supplier of each component. These requirements are not only based to accuracy requirements of the components but also due to the long term stability of each sub-component over the life time of the plant.

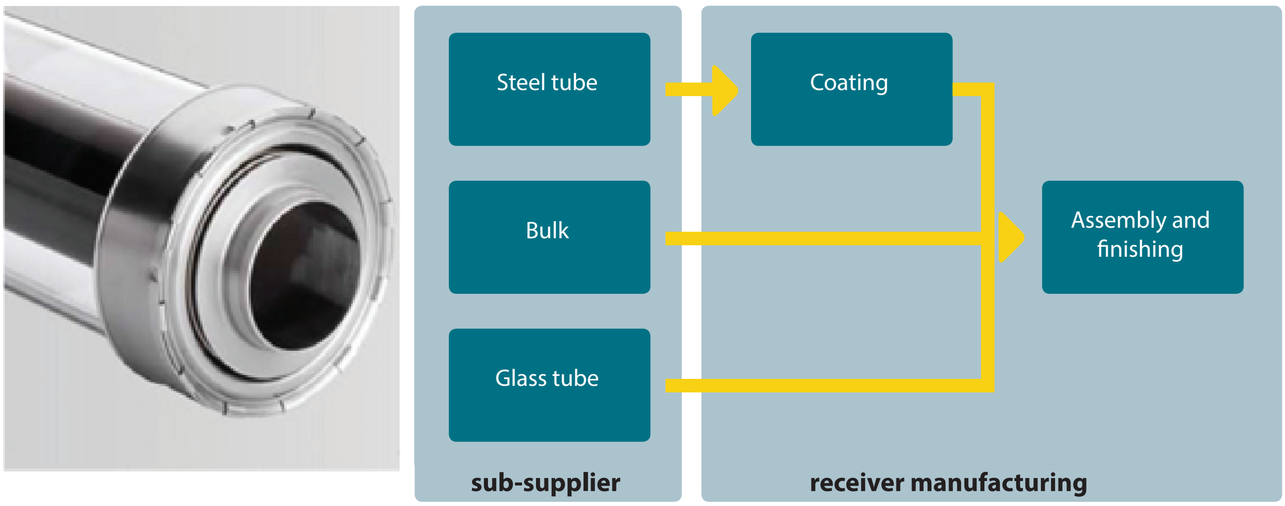

Figure 20: Solar receiver (here SCHOTT PTR70) and assigned value chain [17]

With the implementation of a local receiver facility, also the sub-supplier must be identified and furthermore prequalified. With such a prequalification process, the manufacturing company ensures the quality of its product. The prequalification process includes not only the technical specifications (like the steel composition) of the components, but also the quality of the product and the accuracy of the production steps. For reasons of traceability, every step in the production chain has to be recorded (similar to the automotive industry), putting a threshold on smaller sub-suppliers without the necessary IT. Especially for the long term stability of the components, time-consuming life-cycle tests are necessary. According to Schott Solar CSP such a prequalification process could take more than one year for one sub-supplier.

Summarized the implementation of a local receiver facility requires several steps:

- Foreseeable and stable market volume. According to Schott Solar CSP this must be greater than 150-200 MWe of new installed capacity per year.
- Long list of companies able to act as sub-supplier, short list of potential companies fulfilling the primary requirements of the receiver manufacturing company and interested in delivering components.
- Further cooperated development between sub-supplier and manufacturing company in terms of quality insurance and further improvement.

3 CHALLENGES AND OPPORTUNITIES

The CSP technology and its related value chain are offering several opportunities for local companies, especially considering the socio-economic development. On the other side, the successful and sustainable development of an own CSP industry in a country is challenging. These points are described in the following chapters.

As several countries around the world started to develop their own CSP industry, there are already some "lessons learned", which are summarized in this chapter.

Based on these experiences, this chapter closes with some remarks and recommendations for a successful implementation of a sustainable CSP industry.

3.1 TECHNICAL AND ECONOMICAL RISKS AND OPPORTUNITIES

The whole value chain of the CSP plant offers several technical and economical opportunities for the local companies. Nevertheless there are also some critical items for a successful development of the market that must be taken into account.

Job opportunities

Due to the several components and parts necessary for CSP plants, there are several opportunities for job creation. Of course, during the construction phase of the plant, direct jobs are created, related to the working man at the site. Indirect jobs are arising from greater demand in the supply chain. If the companies active in the supply chain are building up new capacities, this indirect effect results in creating new jobs, otherwise existing jobs are secured.

Besides this job creation along the value chain of the plant, additional induced jobs are created, e.g. as training jobs for the workers or by consumption of goods and services on working sites. Also new jobs in construction and O&M will have a positive impact on induced jobs in the whole region.

To show an exemplary job creation development, an analysis based on [18] is performed, assuming a continuous CSP pipeline of 100 MW/year with thermal storage. The job creation potential is assumed with the following figures, given in full-time employment (FTE) per installed MW:

- *Direct jobs*: Direct jobs are created within the construction phase of the plant. They are directly related to the construction on side (10 FTE/MW) or the manufacturing of components at a facility (4 FTE/MW). Also the jobs related to the operation are assumed as direct jobs (0.8 FTE/MW) but are related to amount of installed CSP capacity. Current numbers from a 377 MW (without storage) project in the USA (Ivanpah, construction by *BrightSource*) indicate a peak amount of 2'100 construction workers and support jobs, resulting in a specific amount of 5.5 FTE/MW. As the thermal storage requires a bigger solar field, again this number fits very well to the given assumptions.
- *Indirect jobs*: Indirect jobs are arising from demand in the value chain. They are related to the construction and O&M-phase. For each direct job 0.9 indirect jobs are created.
- *Induced jobs*: Induced jobs are created as jobs that are not directly related to the CSP plant. Additional jobs such as training for employees along the value chain or due to the consumption of goods and services on working sites or at the component facilities are assumed as induced jobs. For each direct and indirect job, 0.25 FTE are induced.

Based on these assumptions, a summarized job potential (without O&M-jobs) of around 33 FTE/MW is estimated. Compared to the numbers presented in the previous chapters for Spain (2009 – 2012) of slightly more than 40 FTE/MW, this assumption fits to the current state of the art.

Knowledge of the local market

For every component of the value chain, new local manufacturers could enter the market. Based on their experience with the local market, these companies offer a quite well starting point for their market development. As local companies are quite well aware of the specific requirements on permitting processes, local needs and requirements, they offer a certain advance in knowledge compared to global players. Also the necessary effort concerning logistic is smaller.

Based on these local advantages, local companies could be more competitive than global players, if they can offer the same product quality and standards.

Technology development

As the CSP technology offers a wide range of possible applications, the potential for the further development of the technology is given. Especially concerning the key part of the CSP system, the solar field and the thermal storage system, the potential for new innovations or adaptations on local needs is huge. Together with international partners innovative products could be developed not only for the national but also for the international market. There are already some examples from the oil and gas sector, where German and Brazilian companies developed together solutions for the Brazilian market that were exported later to the international markets as well [19].

Current global developments are driven by optimizing the CSP technology towards cost reduction and higher temperatures. For thermal storage systems the development of new storage concepts and the use of new storage materials are key points in the current research and development.

For Brazilian companies, this wide range of possible R&D activities offers on the one hand a very promising opportunity, providing new and especially adapted products and solutions for the local and global CSP market. On the other hand, Brazilian companies have to provide own R&D-activities in order to adapt their already existing production processes to the needs of the specific components. Without these initial adaptations, the Brazilian industry will not be able to deliver specialized components for CSP plants.

Foreign trade impact

Based on the successful development and the growth of the CSP market within the following years, Brazilian companies are able to export also components to foreign markets. It seems likely, that in a first step the Latin American market could be served directly from Brazil, offering short distances and a good knowledge about the market. Afterwards new emerging markets around the world (especially Asia and South Africa) could be focused. This opportunity offers additional growth potential, but also requires additional efforts in the development of quality standards and production methods, in order to adapt the component production to the needs of the new markets.

Financial and economical challenges

The main components of the CSP value chain are often based on products manufactured for different industrial applications. For example, companies active in the supply of mirrors for the solar field will often be based in the conventional glass industry. An emerging CSP market will give them the potential to diversify their market depending on their ability to produce high quality mirror products (i.e. low iron glass). Challenges to enter this new market can be summarized into technical and economical barriers:

- Investment in new infrastructures, processes and training of the staff is necessary to enter the new market segment.
- Knowledge and adequate staff must be built in order to produce the new components.

- Further and fast development in the first years in order to raise the product quality to be competitive.

If Brazilian companies are not able or willing to participate on the CSP technology, CSP plants will not have a chance to increase in Brazil. As there are no high incentives and the awareness of foreign companies for the Brazilian market is not very high at the moment, the CSP market needs impulses from the local companies. From the current point of view, it is unlikely that a significantly increase of the CSP market in Brazil will occur without any participation of Brazilian companies.

Besides public intensives for the energy production (like feed-in tariffs or energy specific auctions), tools to reduce and secure the financing costs are necessary, not only for the owner of the CSP plant but for all companies active along the value chain. To ensure the financing, the investment risks could be transferred. Also concessional finance or improvements of the financial market functions could be implemented.

- **Public guarantees** in the form of full or partial debt repayment to investors (e.g. loan guarantee of the US Department of energy) as insurances to equity investors.

- **Public investments as concessional loans or grants** necessary when the returns from the investment are not enough to compensate the risks perceived by private investors.

- **Public support to financial markets** to ensure provision sufficient tools and products.

Challenging quality standards

Many CSP components require high quality standards during the whole production process, especially components with a high need on accuracy (e.g. mirrors or support structure) or a high demands on the durability (like mirrors, the absorber tubes or the receiver).

There are some general international norms and quality standards for glasses and solar thermal collectors, but the main standards for specific CSP applications are under development. Nevertheless the performance of the plant is directly depending on the accuracy and the quality standards of each component. To achieve a competitive market position it is essential to deliver products close to the international quality standards and afterwards to continuously improve these standards.

To develop and implement the production processes that meet the quality standards, two different paths are suitable:

- International cooperation with already active market players, founding of joint ventures.
- Cooperation with international research institutes that develop international quality standards and measurement methods.

Besides the increase and the securing of quality standards in the production, also new methods are investigated to increase the optical efficiency and the durability of the components. These activities are not limited to academic research. As an example, nearly every international mirror manufacturing company is offering and developing additional coatings to increase the durability of its receivers.

Summary:

- CSP offers a good job potential, not only during the construction phase at the site, but also in the manufacturing industry and with follow-up services.
- Brazil offers a high potential for CSP plants due to the good solar irradiation (DNI) and the geographic location of potential sites near the equator.

- Knowledge of the local market is only an advantage if international quality standards could be provided.
- Companies need their own R&D to adapt their production processes to CSP.
- All companies along the value chain need financial security to bear the investment risks.
- International cooperation with active market players or research institutes help to achieve the necessary quality standards.
- A successful and sustainable development of the Brazilian CSP market needs the active participation of Brazilian companies.

3.2 INFLUENCE OF THE LOCAL PRODUCTION ON THE INVESTMENT COSTS

A key challenge worldwide for the further development of the CSP plants is the reduction of the energy production costs of the CSP plant, the so called levelized costs of electricity (LCOE). These costs depend on two main factors, on the one side the investment and O&M-costs of the plant and on the other side the overall energy production, influenced by many factors like the efficiency, the storage concept used or the location.

The local production of the different components influences the investment costs of the power plant. If the local production could achieve lower costs for specific components, the LCOE of the whole plant could be reduced. The main factors that must be considered when analyzing this influence are:

- Raw material price
- Labor costs and productivity
- Exchange rates to global currencies
- Risks

These factors are briefly discussed and analyzed for Brazil in the following chapters.

3.2.1 Raw material prices

The main components for the CSP plant are steel, concrete and glass. Especially for the glass industry and the necessary industrial "low-iron" sand, no estimation is possible.

The Brazilian steel industry is ranked 9th in the steel producers worldwide. In 2012, more than 50% of the Latin American steel production was based in Brazil. As the steel market is a global market, especially the domestic production is relevant for this consideration. In Figure 21 the installed capacity, the total production and the apparent consumption is shown. In 2012, 9.8 million tons have been exported, representing 28% of the annual production, or 20% of the installed capacity.

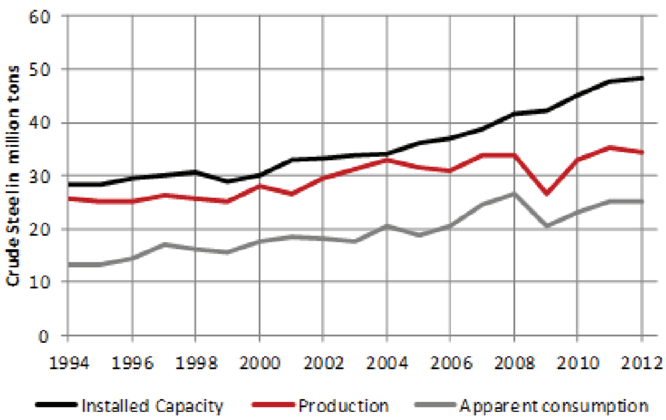

Figure 21: Installed capacity, production and apparent consumption of the Brazilian steel market, based on The Brazil Steel Institute

Based on this figure, the Brazilian steel market seems to be highly competitive, with enough reserve capacities.

Considering the steel price, the Latin American market develops similar to the world market. In Figure 22 deviations of a steel price indicator for several regions around the world are shown. This indicator is created from individual price series, which are then weighted according to their importance. The indicator is calculated by Platts

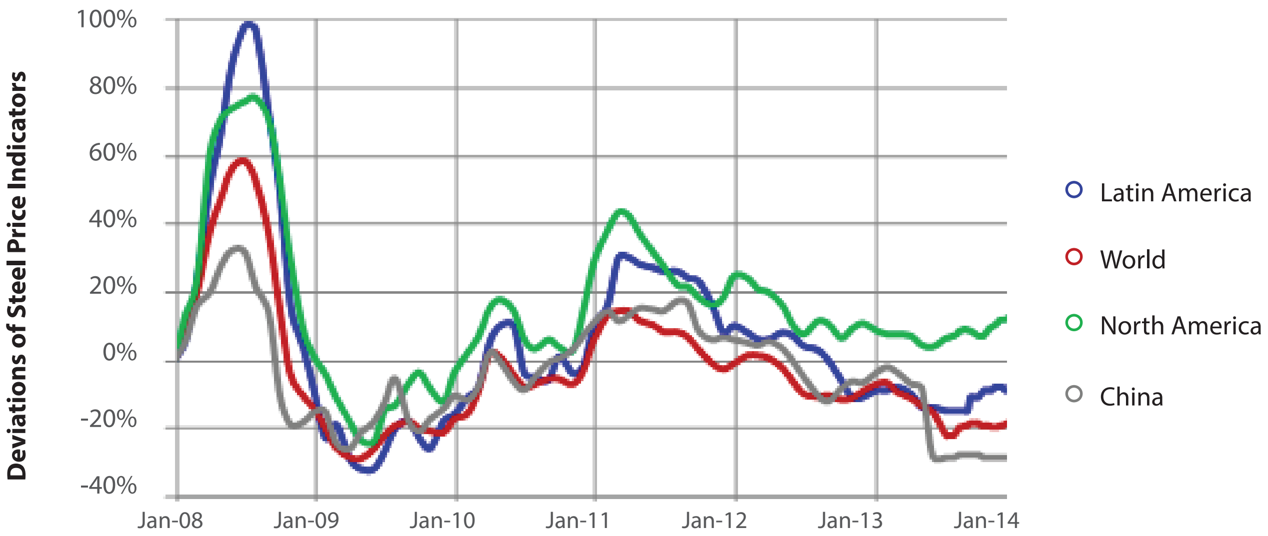

Figure 22: Deviation of the steel price indicator for several regions, based on Platts Metal (steelbb.com)

Metal, London. The behavior of the price indicator for Latin America is comparable to the worldwide behavior.

Due to several big infrastructure projects, the Brazilian construction sector has grown during the last years and is highly competitive [20]. New built CSP plants are in direct competition to other infrastructure projects, because the basic services and materials (like building, foundations or concrete) are in principle the same for each project. If enough capacity is available to serve all infrastructure projects, a competitive price level is expected.

Summarized, raw material for the CSP plants seems to be available on the Brazilian market on a competitive level. Therefore a slightly positive impact on the LCOE of the CSP plant is expected.

3.2.2 Labor costs and productivity

Labor costs have a huge impact on the LCOE. With Table 11, the gross annual incomes of some selected job positions, relevant for the CSP plant are shown. The general level of the labor costs for the different countries is given in [21], compared to Zurich (100), see last row of the Table 11.

Table 11: Comparison of annual gross income of different jobs for 2012, based on [21]

Job description	Spain (Madrid)	United States (Los Angeles)	Germany (Berlin)	Brazil (Sao Paulo)
Industrial (leading)	30’300 €	45’200 €	65’000 €	47’800 €
Industrial (high skilled)	21’100 €	48’100 €	36’600 €	9’700 €
Industrial (low skilled)	17’900 €	36’300 €	22’000 €	5’100 €
Engineering	40’700 €	69’900 €	55’700 €	21’800 €
Overall (100 = Zurich)	43,5	65,9	60,5	22,9

Compared to the values of Spain and the US, the labor costs in Brazil for low-skilled and high-skilled workers in industrial and infrastructure sectors are very low. Also the labor cost for engineering services are much lower. The labor productivity is not taken into account in this consideration.

It could be summarized, that especially for the first plants, with not enough skilled workers and a high effort for training, the LCOE of the plant are not positively influenced by the labor costs. With increasing amount of installed capacity, skilled workers and a higher productivity, the low labor costs in Brazil could decrease the LCOE of the CSP plant, if the necessary accuracy and the long term stability of the components could be also kept on the same level.

3.2.3 Exchange rates and risks

With the implementation of the plant, several critical factors have to be taken into consideration. These risks are influencing the overall costs of the plant, as they are taken as surcharge into account. Also investors take these risks into account, resulting in an increase of the financing costs. For foreign EPCs as well as investors these risks consists of the new country and the new economical environment. For Brazilian companies, the "new" technology CSP is creating surcharges. With the further increase of the installed capacity and Brazilian EPCs these surcharges could be reduced.

With a higher local content share, also the risk of exchange rates is minimized. In Figure 23 the exchange rates for the Brazilian Real (BRL) is shown, compared to the US$ (USD) and the South African Rand (ZAR). Every currency is related to the Euro (EUR). Especially in the second half of the year 2013 a strong increase in the exchange rates could be observed. These risks could be minimized with a higher local share of the components.

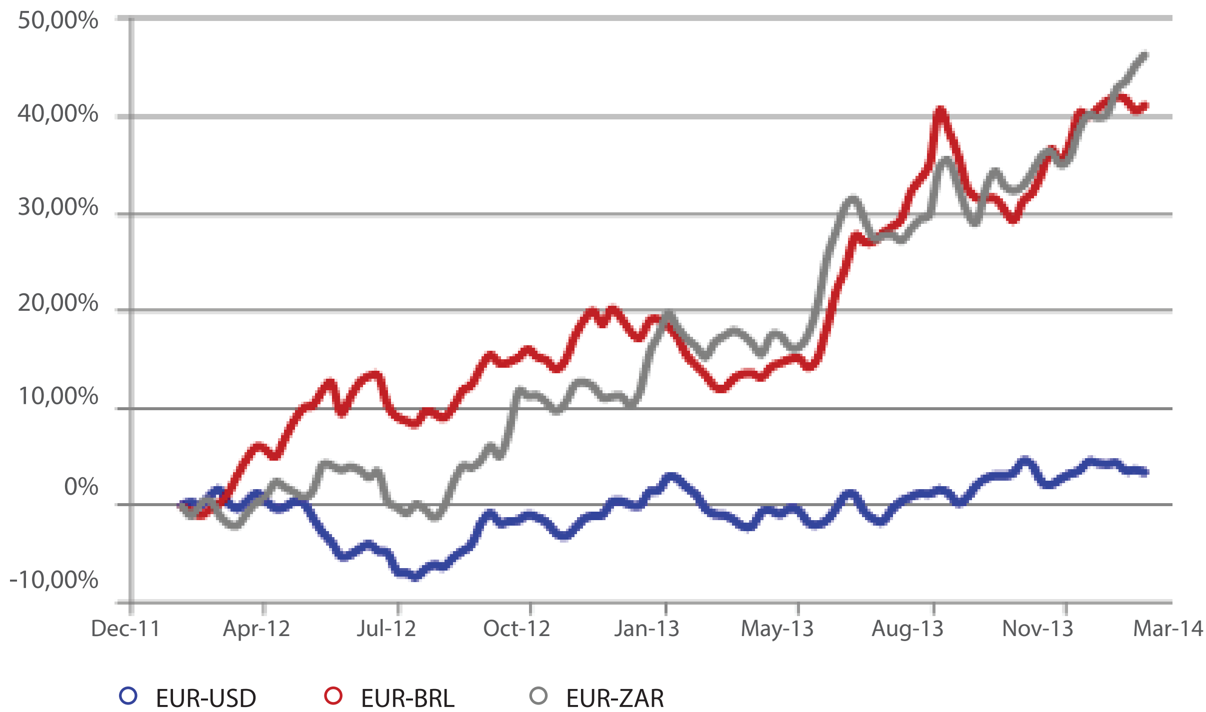

Figure 23: Exchange rates EUR to USD, BRL and South-African Rand

It could be concluded, that the risks for foreign (mainly American and European) companies to invest in Brazilian CSP plants is comparable to the investment in other emerging CSP regions (like South Africa). Due to their knowledge of the market, local companies have the advantage to offer their components with lower risks.

Conclusion:

There are four key points, considering the influence of the local production on the reduction of the investment costs of a CSP plant:

- **Raw material prices:** Compared to the world market, the Brazilian market seems to be competitive. Therefore a slightly positive influence on the LCOE is expected.
- **Labor costs and productivity:** With the first plants, training and investment will overlay the lower loan costs level in Brazil. With increasing capacity and experience, the labor costs will have a positive impact on the LCOE.
- **Exchange rates:** Higher local shares minimize the risks of fluctuating exchange rates.
- **Risks**: Brazilian companies offering knowledge of the market can offer a lower LCOE due to their better risk management.

3.3 LESSONS LEARNED

Since the development of the CSP technology, several lessons learned scenarios were performed, especially regarding technical and economical risks.

The main lessons learned from other countries are listed below.

- **Local investments:** Uncertainties about the CSP pipeline and the security of potential investments are a substantial barrier for the development of the industries along the CSP value chain. Especially companies along the value chain that require a huge investment in new production lines or facilities need a **predictable and stable** pipeline of new plants in order to cover their investment.
- **Long time horizon:** To **secure the investment** in new production pipelines, the investor needs the security, that the boundary conditions for the investment are **not changed** during the payback period of the investment. Therefore the boundary conditions must be formulated and secured over a long time horizon.
- **Competition with other technologies**: On the one hand, CSP plants are in direct competition to other energy generation unit and have to offer electricity on a comparable price level. They offer certain advantages (dispatchable generation, spinning reserve, etc.) which must/could be included in the pricing. On the other hand, the components and production capacities necessary for the CSP plants also are used for other technologies, like buildings, other energy generation units or infrastructure projects. But there are also industrial applications for the CSP technology in addition to power generation.
- **Sustainable jobs:** The jobs created along the value chain are not mainly short time based construction jobs. Most **created or secured jobs are sustainable** due to the fact that several plants are built over a long time horizon.

- **Usage of niches**: Put effort on R&D into areas hardly developed, but interesting for the specific country. In Brazil's case increased improved thermal storage systems, regulating capabilities, fast charging / discharging of thermal storages and co-firing are some possible options.

To overcome the already mentioned barriers, some key actions are formulated that were used in other countries to enable a significant rise of the CSP related industry [22]:

- Provide sufficient incentives to developers to balance high up-front investment costs against savings in fuel and O&M-costs. These incentives could either be public or private.
- Avoid overpriced incentives resulting in investment bubbles and high societal costs. The increase in capacity must be always connected with the increase of the local CSP industry, in order to ensure a sustainable growth.
- Rise of the awareness of the CSP technology and the advantages for the electrical system and the industry.

There are also some key points that must be considered when creating the boundary conditions for the CSP related industry.

- Examine the various public finance mechanisms used in different countries to support CSP. Countries which have started recently to implement CSP, like India and South Africa, use competitive tenders or reverse auctioning, instead of fixed feed-in tariffs [23]. Another option is concessional loans, like in the USA.
- For the successful development and design of a CSP plant, an exact knowledge of the solar resource is necessary. As the DNI has huge influence on the technical and economical parameters of the plant, it is necessary to have accurate measurement values over at least one year for the specific location. Also DNI accuracy matters, therefore high class and proven measurement systems are necessary.
- Boundary conditions for the local content within a PPA or other energy contracts are a possibility to achieve a high local content. Nevertheless fixed local content rates could also deter potential investors, especially for the initial plants. Too high local content rates increase the costs of specific components. This effect has also been observed in other industry sectors [19]. To avoid this overpricing effect it is necessary to establish an ongoing monitoring process of the local content rates or to implement individual rates per project. This monitoring must be started in parallel to the increasing market and must be technology independent. Based on the monitoring results, the local content rate must be adapted in both directions.
- Increasing a small share of local content is simpler than increasing an already high share. First try to focus on few components which can be produced locally at high quality. Export these components, instead of achieving a high local content at the expense of quality. Make sure for these components that crucial materials in the supply chain are available in sufficient quality and quantity.
- A possible solution to ensure R&D and training of stuff is implemented within the CSP program of K.A. Care (Saudi Arabia). Within this program, 2% of the revenues are given to a special fund. This fund is used to support on the one hand R&D-projects related to the further development of the CSP technology and the adaption to the local market. On the other hand, this money is used for training programs for local staff active along the CSP value chain. Such measures ensure the increase of the local R&D and training facilities, as the CSP industry is increasing.

Nevertheless, the situation in Brazil is different compared to the other CSP developing countries. For the most countries with ambitious CSP programs, the key focus is on replacing existing, CO_2-based energy generation units (like US, Spain) or on increasing of the total amount installed energy generation units by building new and renewable power plants (like

South Africa, India or MENA). **The key focus for Brazil could or even must be the development of new energy generation units with integrated storage technology that could be implemented in regions without big water reservoirs.** The CSP technology offers this possibility. Therefore the boundary conditions must be enabling the CSP related industry to develop power plant with integrated storage system. Any incentives or other official support should focus on the reason why CSP is wanted in Brazil: They should be linked to storage capability, but should not put (large) limitations on other technology options (e.g. co-firing, cooling technology or other CSP technologies). This has also a positive impact on new jobs, new production lines and R&D-possibilities.

3.4 DEVELOPMENT PATHS FOR THE IMPLEMENTATION OF A CSP INDUSTRY

Within this chapter, some recommendations for possible paths towards a successful implementation of the CSP industry in Brazil are given.

Main objective of all further steps must be the implantation of a new and dispatchable energy generation unit in Brazil. Therefore, all measures must always connect the thermal storage with CSP.

The recommendations are formulated as key points. These recommendations are mainly based on the chapters above. In order to categorize, the development paths are divided in three sections.

Industrial development:

- First of all, **the awareness of the CSP technology within Brazil must be raised.** Therefore main advantages of the technology, including the integration possibility of a storage system must be pointed out, also the differences between the two solar driven technologies PV and CSP. This process must include not only the energy sector but all members of the value chain. In order to identify the main local players along the value chain, long lists of potential component manufactures are helpful.
- Potential players along the value chain could **form international cooperation or joint ventures** with international players in order to get in touch with the technology and the typical requirements on the specific components. Also a network of the companies along the local value chain could support the development of the local industry, providing the visibility of the local players and supporting partnerships with international players.
- Within the last years, the CSP technology has developed to a growing industrial technology. There are **several international standards and quality norms**, new players along the value chain have to phase with. As quality and accuracy, especially but not only of the solar field and the solar absorber, have a huge impact on the economical values of the plant, it is very important **for new players to match these standards** in a short time.
- **Pilot plants** developed by international companies or international (or local) research centers together with local components manufacturers are a possibility to raise the awareness of the technology and to provide the knowledge and experience about necessary requirements on quality and accuracy of the several products.

Technology and R&D:

- The **knowledge of the solar resources** (for CSP the Direct normal irradiation (DNI)) is one key factor for the successful development of a CSP plant, and also one key element for international financial support. Local developers and/or local research institutes could provide these measurement and potential analysis.

- The technology development must be strongly connected between the research performed at research institutes or universities and the industrial development within the industry. A **strong interconnection** between both sectors supports the specific development.
- **Local needs of the technology** are a strong driver for the technology development. Therefore the needs from the industry must be transported to the academic sector.
- In order to support the industrial development, universities must provide the related skills. Therefore specific educational programs must be established. With the increasing CSP sector, education and training becomes an important factor ensuring that sufficient local labor and knowledge is available.
- **International cooperation** and pilot plants are an important key element in the development of an international visible CSP market.

Governmental and legal framework:

- To quantify the CSP potential of Brazil, a **potential analysis of the CSP technology** in Brazil is necessary. Such a potential analysis should not only include the solar resource but also the demand for local dispatchable generation units, divided in several interesting regions of Brazil. The results of this analysis could be a feedback of the **potential Brazilian market size**, which is necessary for the local and international players.
- The legal framework must ensure a l**ong lasting and a long horizon development** of CSP plants in Brazil. The development of the CSP technology, the developments along the value chain and the local value of the value chain must be monitored and the framework must be adopted if necessary.
- **Financial support** for the development of educational programs, pilot plants and local research related to the CSP technology over a long time horizon supports the development of the technology and creates new and highly qualified jobs.
- **Tax incentives** could be used to support the development of the CSP technology at the **start of the development**. As the value chain of the technology covers several industrial sectors, these tax incentives must not only be limited to "solar specific" products, but also to other "high value" parts like the heat exchangers.
- With **higher taxes** on external products, the **local production** of specific components could be improved by avoiding the import of cheaper components. Nevertheless this measure could also raise the specific costs of the plant in a first step. It must also be ensured that **enough raw materials** are available and the quality standards are fulfilled with the local production.

Conclusion: First steps for a successful development

- The awareness for CSP and the opportunities for the local industry and the energy system must be presented to the involved market players.
- Implementation of first pilot plants with local production to demonstrate the boundary conditions and quality standards.
- Knowledge of the solar resources, in order to allow a successful development.
- Create a long lasting and long horizon legal framework for the CSP industry in Brazil.

4 ESTIMATED DEVELOPMENT OF THE MARKET

In order to estimate the development of the Brazilian CSP market, the influence of the CSP capacity increase on the market is analyzed.

Therefore, each part of the value chain is categorized based on its expected behavior. Following this approach, each category is weighted according to its share of the overall CSP plant. This combination is resulting in an overall estimation of the local content and the related capacity increase.

The different categories and exemplary behaviors are given in Figure 24.

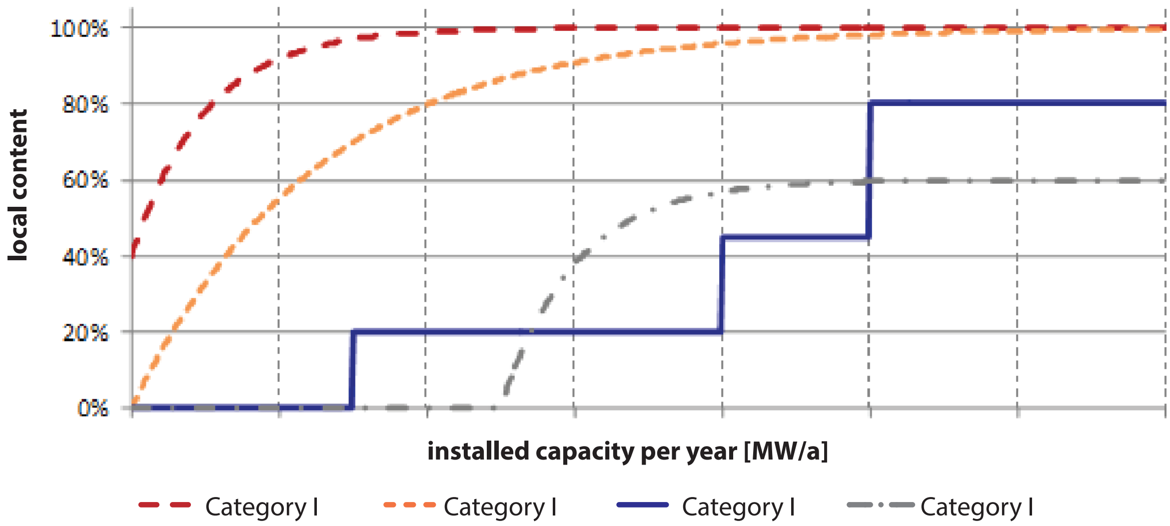

Figure 24: Different categories to quantify the local content of different CSP components, enolcon 2014

Following, the different categories are described, and typical components of the CSP value chain are given. The allocation of the specific component to each category is shown within Table 12.

Some components of the CSP plant (like the solar salt) could not be produced locally, due to the lack of the raw material. These components are not allocated to any category.

Category 1:

Within this category, all components are described that do not need special equipment or knowledge. This works, like the preparation of the site, could be performed by local companies. Main parts of this work are similar to large infrastructure projects. In the initial state, supervising and guidance from CSP experienced companies or workers is necessary, resulting in a limited share of local companies. With increasing amount of installed capacity, this share is decreasing and all necessary works can be performed by local companies.

Category 2:

Within this category, all components are described that could be produced by local companies, but needs special equipments or adaption of already existing production processes. Therefore investment of local companies is necessary. With increasing capacity and a positive market outlook, the companies start to invest and the share of local companies is increasing. With further experience, local companies start to dominate the market; a 100% share is possible with huge effort.

Category 3:

Within this category, all components are included that need specific adoptions to already existing production lines, or the implementation of new production processes. In order to ensure the investment in these new facilities, a certain amount of installed capacity must be achieved. Compared to the other categories, the local content is modeled with a stepwise or discrete behavior. The market for these components is dominated by international players; therefore the market share of local companies is depending on the product quality and the price of the components. A 100% share is not realistically possible.

Category 4:

Within this category, all components are included that are specific components with a high investment necessary in the production lines. These components (like the steam turbine) need a lot of engineering in the design process and a highly accurate manufacturing. A local share is only possible, if already existing manufacturing companies starts to adopt their portfolio to the needs of the CSP plant. As this requires a huge engineering effort, this adaption process will only start after a big threshold is achieved. The market is dominated by big international companies. Market shares of 100% are not possible.

A detailed overview of the different components and their assigned categories is shown within Table 12. The different components are related to their position within the CSP part, like the solar field or the power block. Components that are relevant for all parts of the CSP plants are declared as "overall" parts, like the logistics, EPC-services or the project management.

Table 12: Overview of CSP components and allocation to category

Component	CSP part	Category I	Category II	Category III	Category IV
Buildings	overall	x			
Logistics	overall	x			
Project Management	overall		x		
EPC-services	overall			x	
Cabling & electrical installation & control	overall		x		
Heat Exchangers	Power block		x		
Piping	Power block		x		
Balance of Plant	Power block		x		
ACC / wet cooling	Power block		x		
Steam Turbines	Power block				x
Site preparation	Solar field	x			
Flat Mirrors	Solar field		x		
Support Structure	Solar field		x		
Bended Mirrors	Solar field			x	
Absorber tube	Solar field			x	
Receiver	Solar field			x	
HTF-thermal oil	Solar field			x	
HTF-pumps & auxiliary systems	Solar field		x		
Tracking system	Solar field				x

Component	CSP part	Category I	Category II	Category III	Category IV
Foundation	Solar field	x			
Pumps & Auxiliary systems	Storage system		x		
Heat Exchangers	Storage system		x		
Foundation	Storage system		x		
Vessels	Storage system	x			
Storage material (solar salt)	Storage system				

4.1 CRITICAL COMPONENTS

As shown in the previous chapters, each component of the CSP value chain has its own development path and its own requirements. Nevertheless some components could be matched together, resulting in four possible behaviors of the local content potential. These categories were described within the previous chapter.

Within this chapter, key components of the CSP plants are identified, that have a huge influence on the value of the plant. Therefore an evaluation of the investment costs for the whole CSP plant is shown in Figure 25, based on a typical state of the art 50 MW CSP plant with parabolic trough technology and 7.5 h molten salt storage system is shown, adopted from [24]. The components are divided into the different sections, according to chapter 4.

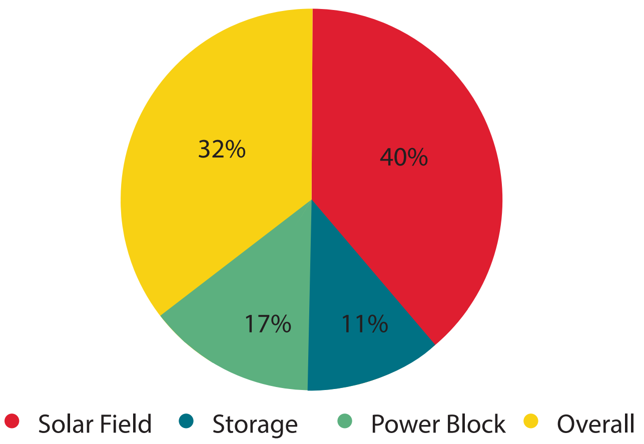

Figure 25: Estimated cost breakdown of a typical state of the art CSP plant, based on [24]

Based on this cost breakdown, most value of the CSP plant is generated with the construction of the solar field. The services performed in the category "overall" are mainly engineering, project management services and infrastructures. As already mentioned, the share of the molten salt storage is dominated by the storage material.

It is challenging to determine a critical market volume for each component, to establish a new manufacturing line. Following, there are some key values for the most critical components given, based on public available information and direct company interviews. There are also several information from the oil and gas sector included, where *Petrobras* has already analyzed the value chain for several components necessary for the development of oil and gas fields [19].

- **Absorber tubes:** According to Schott Solar CSP, first local manufacturing could be started with an equivalent amount of 150 – 200 MW new CSP capacity build per year. As the absorber tubes are only used for line focusing system, this value is only valid for parabolic trough and Linear Fresnel plants. The absorber tubes represent approx. 69% of the overall value of the CSP plant
- **Flat mirrors:** As the production process of the glass production needs a steady utilization, normally several production lines are implemented in glass manufacturing companies. As the solar glass needs another sand quality as normal glass (so called "green glass"), the lines for the production must be adapted and then driven for a long time. Based on values from South Africa [18], an equivalent glass production between 90 130 MW

per year is necessary for an economical utilization. New manufacturing lines will be installed when reaching a capacity of around 200 MW. International players need a higher value to invest in new facilities. Additional local value is created by the necessary logistical effort.

- **Bended mirrors:** The production process for the bended glass production is based on the flat glass production. Due to the bending process additional process steps (bending, tempering) are necessary that require special equipment, especially concerning the size of the used mirrors. Therefore the necessary market volume must be higher than for the flat mirrors. It is estimated to values between 100 150 MW for already existing facilities. For new facilities the threshold is kept to the same values as the flat mirrors. According to international market players, some finishing process steps like the gluing of the ceramic steps could be realized locally with lower capacity values around 50 MW/year. The mirrors represent around 5 8% of the value of the CSP plant. The whole SCA represents between 25 30% of the whole value of the plant.
- **Turbines:** As steam turbine manufacturing is a very complex manufacturing and engineering process, it is not expected that a steam turbine manufacturing only for CSP plants is economical feasible. It seems more likely, that already existing local facilities will react on the increasing market and adopt their existing portfolio to the needs of the CSP plants, especially concerning the size of the steam turbine. It is expected that this effect will start with a yearly amount of 200 MW/year installed capacity. According to [19], the market concentration for steam turbine manufacturers is very high, resulting in only a few local market players. Other parts of the water-steam cycle of the CSP plant, are similar to the "conventional" water-steam cycle of coal or gas-fired plants. Therefore only slight adaptations on the production processes are necessary and an early market entrance is possible. According to [19] especially local produced electrical components are challenging, considering delivery time and price.
- **Heat Exchangers:** Heat exchangers need a lot of detailed works in the design. Most barriers for the implementation of new production facilities are IP-rights and the specific demand (Heat exchangers must be adapted to the special process needs). Therefore only the adaptation of already existing production lines to the need of the CSP plants seems to enable the local production. As heat exchangers are also necessary for other industry sectors, the CSP industry must face this competition. If there is no local production facility available, the engineering services could be performed locally. As the international market players are already active in Brazil, this entrance could be performed with a low annual new build capacity.
- **Solar collector assembly and site preparation:** Labor costs for the site preparation and the assembly of the solar collectors are commonly "natural" local shares. As the necessary skills and equipment are similar to large infrastructure projects, it is very easy to execute these works with local companies. Nevertheless, the engineering, managing and supervising of the necessary works is specific. Therefore, experienced experts are necessary. Site preparation works, foundations and buildings represents around 10 15% of the total value of the plant, of course strongly depending on the site conditions.
- **EPC-services:** The companies responsible for the construction and engineering of the whole CSP plant and acting as ECP are often companies originally based in the construction and implementation of huge infrastructure or power plant projects. Besides their experience in managing big sized projects, they have the financial strengths to handle and to secure the huge investment costs. There are only a few companies around the world acting as EPC for CSP plants. Local companies with experience in similar projects could enter this market, although it seems only likely with a certain market volume. The threshold is estimated with an installed capacity of 100 175 MW/year.

4.2 ESTIMATED MARKET SHARE OF THE DIFFERENT CATEGORIES

Based on the assumptions and the different categories shown in the previous chapter the local share of the different categories is estimated in this chapter. It is assumed, that every CSP plant has a thermal storage system. It is assumed that 50% of the new installed capacity is based on parabolic trough, 30% is based on solar tower and 20% is based on Linear Fresnel technology.

To estimate the behavior of one category, the behavior of each component is estimated. Based on the share of the component on the total value of the CSP plant, the different components are weighted and summed up. So, the resulting and shown behavior represents an average of all components related to one category. With this method, a first estimation of the local share of each category could be created. This analysis could just represent a first estimation. The behavior of the local share must be more refined with a detailed market analysis, which was not part of the scope of this study.

As already mentioned in the previous chapter, not all components could be produced locally, due to the lack of raw material. Therefore, the sum of the following shares is not 100%.

Category 1

The components summarized in category 1 represent approx. 17% of the total value of the whole plant.

The estimated behavior of the local share is shown in Figure 26. The “initial” local share could be estimated with values slightly above 50%. Many local companies are able to deliver the services necessary, resulting in a fast increase of the local shares with increasing amount of installed capacity. As especially the supervising and the quality management needs experienced workers, the last 5 10% of the local share is only slowly increasing.

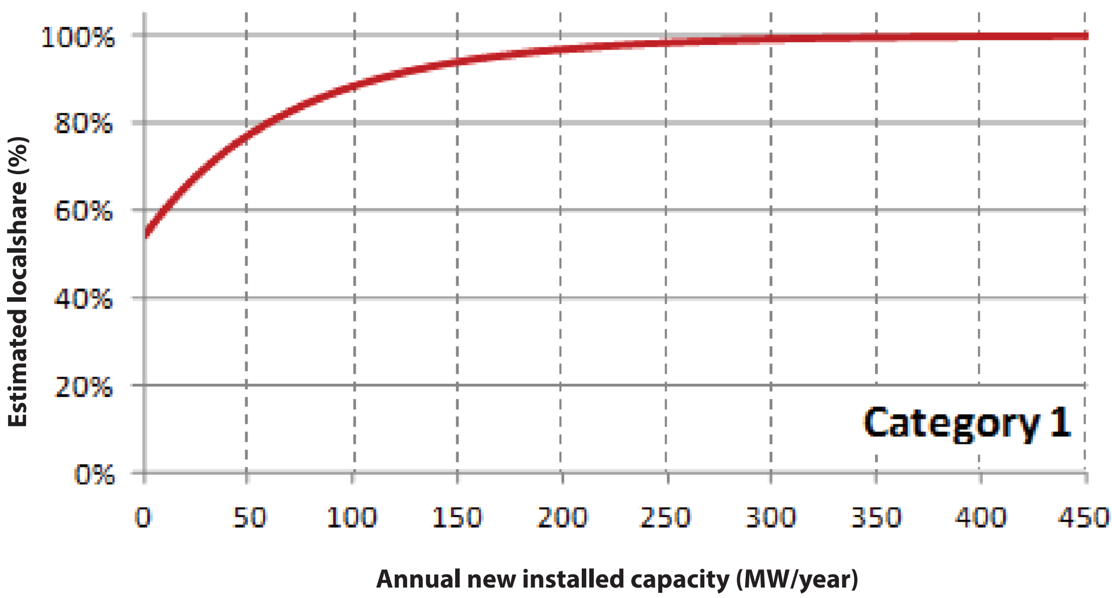

Figure 26: Estimated local share of category 1 components

Category 2

The components summarized in category 2 represent approx. 46% of the total value of the whole plant, resulting in the highest share of all categories.

The estimated behavior is shown in Figure 27. The main increase of this share is expected with an annual new installed capacity of about 50 – 100 MW/year. Especially steel components for the solar field and additional parts for the power block could be provided by local companies that adopt their product portfolio or their production lines to the increasing market.

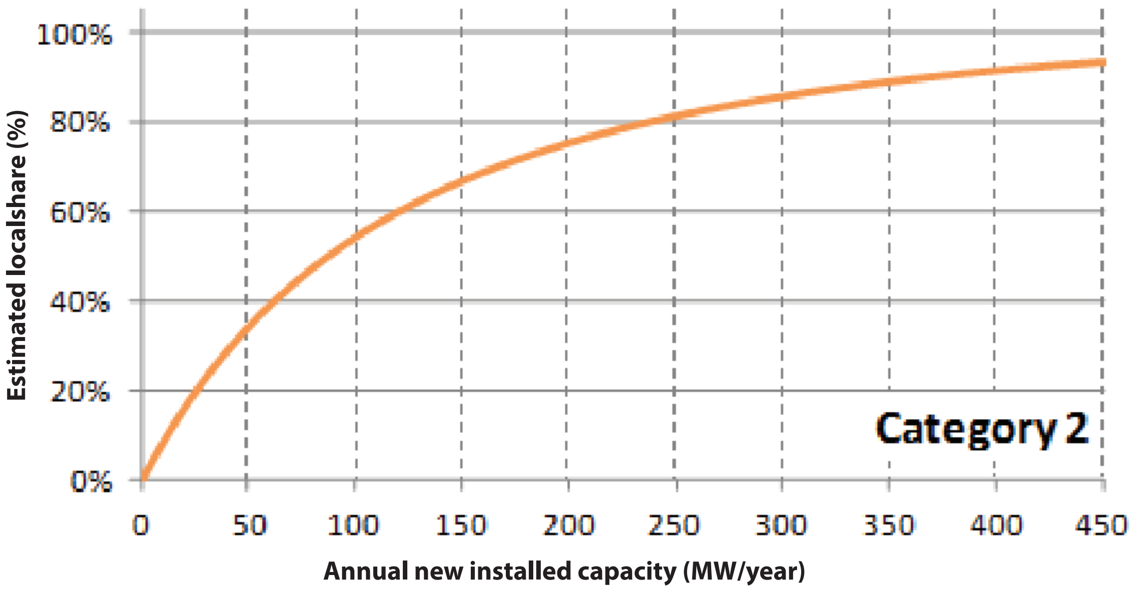

Figure 27: Estimated local share of category 2 components

The last 20% of the local share are, similar to category 1, slowly increasing. Due to the fact that especially international players stay competitive on specific components or some components could only be manufactured with international training or support, the effort to produce this last share is very high.

Category 3

The components summarized in category 3 represent approx. 17% of the total value of the whole plant.

The estimated behavior is shown in Figure 28. Compared to the other categories, no continuous increase is expected, to the fact that new production facilities or services are introduced. For this analysis it is expected that with an annual new installed capacity of around 100 MW the first EPC-services could be provided locally. It is assumed that only one plant could (over 3 years) be built by this local EPC at once. A huge increase could be observed between 150 MW and 200 MW new installed capacities with the implementation of the first receiver manufacturing lines and bended mirrors production lines.

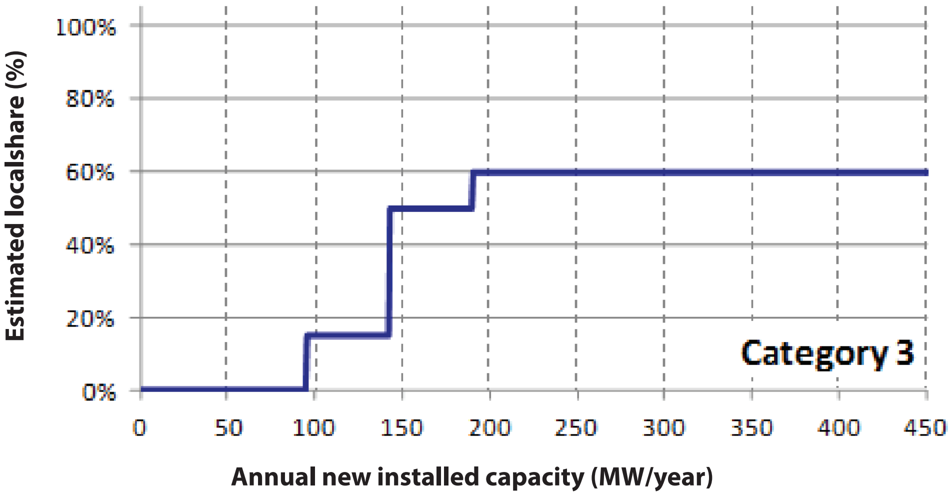

Figure 28: Estimated local share of category 3 components

As the international market players are very competitive and experienced in this sector, especially concerning the EPC-business, a maximum local share of 60% is expected.

Category 4

The components summarized in category 4 represent approx. 8% of the total value of the whole plant.

The estimated behavior is shown in Figure 29. This category is dominated by the development of the steam turbine. As shown in chapter 4.1, it is expected that first local manufacturers starts to adopt their portfolio with an annual installed capacity of around 200 MW.

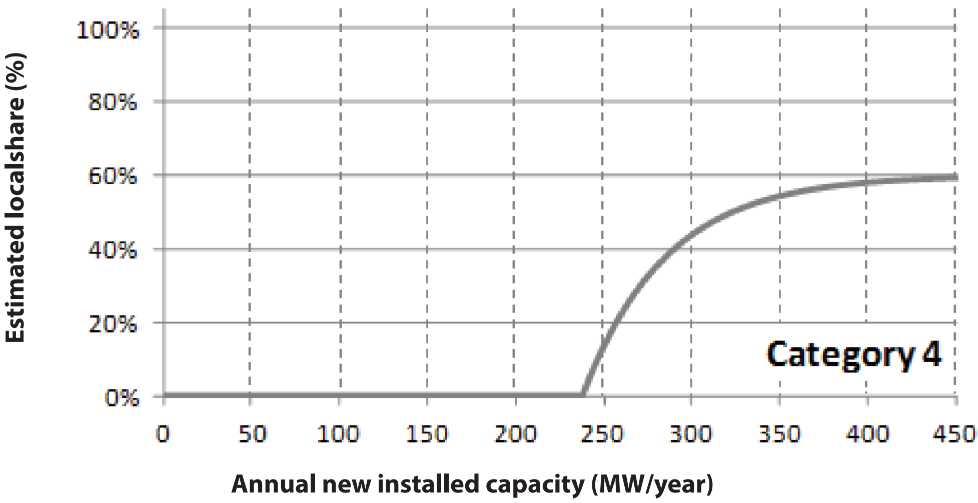

Figure 29: Estimated local share of category 4 components

4.3 ESTIMATED LOCAL SHARE

Based on the shown estimations for each category, as weighted sum of the different shares and behavior is calculated, estimating the overall local share of the CSP industry for an annual new installed capacity. The resulting behavior is shown in Figure 30. Of course, this behavior is a rough estimation, based on the above mentioned assumptions.

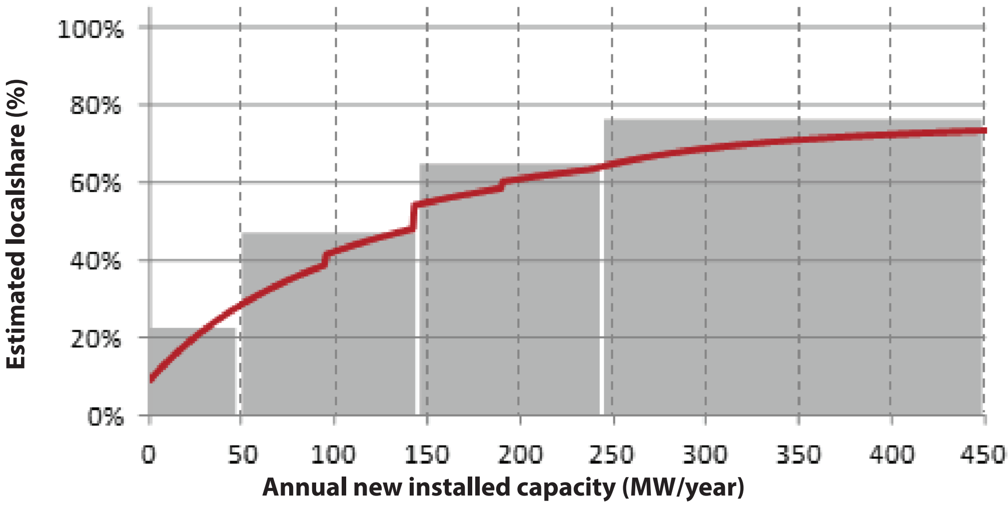

Figure 30: Estimated local share of the CSP industry, enolcon 2014

Nevertheless, the behavior could be divided into four different sections based on the development and the adaption of the local industry.

The initial local share of around 20% could be considered as the “natural” local content. This could be achieved without any adoptions of the local industry.

The second stage is mainly dominated by components defined in category 2. As the main growth of these components is in the range between 50 MW and 100 MW of new installed capacity per year, the huge impact on the overall behavior is clearly visible. Nearly half of the value of the CSP plants could be produced locally, if the (already existing) production lines and facilities are adapted to the needs of the CSP industry.

With the future increase of the annual new installed capacity, also further adoptions within the related industry are necessary. With the implementation of new manufacturing lines and the investment in new facilities of international companies in Brazil, the local share is further increased. With new installed capacities above values around 200 MW per year, local shares of around 60% of the whole CSP plant could be achieved. In order to ensure the investment in new production lines and facilities, the yearly increase of the installed capacity must be secured over a long time horizon.

As the rate of new installed CSP plant exceeds 250 MW per year, adoptions in all industry sectors related to the CSP value chain are necessary and suitable. With the implementation and adoption of new facilities and the local production of highly specific components, the local share of the CSP value chain could be increased to values above 75%, comparable to values that are achieved in Spain or the US. As already mentioned, these values could only be achieved with ensuring a steady annually increase of the CSP capacity.

5 SUMMARY AND CONCLUSION FOR BRAZIL

Based on its setup the value chain of a CSP plant covers a wide range of industrial sectors, which are involved through the whole life cycle of the plant. Therefore local production and service companies benefit from the CSP plant, as the required components are similar to common industrial parts. Nevertheless, the local companies need to adapt their product portfolio and their production lines, to deliver the necessary components in the required quality and accuracy.

As nearly all necessary components of the CSP plant have an influence on the performance of the plant, it is necessary for the local companies to achieve the international level of standards on accuracy and long-term stability. Therefore investment for new or updated production lines and for education and training of the own workers are necessary. Cooperation or joint venture with already established and active market player also enables a fast entrance into the market. Based on these cooperation Brazilian and international market player could develop together new or improved components for the Brazilian and the international market.

Within this report it has been shown, that a local share of around 70% could achieved with an annual increase of approx. 250 MW or more. Especially within the increasing market, the estimated local share is rising very fast. But it has also been considered, that without any adaptations in the different industry sectors, only a small local share is achieved. An emerging CSP market needs the support and the active market participation of the local companies. With local companies active on the value chain, also positive impacts on the energy generation costs are possible.

Both, investors of CSP plants and the companies along the value chain needs attractive and reliable boundary conditions to secure their investment in new facilities and the power plants. The legal framework must follow some guidelines:

- A high local share must be supported without increasing the costs of the plant with a unrealistic high local share.
- Financing of new equipment and training of workers for local companies must be supported.
- Based on the needs of the federal state and the particular regions, detailed and long horizon action plans to increase the installed CSP capacity supports the investment security.

The motivation to invest in CSP for Brazil differs from most countries in the world. The main focus must be in developing a new technology that enables a dispatchable operation during several days in regions without enough hydro plants with storage. For other emerging markets in the world, thermal storages and dispatchability are also an essential part of the CSP technology, but there are also additional points like CO_2-reduction or the increase of generation units. **The key focus for Brazil could or even must be the development of new energy generation units with integrated storage technology that could be implemented in regions without big water reservoirs.**

A structured and suitable local value chain, based on CSP plants has a positive impact on several aspects for Brazil:

- **Socio-economic benefits:** The CSP plant and the related value chain create several direct jobs, not only at the construction site of the plant but also in the related industry sectors delivering the components and sub-components. These jobs are not only low-skilled works but also high-skilled and academic jobs.
- **Technology development:** The CSP technology has developed during the last years to a nearly mature technology, regarding the main parts of the plant. Nevertheless there is a huge innovation potential in nearly every component of the plant, regarding long time stability, performance or cost efficiency. Based on local developments new solutions and innovations for the world market could be found.

A successful implantation of a CSP industry in Brazil has a positive impact on all included actors along the value chain, like research institutes, component suppliers, project developers or energy suppliers. Based on the experiences of other countries with CSP and other developed industry-sectors in Brazil, a pathway to establish a sustainable CSP value chain in Brazil should be developed.

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