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Energías Renovables
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en Chile

CSP – localization potential:

Analysis and further potential for Chile

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Declaration:
The content of this study is based on a study elaborated by GIZ Brazil, which was herein adapted to the local context of Chile.

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List of abbreviations

ARS	Argentina Pesos
BRL	Brazilian Real
CLP	Chilean Pesos
CSP	Concentrated solar power
DNI	Direct normal irradiation
EPC	Engineering, procurement, construction
EUR	Euro
FTE	Full-time employment
GDP	Gross domestic product
HCE	Heat collector element
HTF	Heat transfer fluid
LCOE	Levelized costs of electricity
O&M	Operation and maintenance
PPA	Power purchase agreement
PURPA	Public utility regulatory policy act
PV	Photovoltaic
R, D&I	Research, development and innovation
RD	Royal Decree
RESIA	Reliable electricity service investments act
RTO	Regenerative thermal oxidizer
SCA	Solar collector assembly module
SCE	Solar collector element
SEGS	Solar energy generation station
US	United States of America
USD	U.S. Dollar

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1. Introduction

Chile is one of the few markets offering a nearly perfect troika of advantages to develop renewable energies and especially CSP: the renewable resources (solar irradiation) are among the best of the world, there are poor domestic fossil fuel resources available and the business environment is stable and offers big advantages. Compared to other emerging markets, not only in Latin America but worldwide, this troika of advantages is hard to find. For the further development of renewable energies in Chile, solar thermal power plants can play a key role [1].

Solar thermal power plants for electric 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 1.

Figure 1-1: 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 electric system. Due to the fact that electric 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 electric 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 Chile for energy generation units including the possibility to store energy, CSP could be one part of the solution.

Based on the available solar resource, the so called "direct normal irradiation" (DNI), Chile offers a huge potential for the CSP technology. Especially in the north of the country, DNI values of more than 3200 kWh/year are measured. Compared to other emerging markets these values are quite high, see Table 1.

Table 1: Overview of DNI values of selected countries

Country	Average annual sum of DNI value (kWh/m²)	Maximum annual sum of DNI value(kWh/m²)	Installed CSP capacity
Spain	2'200	2'400	2310 MW_{el} (operation)
Morocco	2'400	2'700	~170 MW_{el} (under construction)
U.S. (Nevada)	2'500	3'000	1470 MW_{el} (operation), 400 MW_{el} (construction)
South Africa	2'800	2'900	300 MW_{el} (under construction)
Chile	2'900	3'200	110 MW_{el} (under construction)

Besides the good solar resource, the need for a secure and highly available energy supply is huge, especially in the North of the country with its mining activities. The combination of a very high solar irradiation and the thermal storage possibility of CSP plants results in a highly promising and cost competitive alternative for the Chilean energy sector.

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 adaptations 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 classic power plant industry also companies active in the steel and glass industry, chemical and petro-chemical 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 for CSP technologies. 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 Chile 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 was mainly influenced by the development in 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 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 1 these phases are shown.

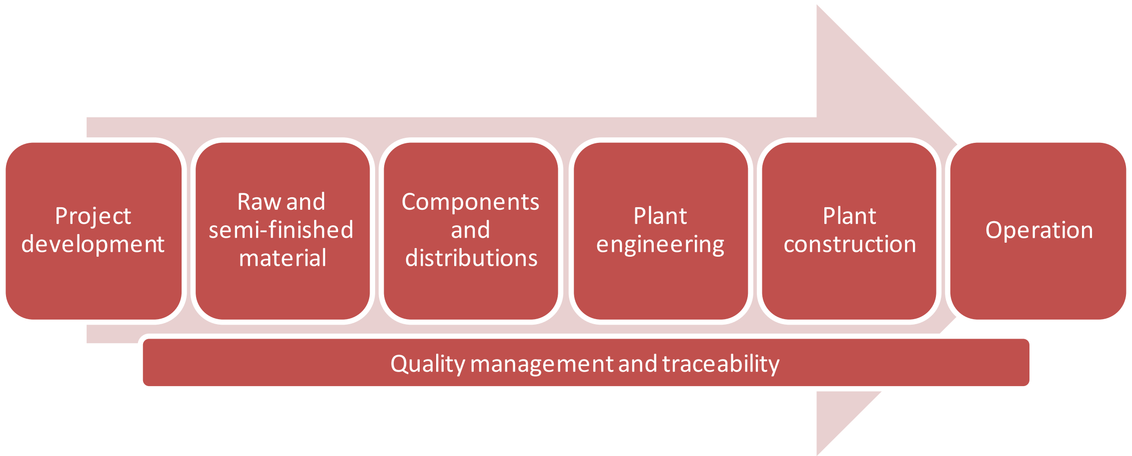


Figure 2 1: Different phases along the development phase of a CSP plant

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 are 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 site, 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. The costs for this phase are very often underestimated.

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 logistic 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 (parabolic trough), 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 [2].

Components and subsystems

The CSP plant consists of several key components or subsystems produced independently. For each component, several specific industrial sectors are necessary. The considered components are:

- Solar field (subsystem): 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 (subsystem): 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. The EPC is selecting all the suppliers and awards most of the jobs to subcontractors. Sometimes, even before the contracting entity chooses the final EPC, certain component suppliers have been already chosen 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 [2].

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 components. In case of a failure, the supplier must be able to offer sufficient and precise information about the production 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 and subsystems.

2.1.2. Industrial view on the value chain

The scheme shown Figure 2-2 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 2 2. This overview of the value chain for all relevant components is similar for all CSP technologies.

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.

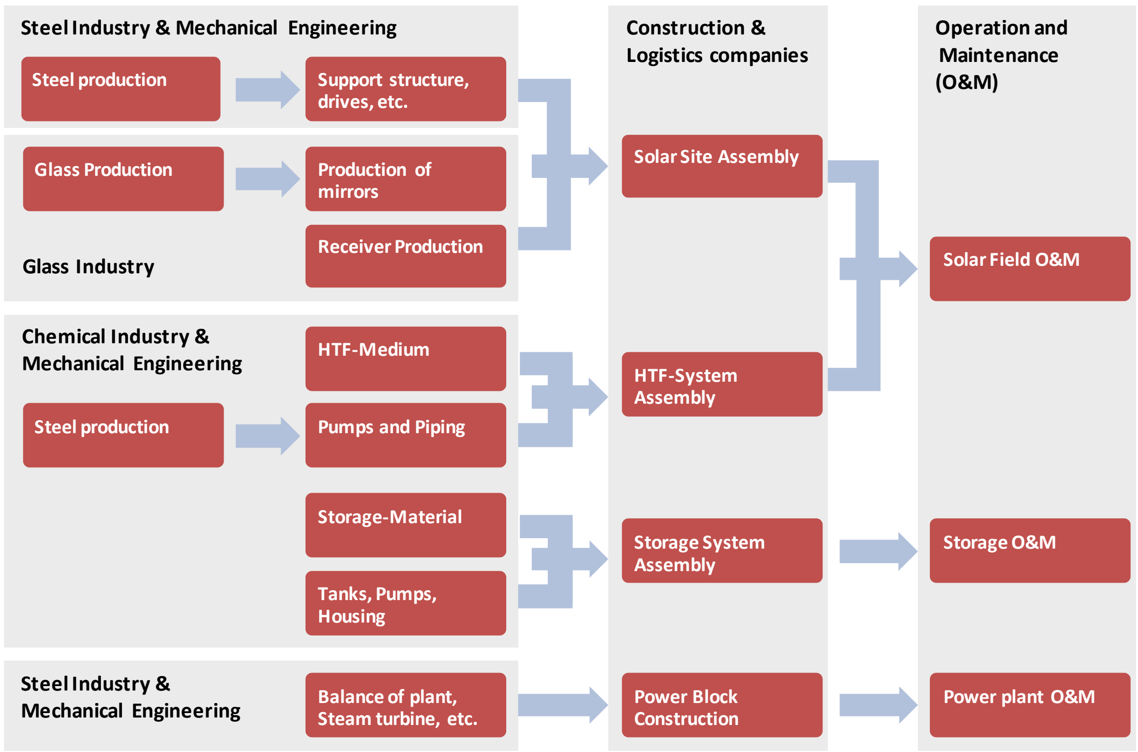


Figure 2 2: Overview of all industrial components related to the CSP plant

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 from 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 2 3.

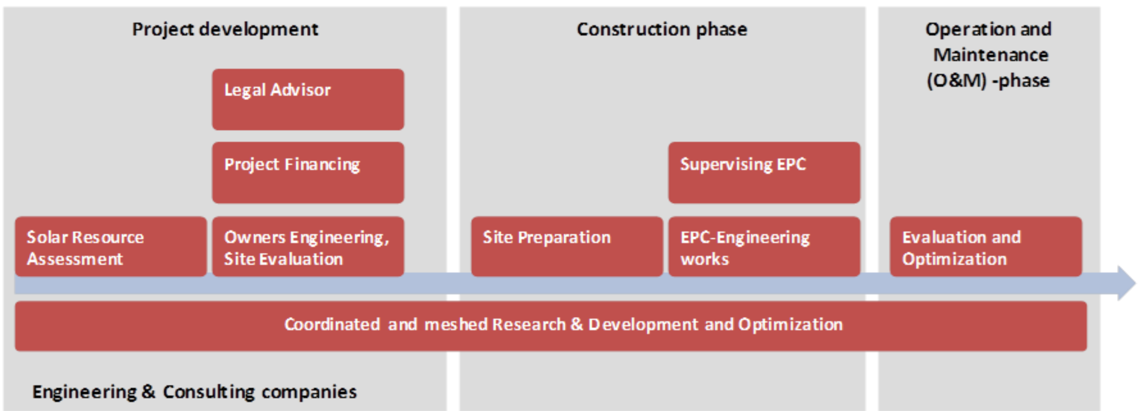


Figure 2 3: Overview of all engineering services related to the CSP plant

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 continuous 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 specific 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 2 4 the different designs of heliostats (for solar tower), solar collector element (SCE, parabolic trough) and primary reflector module (linear Fresnel) are shown.

Figure 2 4: 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 2 5.

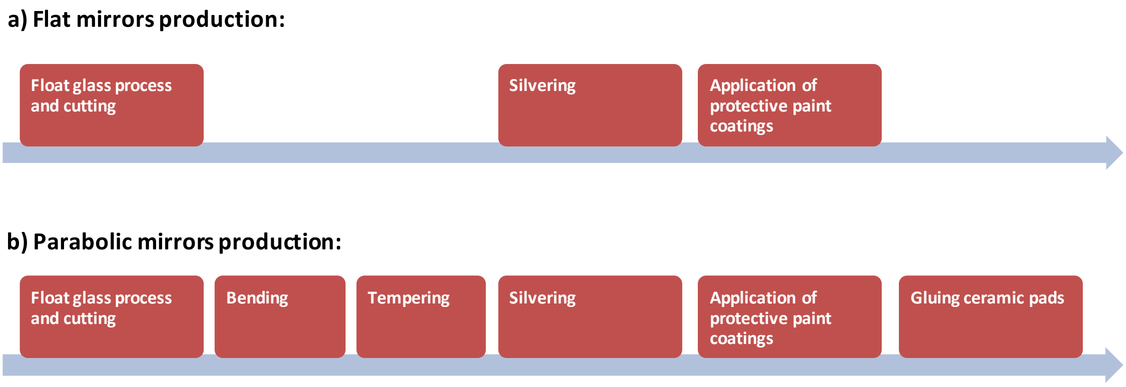


Figure 2 5: Construction of solar glass mirrors, adapted from [3]

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 (FLABEG Solar, 2012). 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 (FLABEG Solar, 2012):

- *Parabolic trough:*
  - Dimensions: up to 2030x2010 mm
  - Thickness: 4 mm
  - Exemplary demand (*Andasol, Spain*): Around 574’050 m² 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 can 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 (Anderson, 2014) there are silica sands available in Chile. There is no information about the iron content available.

As Chile has a very strong mining industry, there are also other raw materials like iron, steel, cement, cooper or nitrates available. This offers on the one side a good availability of raw materials. One the other hand, as Figura 2-6 shows, these mines are located in the north of Chile in regions with excellent solar irradiation, offering the possibility to cover the thermal or electric load (or even both) of these mines with CSP.

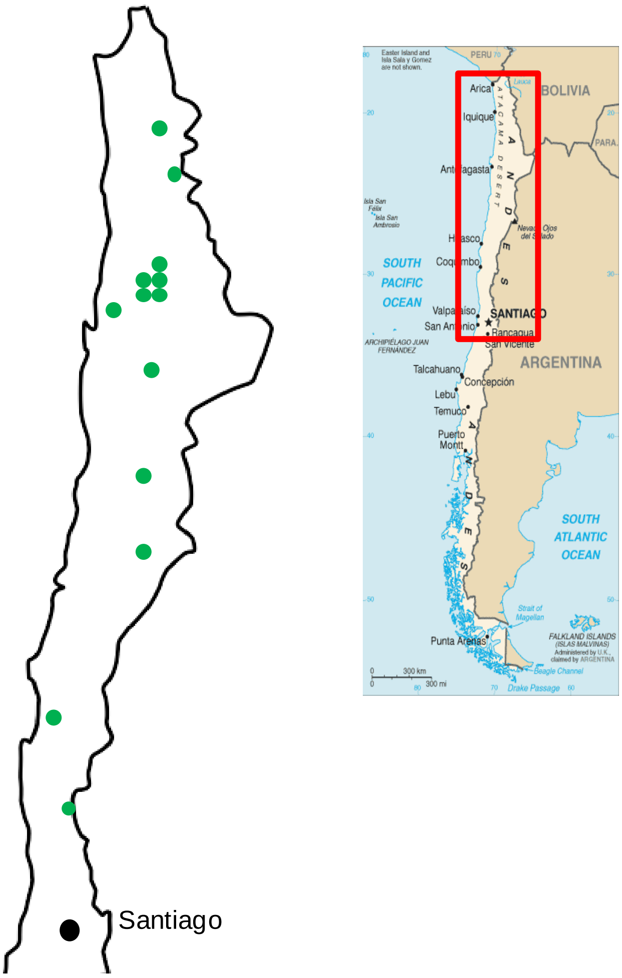


Figure 2 6: Location of selected, relevant mines [6]

The steel support structure necessary for the SCE (solar collector element) 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 (parabolic mirror), 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”, exemplarily shown within Figure 2 7. The overall manufacturing process could be arranged along an automatic assembly line (Herrmann & Pfänder, 2013).

Figure 2 7: Exemplary assembly rig for a SCE (here Flagsol) [7]

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 site.

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. Logistics 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, requiring only slight adaption and investment by 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 superheated 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, 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. As current suppliers only mines in China and Chile are able to serve big markets. The market is dominated by a few players, with the company SQM from Chile as market leader. 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.
  The main mines of SQM are presented in Figure 2 8, the raw materials *Caliche Ore* and *Salar Brines* are used to produce nitrates.

Figure 2 8: Main mining areas of SQM for Caliche Ore and Salar Brines [8]

- *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 industrial applications necessary like regenerative thermal oxidizers (RTO) or exhaust air treatment.

Based on the market framework in Chile, CSP plants with thermal storage offer an additional value to the grid. The thermal storage system could be used to stabilize the grid. For industrial applications like the production of process steam or process heat (e.g. for the mining industry), CSP plants with thermal storage enable a 24 h production.

Thinking of cost reduction potential, the thermal storage system is one possibility to increase the load capacity of the plant. Together with the high irradiation and the lower costs of the thermal storage system, this effect reduces the levelized costs of electricity (LCOE) for the CSP plant significantly.

Summarized, thermal storage systems and especially molten salt storage systems are one key element for the further development of the CSP technology in Chile. It must be emphasized that experienced local companies are able to enter this sector very easily. Companies with experience in handling the necessary solar salts could also further develop the used storage materials.

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 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 the Chilean CSP Projects, for both thermal and electric usage.
- As the main supplier of the solar salt is based in Chile, further development potential is possible.

2.2. 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 electric 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 itself, shown in Figure 2 9, 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.

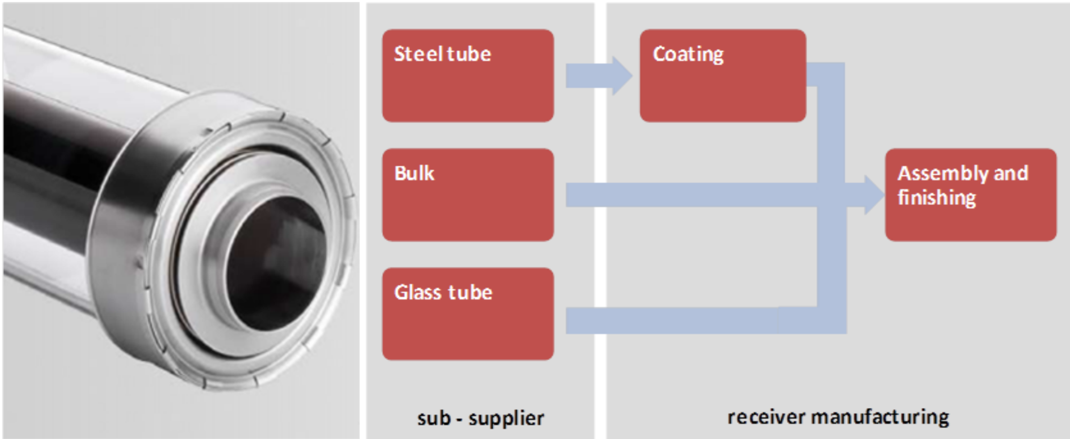


Figure 2 9: Solar receiver (here SCHOTT PTR70) and assigned value chain [19]

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 MW 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.

2.3. **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.

2.3.1. 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 demonstrations plants have been built in the other European countries so far (e.g. Germany, Italy and France).

2.3.1.1. Generation Mix in Spain

Traditionally, the electric 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 shows in Figure 2 10, usually more than one half of the annual electricity has been produced by combusting fossil fuels. During the last three years energy consumption decreased continuously. The further increase of renewable energies is clearly visible, resulting in a share of over 50 % (hydro and other renewable) in 2013.

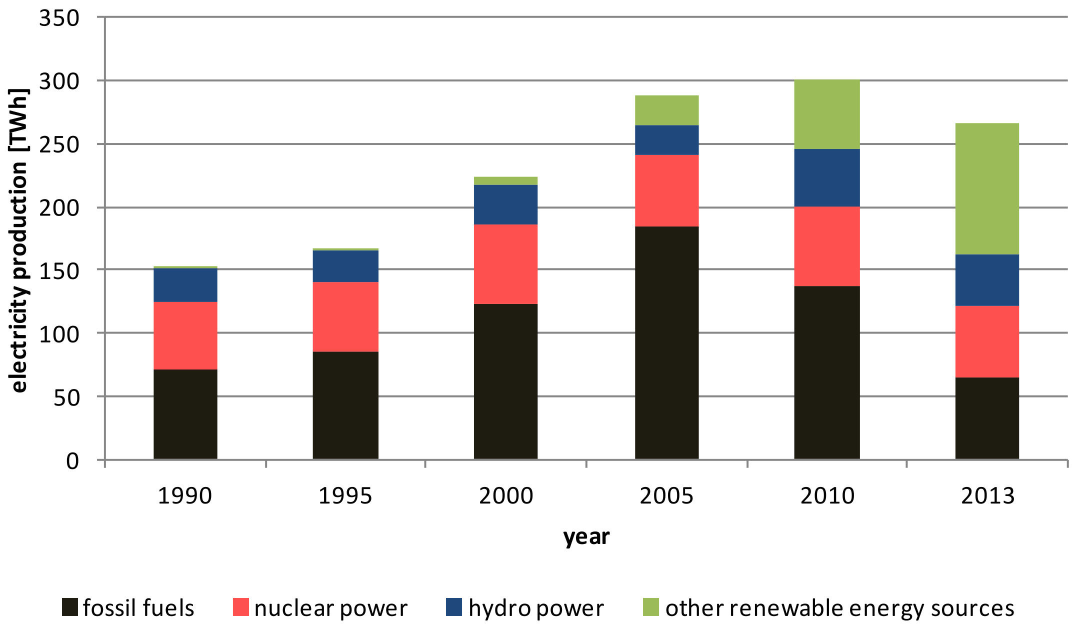


Figure 2 10: Electricity Production in Spain by Source, 1990 to 2010, based on [9] and Red Electrica de España

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. 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 Figure 2-10**¡Error! No se encuentra el origen de la referencia.** 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 CO2.
- Nuclear power is considered as bridge technology until renewable energies are developed.
- Increase in share of renewable energies in Spain due to high subsidies (until 2012).

2.3.1.2. Development of CSP in Spain

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 2 11 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 [10]:

- Large solar irradiation
- High subsidies for CSP (until 2012, described in detail in chapter 2.3.1.3)
- Support for research on CSP since the 1970s

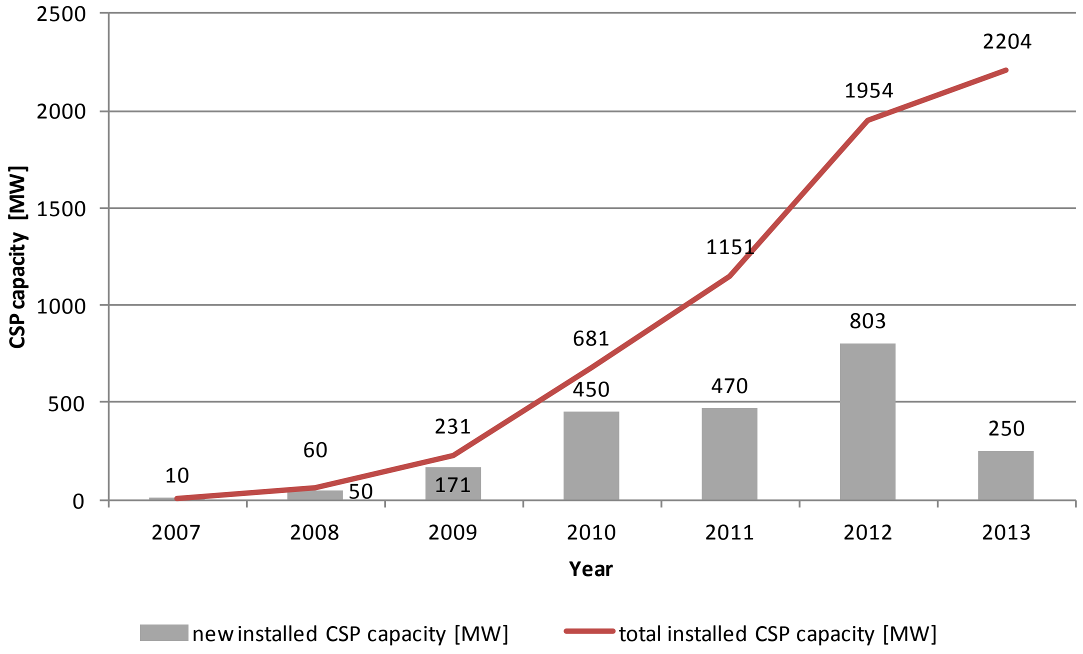


Figure 2 11: Development of installed CSP capacity in Spain, 2007 to 2013, based on [11]

The following Figure 2-12 shows the average direct normal irradiation (DNI) in Spain (left) and the location of the operating CSP plants. In comparison with the average direct normal irradiation in the North of Chile (right), the solar potential in Chile is much better compared with Spain. With the first plants under construction in the region of Antofagasta, the development has just started.

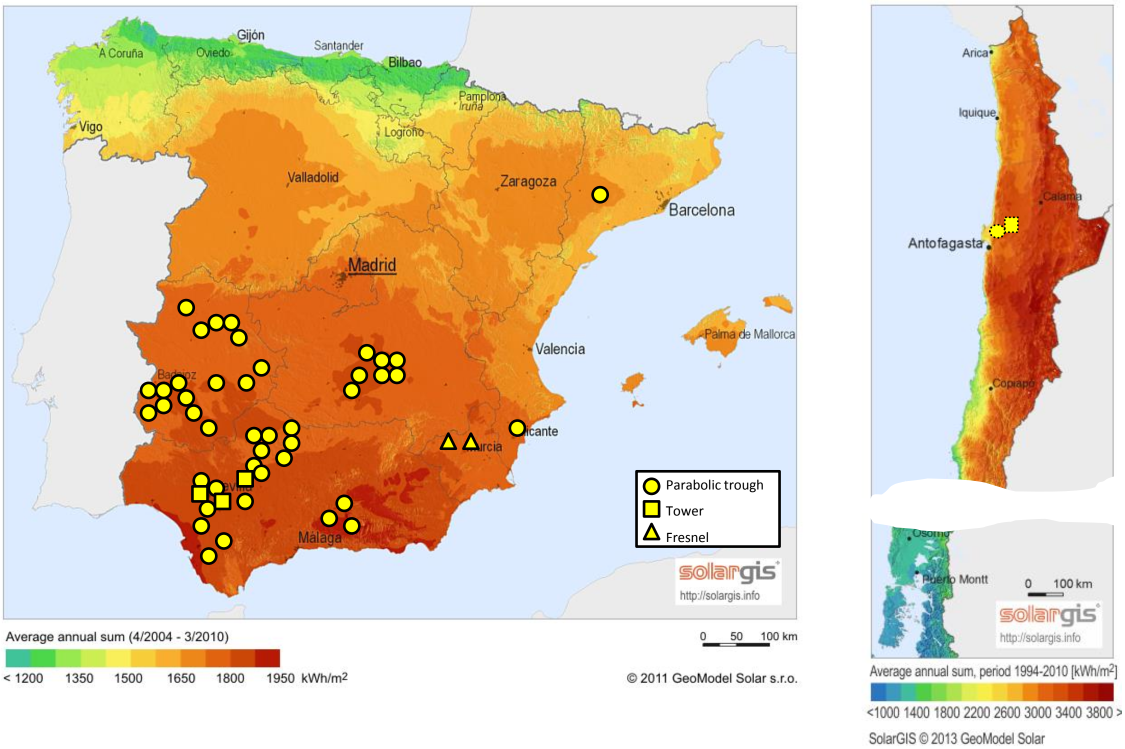


Figure 2 12: Average direct normal irradiation in Spain with location of operating CSP plants and Chile with plants under construction, based on [11] and [12]

The graph shows that the CSP plants are located in areas with high DNI and almost only parabolic trough technology is used. Because subsidies were 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 2 13 shows the global CSP capacity in 01/2014 by status:

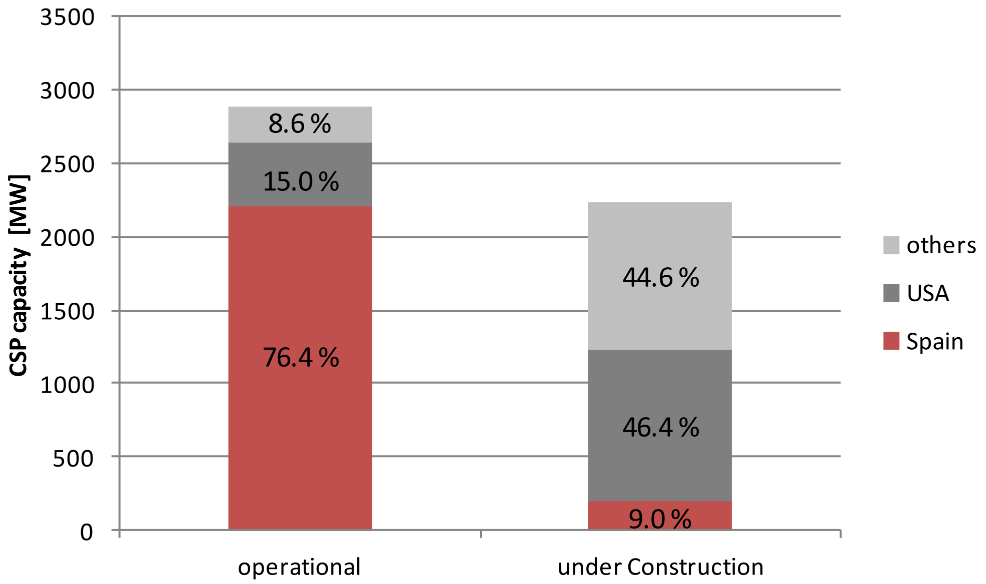


Figure 2 13: Global CSP Capacity in 01/2014 by status]

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.

2.3.1.3. Legal framework for CSP in Spain

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 2 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 2: Laws and regulations in Spain 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 3 gives an overview on the laws and regulations between 2002 and 2008 setting the feed-in tariff for CSP:

Table 3: Laws and regulations in Spain 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 4.

Table 4: Laws and regulations in Spain 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, Jose 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 [13].

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 technically or economically based.
- Investors need security.

2.3.1.4. Economic Impact in Spain

The economic impact of CSP in Spain is particularly interesting because the rise of CSP occurred while the Spanish economy fell. The following graph (Figure 2 14) shows the contribution of CSP to the Gross Domestic Product (GDP) of Spain in the years 2006 to 2012:

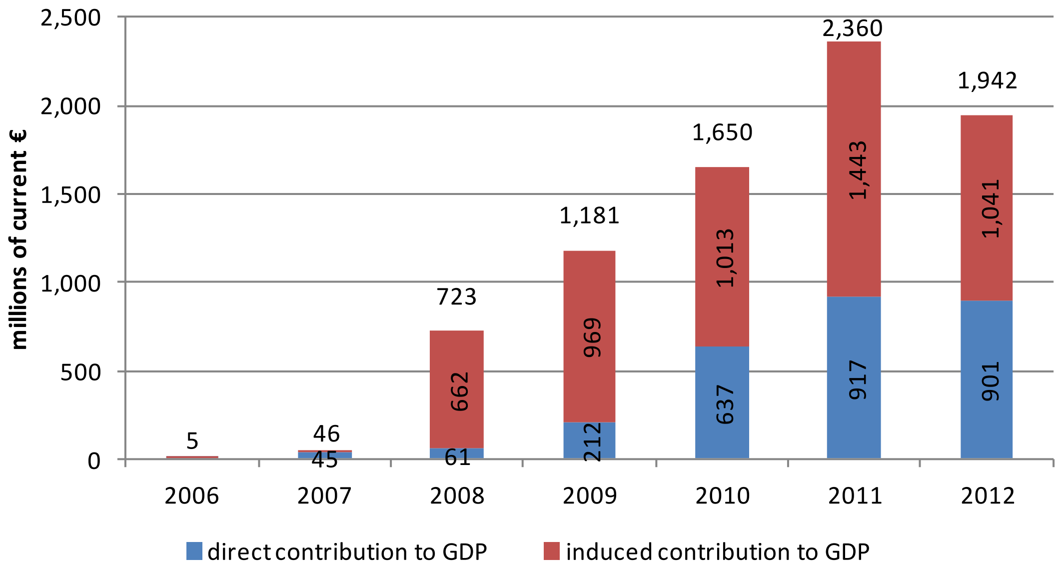


Figure 2 14: Contribution of CSP to GDP in Spain, 2006 to 2012, based on [14]

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 (Protermo Solar, 2011).

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 are shown in the following Figure 2-15:

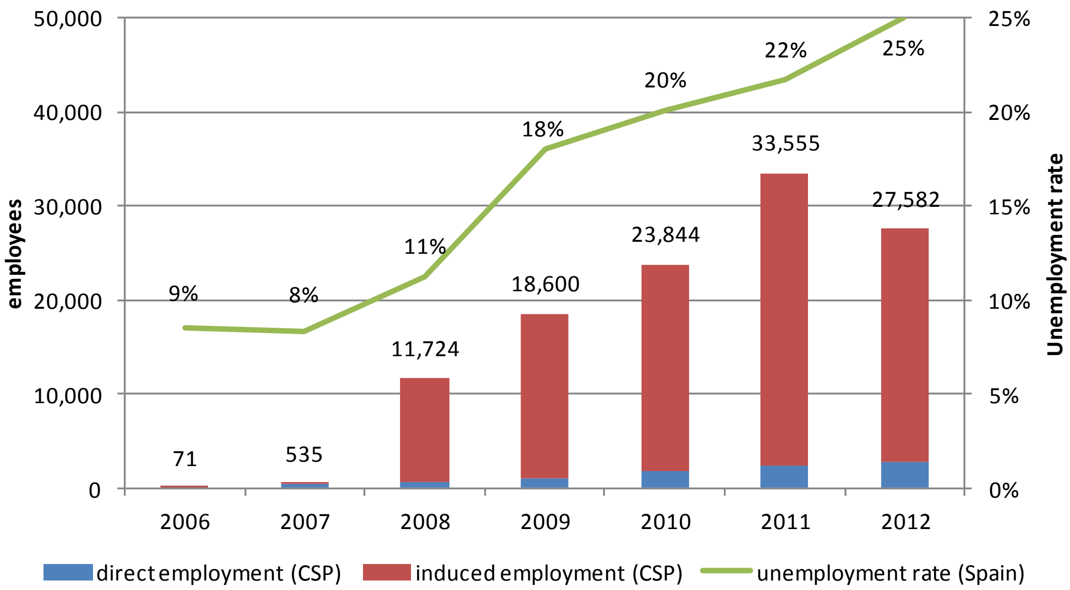


Figure 2 15: Employment through CSP in Spain, 2006 to 2012, based on [14]

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 [10].

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 [15].

Figure 2 16 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 [10]. 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.

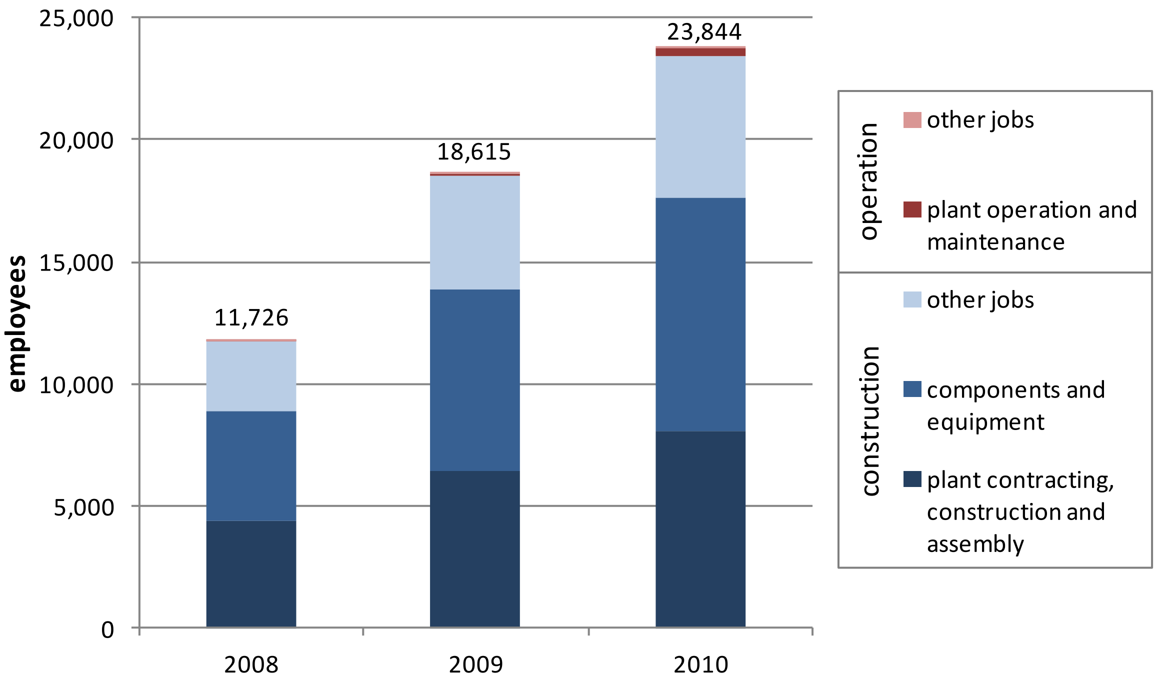


Figure 2 16: Employment through CSP in Spain by sector in 2008 to 2010, based on [10]

When looking at the economic impact of CSP in Spain it is also important to look at the local content, i.e. the percentage of investment which remains in Spain. Because Spain has been using mainly fossil fired thermal power plants, they have great knowledge on thermal power plants. Figure 2 17 shows the development of the local content in the CSP industry for CSP plants with and without a thermal storage from 2008 to 2010. For the following two years 2011 and 2012, the local content remained on the 2010 level. With the stop of new build plants, no calculations are available any more.

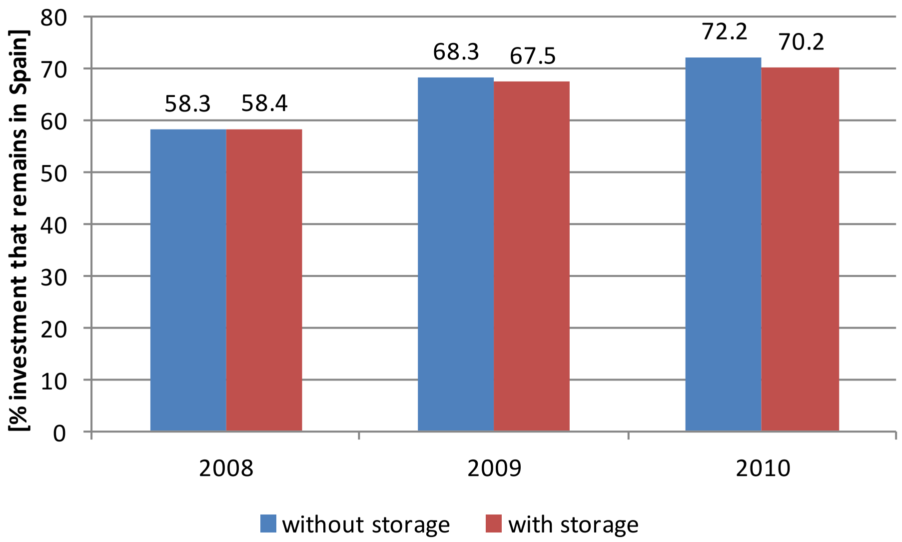


Figure 2 17: Local content of CSP in Spain from 2008 to 2010, based on [10]

While in 2008 only little more than one half of the investment remained in Spain, was it in 2010 almost three quarters. The following graph (Figure 2 18) shows the distribution of local content by sector for CSP plants with storage:

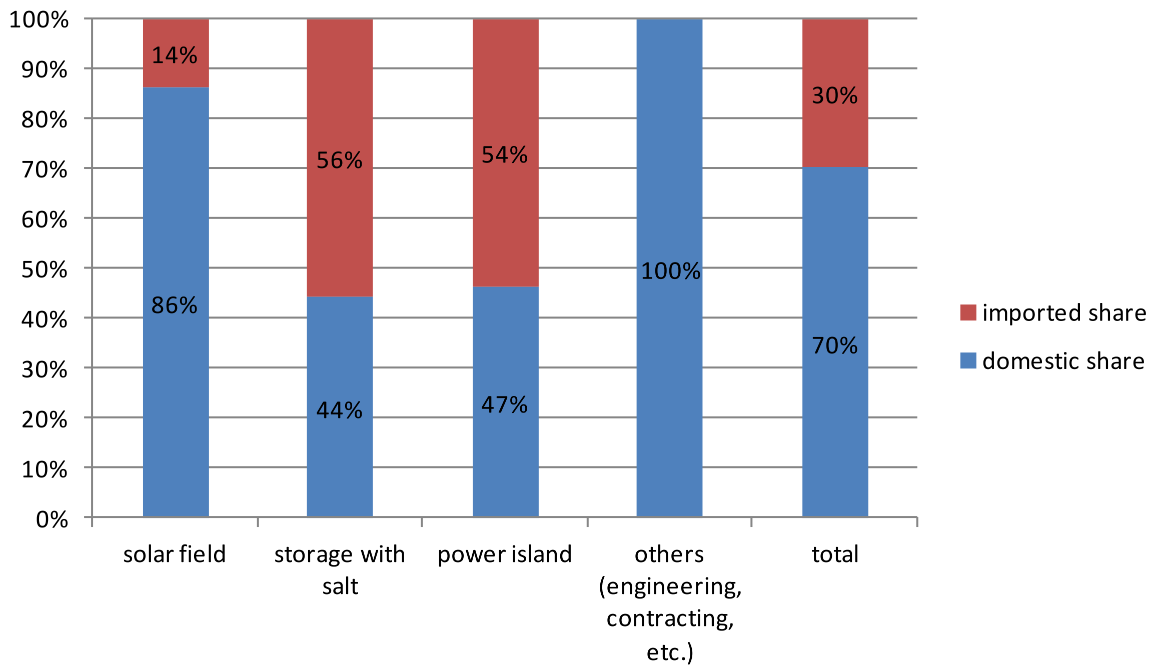


Figure 2 18: Itemized percentage of investment which remains in Spain for CSP with storage (2010), based on [10]

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 2 19:

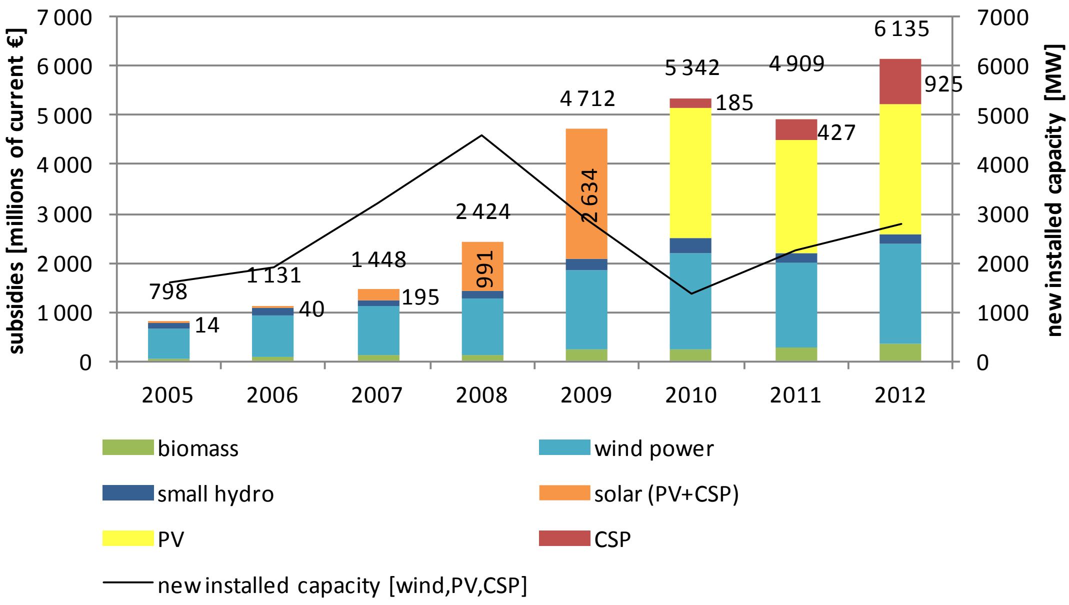


Figure 2 19: Annual subsidies paid to renewable energies in Spain, 2005 to 2012, based on [14]

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 the 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.

2.3.2. USA

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

Figure 2 20 shows the annual installations of CSP plants between 1984 and 2013 in the USA and additionally plants under construction and under development by technology.

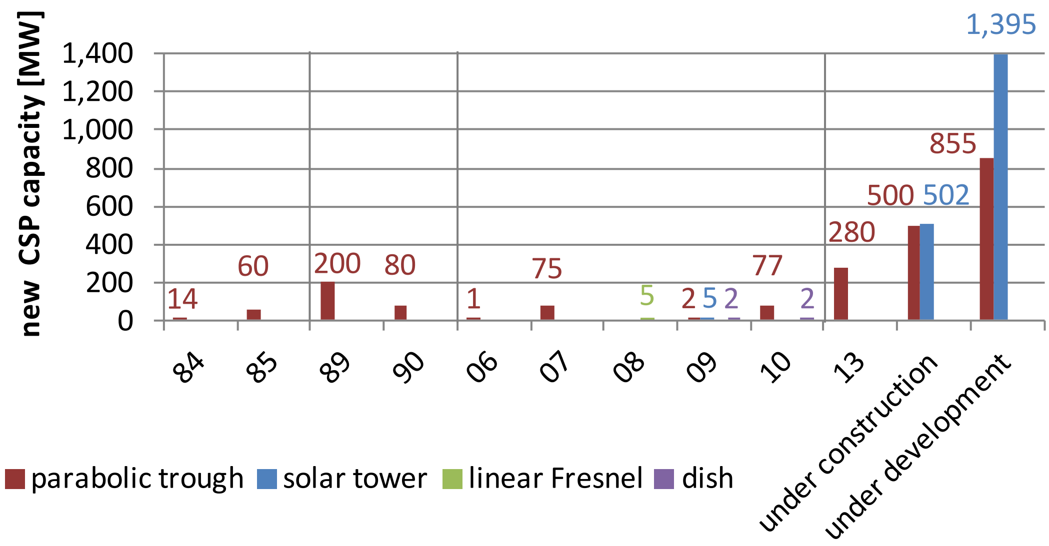


Figure 2 20: Annually new installations of CSP capacity in USA, 1984 to 2017

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

2.3.2.1. History of CSP Plants in the USA (1980-2000)

Between 1970 and 1980 the world market price of oil increased to the double 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, an extensive research and development started in USA and in Europe (especially in Germany and Spain) on large scaled concentrated solar power plants.

In 1978, the US 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 electric power of 13.8 MW. The SEGS IX started operation in 1990 with an electric power of 80 MW. The total installed electric 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.

2.3.2.2. 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 5:

Table 5: Technical data of SEGS projects

Plant	Year	Capacity [MW_e]	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 6:

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

Table 7: 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

2.3.2.3. Solar towers in the USA

In the beginning of the 1980s a solar tower was designed and erected by the *Institute Development of Energy* (DoE) with an electric 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

[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.

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

Technical Data (Table 8) and key supplier (Table 9) of Solar One and Solar Two:

Table 8: Technical Data of Solar One and Solar Two

Plant	Cap-acity [MW_e]	Number of helio-stats	Area of one helio-stat	Aperture area [m²]	Medium	Turbine temperature [°C]	Turbine pressure [bar]	Storage tempera-ture [°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 9: 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 where built.
- Nearly all components were manufactured by US based companies, influencing the whole CSP industry.
- After a drop of energy prices in the 90s, no more commercial plants were built.

2.3.2.4. Recent development in the USA (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 10: CSP projects in the USA since 2006

Power Plant (Owner/EPC contractor if known)	Location	Installed Capacity [MW]	Operational since	Technology
Saguaro Power Plant (Arizona Public Service/Solargenix)	Red Rock	1.16	2006	Parabolic trough
Nevada Solar One (Acciona Energía/Lauren Engineering)	Boulder City	75.00	2007	Parabolic trough
Kimberlina Solar Thermal Power Plant (Ausra/Ausra)	Bakersfield	5.00	2008	Linear Fresnel
Sierra Sun Tower (eSolar/eSolar)	Lancaster	5.00	2009	Solar tower
Holaniku at Keahole Point (Keahole Solar Power / not known)	Keahole Point, Hawaii	2.00	2009	Parabolic trough
Colorado Integrated Solar Project (Xcel Energy/Abengoa)	Palisade	2.00	2010	Parabolic trough
Martin Next Generation Solar Energy Center (FloridaPower/Lauren Engineering)	Indiantown	75.00	2010	Parabolic trough
Maricopa Solar Project (Tessera Solar/Mortenson)	Peoria	1.50	2010	Dish
Solana Generating Station (Abengoa/Abener-Teyma)	Phoenix	280.00	2013	Parabolic trough
Ivanpah Solar Electric Generating Station (NRG Energy,BrightSource/Bechtel)	Primm	392.00	2014	Solar tower
Crescent Dunes Solar Energy Project (SolarReserve/ACS Cobra)	Tonopah	110.00	Under construction	Solar tower
Abenogoa Mojave Solar Project (Mojave Solar/Abener-Teyma)	Harper Dry Lake	250.00	Under construction	Parabolic trough
Genesis Solar Energy Project (NextEra Energy/Blattner)	Blythe	250.00	2014	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.

2.3.2.5. Legal framework for CSP in the USA

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 11: Overview of incentives in the USA, based on [16]

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 (CSP Today, 2014). It was designed for projects larger than $ 25 million starting construction before September 30, 2011 and with a repayment period of 30 years (U.S. Department of Energy, 2013).

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.

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 economic risks and opportunities

The whole value chain of the CSP plant offers several technical and economic opportunities for 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 job creation opportunities. Of course, during the construction phase of the plant, direct jobs are created, related to the working men 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, these indirectly result in 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 (SAGEN, SASTELA, DTI, 2013) 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) and 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.

At the moment the unemployment rate in Chile is a very low (around 6 % in 2013 (Central intelligence agency)), many people are employed in the mining related industrial sectors, especially in the North. In this region, the created CSP jobs are in direct competition to already existing jobs.

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 logistics 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.

Transmission grid

The Chilean grid is divided into 4 different zones, with 2 dominating players covering over 99 % of the load, with more than 17 GW overall installed capacity. The northern network (operated by SING, "*Sistema Interconectado del Norte Grande*") represents about 35 % of the installed load, nearly 64 % are covered by the central network (operated by SIC, "*Sistema Interconectado Central*"). Both systems show a different characteristic load behavior, especially the northern network is dominated by mining companies, resulting in a nearly constant load profile. With further installation of volatile energy sources like PV or Wind, the demand for dispatchable energy will rise from the transmission system operator as well as from the electricity off-taker (in general the mining company), offering a chance for CSP with storage.

The central system supplies classic customers with a floating load profile as well as base load off-takers, resulting in a more fluctuating load profile. In this network, a combination of PV and CSP technology could result in a similar setup as it is implemented in South Africa. PV is covering the load demand during day time, while CSP with storage is covering in addition the demand during night and at peak time.

Based on (Krenzlin, Wandelt, & Glatz, 2012) the load demand and following the installed capacity need to be doubled within the next 10 years in order to follow the expected economic growth of 6 %. Besides the increase of installed capacity the transmission capacity needs to be strengthened.

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 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. A cooperated technology development of national and international companies seems to be possible, especially in the field of combining different industrial sectors. In (Vasters & Sonnenberg, 2011) the challenges and opportunities of national and international companies active in the mining sector are described. Especially concerning the energy supply of these mines, a combined technology development could have a big influence.

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. As the solar salt used for the thermal storage system is mainly produced in Chile, the further developments towards higher temperature ranges and thermal stability should also be supported by the local producers. Together with local and international research institutes and partners this research could support the global development.

Summarized, Chilean companies currently not active in the power plant business but familiar with high energy demanding processes are able to develop new products and integration possibilities using CSP. In addition, players already active along the value chain need to further develop their products in order to follow the global development towards higher temperatures, increased efficiencies and lower costs. Other local players wanting to enter the already existing supply chain have to adopt their already existing production lines in order to fulfill the particular needs of the CSP technology.

Foreign trade impact

As the solar resource offers great opportunities for the development and construction of CSP plants in Chile, a sustainable CSP market could be developed during the next years. Based on the ability of local companies to participate on the supply chain, local companies can also participate in this development. As the industrial base in Chile is not that strong, compared to other countries in the region (e.g. Brazil) the industrial base might be too small for most companies on the supply chain to export their components to other countries.

For local companies already active and specialized in the CSP market (especially SQM), the international CSP market would be still the primary market. Additional developments within the country will further raise the visibility of the technology. This could help already active companies in finding well educated and skilled workers and researchers.

If the Chilean industry and especially the mining industry is able to develop integration methods to use CSP for mining applications, these experiences could help them to export these technologies to other countries with high mining possibilities.

Free Trade Arrangement

Free Trade Arrangement with countries dominating the CSP market allows an easier entrance for the foreign company into the local market. With such an arrangement, especially financing issues and trading is easier. Nevertheless, especially points like the securing of IP rights must be agreed within these arrangements in a proper way, so that they support the forming of joint ventures and other closed cooperation.

Considering the situation in Chile, most of the free trade arrangement are negative for the Chilean export statistic, meaning that more products are imported than exported (e.g. for Switzerland around 20% of the trading volume was exported from Chile between 2000 and 2006 (Leitner, 2007)). For the CSP industry it could be assumed, that a similar effect occurs, resulting in a huge import of components and parts, especially within the initial plant. The forming and supporting of joint ventures between local and international players could help local companies to enter the market and create a sustainable business. If such cooperation are supported by the local legal framework (e.g. by subsidies or loans) a successful development of the local market could be achieved without blocking the international companies.

Financial and economic 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 economic 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 up 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 the first already ongoing or planned projects show a business case for the CSP technology in Chile reaching low LCOEs, international companies will enter the Chilean market and start to develop their own projects. If local companies want to participate on the value chain, especially in component manufacturing, of the technology, they have to be very flexible in this situation. The forming of joint ventures and partnerships with international active players could create a win-win situation for both partners: The Chilean Company gets in touch with the technology while the international company can participate on the local knowledge and local workforce.

Besides public incentives 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. High perceptions of risk will result in financing at unaffordable rates, which drives up the LCOE. To ensure the financing at good conditions, 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, World Bank, etc.) 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 of sufficient tools and products.

Based on (Inter-American Development Bank, 2013), an analysis for Chile shows that electricity off-takers do assign a hedging value of long-term contracts with renewable energies, in order to secure them from rising fossil fuels prices. In addition, the RPS (Renewable portfolio standards) requirements increase the value of solar produced energy using RE certificates (integration in the own portfolio or selling them). But as CSP technology and especially the initial projects, still face technological and especially country specific risks and barriers, it will require public support, at least in the short-term.

Experiences from the PV industry show that even in a financially relatively stable country like Chile the support of development banks for big projects could be helpful. For example the project San Andres (50.7 MW installed capacity, Atacama region) has received loans from the World Bank International Finance Cooperation (IFC). Other projects from foreign developers (e.g. SunEdison from the US) have been supported by their own country (e.g. US Government's Overseas Private Investment Corporation) (Roselung, 2014).

During an interview with Andrew Kurth LLP (Andrews Kurth LLP, 2014) it was stated, the also commercial banks are willing to finance renewable energy projects in Chile as long as several key points are fulfilled:

- Project developer and EPC show a proven track record.
- A solid PPA is concluded.
- Proven technology.

With the possibility to include also commercial financing into the project financing, the costs for the financing could be reduced ("World is awash in capital looking for a safe, good return (Andrews Kurth LLP, 2014)").

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 structures) or have high demands on 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 (Lüpfert, 2013). The main standards already applied are dealing with thermal collectors (ISO 9806 and ISO 9459), measuring equipment (ISO 9060 and ISO 9059) or glass (ISO 9050). 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 (e.g. 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.
- Chile offers a high potential for CSP plants due to the good solar irradiation (DNI) and the need for secure energy supply.
- 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.
- 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.
- Financing is a challenge, but Chile offers very good and stable economic conditions
- If the first projects show a competitive LCOE level, the Chilean CSP market could be developed very fast.

3.2. Sector specific industrial capacities in Chile

Based on an analysis performed in (Ellermann, 2012), the relevant industrial sectors for Chile could be formulated as:

Plant construction and engineering

Most relevant for Chile is the manufacturing of machines used in the mining and construction sector. There are some local manufacturers but due to the big demand, a lot of components are delivered by international companies.

Construction sector

This sector was booming during the last years, especially due to the rebuilding activities after the earthquake in 2010. In 2013 a slowing down of the growth was expected. The industrial sector has the capacity to build new large infrastructure projects and is especially interested in new infrastructures in the energy sector.

Float glass production

The NSG group (Pilkington) operates since 1996 a production facility for high quality floating glass (so called “float line”) in the South of Chile (near Concepción) producing for the automotive sector. In South America there are currently (2011) eight float lines installed, six of them in Brazil.

In general, the demand for glass in South America is higher than the actual production capacity, mainly driven by the growing automotive industry in Brazil and Argentina. Additional demand for “solar glass” will tighten this situation, because existing floating lines have to be adapted (NSG Group, 2011).

Energy sector / Utilities

The increase of installed energy generation units is the major factor for the energy sector. As the electricity demand is rising extremely, the need for new built facilities is critical. Huge projects (like water) are challenging, the focus has shifted to smaller projects especially in the not established renewable likes wind and solar (PV and CSP).

Mining sector

The mining sector wants to expand its production, there are several projects planned. The main challenges are the secure supply of energy and the lack of water. Another challenge for this industrial sector is the lack of workers.

Summarizing, the relevant industrial sectors are present in Chile, offering knowledge and already existing capacities. But the overall capacity is limited, especially regarding component manufacturing industries.

3.3. Influence of local production on the investment costs

A key challenge worldwide for the further development of the CSP plants is the reduction of 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 or the location.

Local production of different components influences the investment costs of the power plant. If 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 these influences are:

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

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

3.3.1. Raw material prices

The main components for a CSP plant are steel, concrete and glass. There is one float glass production line in the South of Chile, producing “normal” floating glass. Up to now, no “solar glass” manufacturing line has been installed.

The steel production in Chile is not covering the domestic steel demand, resulting in an import of steel products. In 2012 the domestic companies delivered around 1.20 Mt of finished steel products to the domestic market (dominated by Compañia Siderúrgica Huachipado (CSH) with more than 1.1 Mt). More than 1.77 Mt of finished steel were imported. Leading sectors for the steel demand are the construction and the mining sector (Anderson, 2014). Figure 3-1 indicates the relation of the Chilean steel production to other in South America, with Chile ranked 4th.

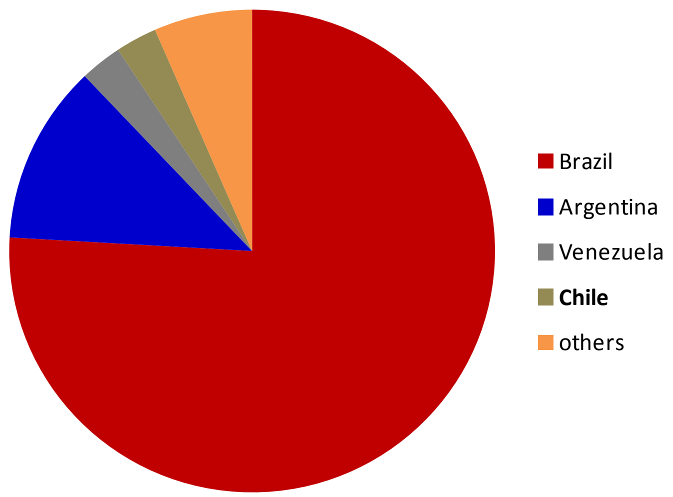


Figure 3-1: Crude steel production in South America, March 2014 (World steel association, 2014)

Although the iron ore production is quite high (Compañia Minera del Pacífico (CMP) in 2012 12.12 Mt), more than 85 % is exported and only a small percentage of around 15 % is delivered to the domestic steel production.

Other metals (especially copper) are available, also the solar salts necessary for the thermal storage, see Figure 3-2.

Considering the steel price, the Latin American market develops similar to the world market. In Figure 3-2 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 Metal, London. The behavior of the price indicator for Latin America is comparable to the worldwide behavior.

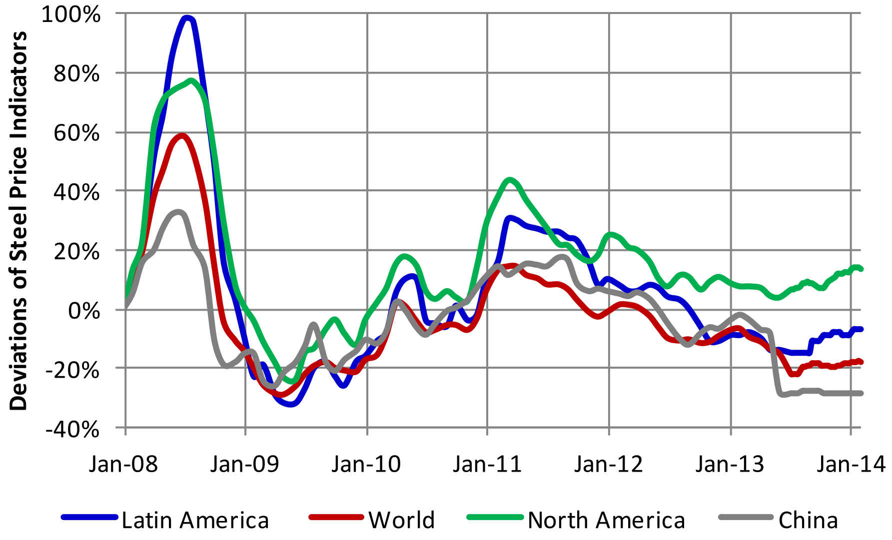


Figure 3-2: Deviation of the steel price indicator for several regions, based on Platts Metal (steelbb.com)

Due to the rebuilding activities after the earthquake in 2010, the Chilean construction sector has grown during the last years and is demanding for new infrastructure projects (Ellermann, 2012). New built CSP plants are in direct competition to other infrastructure projects especially in the energy sector, 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, although the demand for skilled workers is very high.

Summarized, raw materials for CSP plants seem to be available on the Chilean market at a competitive level. The main challenge is the demand for finished steel products and the lack of production capacity. Already active local companies are aware of this situation and have already established a supply chain of different and experienced local suppliers.

Nevertheless, and with special regard to the good and easy supply of solar salt for thermal storage, a slightly positive impact on the LCOE of the CSP plant is expected.

3.3.2. Labor costs and productivity

Labor costs have a huge impact on the LCOE. With Table 1, the gross annual incomes of some selected job positions, relevant for the CSP plant are shown. The general level of labor costs for different countries is given in (CIO Wealth Management Research, 2012), compared to Zurich (100), see last row of the Table 1:

Table 1: Comparison of annual gross income of different jobs for 2012, based on (CIO Wealth Management Research, 2012)

Job description	Spain (Madrid)	United States (Los Angeles)	Germany (Berlin)	Chile (Santiago)
Industrial (leading)	30’300 €	45’200 €	65’000 €	21’700 €
Industrial (high skilled)	21’100 €	48’100 €	36’600 €	9’400 €
Industrial (low skilled)	17’900 €	36’300 €	22’000 €	5’200 €
Engineering	40’700 €	69’900 €	55’700 €	24’700 €
Overall (100 = Zurich)	43.5	65.9	60.5	17.3

Compared to the values of Spain and the US, the labor costs in Chile 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. Compared to other countries in Latin America, the annual income for workers is in general comparable (overall index for e.g. Sao Paulo 22.9; Buenos Aires 18.0; Lima 16.9). The labor productivity is not taken into account in this consideration. Nevertheless, considering country averages for labor costs in Chile might lead to an underestimate as direct competition for solar industrial workers is the mining industry, which provides the highest wages in the country.

It could be summarized, that especially for the first CSP 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 Chile 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.

Besides the labor costs, also the availability of high and low skilled workers is a key point analyzing labor costs. Due to the low unemployment rate and the huge demand of the mining companies, new jobs in the CSP sector could be in direct competition to already existing jobs. In addition, higher costs for consumables (especially energy) during construction could even in a long term horizon compensate the lower labor costs.

3.3.3. Exchange rates and risks

With the implementation of a plant, several critical factors have to be taken into consideration. These risks are influencing the overall costs of the plant, as they are taken into account as surcharge. Also investors take these risks into account, resulting in an increase of the financing costs. For foreign EPCs as well as investors these risks consist in the new country and the new economic environment. For new Chilean companies entering the market, the “new” technology CSP is creating surcharges. With the further increase of installed capacity and local EPCs or at least construction companies, these surcharges could be reduced.

In general a higher local content share minimizes the risk of exchange rates. In Figure 3-3 the exchange rates for the Chilean Pesos (CLP) is shown, compared to the US$ (USD) and the Brazilian Real (BRL). Every currency is related to the Euro (EUR). As the CLP is linked to the USD, the differences (and therefore the risks) are small. The risks related to the exchange rate could be especially observed during the second half of the year 2013 with a strong increase in the exchange rates of the BRL and even more of the Argentina Pesos (ARS). The linking to a big international currency minimizes the risks due to exchange rates and allows an easier entrance for foreign companies into the local market.

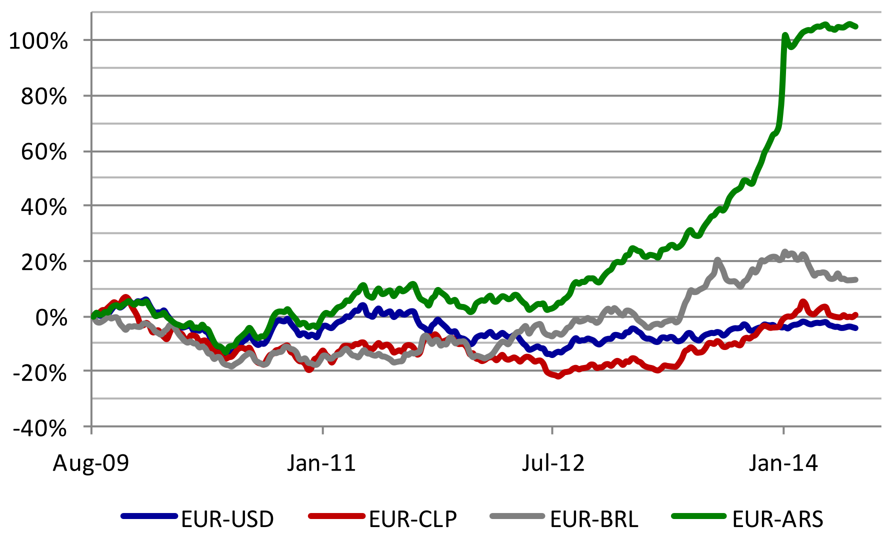


Figure 3-3: Exchange rates EUR to USD, Chilean Pesos (CLP), BRL and Argentina Pesos (ARS)

It could be concluded that the exchange risks for foreign (mainly American and European) companies to invest in Chilean CSP plants is lower than for the investment in other emerging CSP regions (like South Africa or Brazil) with free floating exchange rates. As long as the linking to the USD exists, the exchange risks and all related security surcharges could be kept low.

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: The Chilean market is importing steel. Other raw materials are locally available especially the “solar salt” for the thermal storage system.
- Labor costs and productivity: With the first plants, training and investment will overlay the lower loan costs level in Chile. With increasing capacity and experience, labor costs will have a positive impact on the LCOE, although the high energy costs are an important factor.
- Exchange rates: The linking of the local currency to an international currency minimizes the risks of fluctuating exchange rates, allowing an easier entrance for international players into the market.
- Risks: Chilean companies offering knowledge of the market can offer a lower LCOE due to their better risk management.

3.4. Lessons learned

Since the development of the CSP technology, several lessons learned scenarios were performed, especially regarding technical and economic 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 units 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 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. As already mentioned, for Chile such a niche could be based on the integration of solar thermal applications to the mining business including the secure supply of electricity and additional heat or process steam if required. Due to the very high solar irradiation and the challenging ambient conditions (dust load, high UV-irradiation) also the adaption of already existing technologies (e.g. solar collector design) could be a promising R&D-niche.

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 (Kulichenko, 2012):

- 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 to 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 electric system and the industry.

There are also some key points that must be considered when creating the boundary conditions for a 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 (Stadelmann, Frisari, Boyd, & Feas, 2014). 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 economic 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 (Döhne & Erwes, 2012). 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 staff 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 Chile is different compared to the other CSP developing countries. The good renewable resources especially for solar based energy generation units compared with the need to find private PPAs put a huge pressure on CSP to reduce the LCOE. Due to the excellent DNI values combined with a thermal storage (providing on the one hand a secure and dispatchable energy supply and on the other hand increasing the capacity factor) a further reduction of the LCOE compared to the worldwide level is possible. **The key focus for CSP in Chile must be the supply of secure and dispatchable renewable energy at a competitive price level.** In parallel the awareness of CSP as dispatchable energy generation units on both sides, electricity off-takers and already existing utilities must be increased. All activities 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.

3.5. 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 Chile are given.

Main objective of all further steps must be the implantation of a new and dispatchable energy generation unit in Chile. Therefore, all measures must always connect the thermal storage with CSP, offering a huge cost reduction potential and gives a unique characteristic compared to other renewable resources entering the Chilean market.

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 Chile must be raised, with a special focus on the electricity off-takers and grid operating companies.** Therefore, main advantages of the technology, including the integration possibility of a storage system and the possible supply of heat must be pointed out, also the differences between the two solar driven technologies PV and CSP. This process must include not only the energy off-takers 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 and off-takers 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. Such a network should closely cooperate with the dominating players in the region like the mining business and shall include utilities.
- Within the last years, the CSP technology has developed to a growing industrial technology. There are **several international standards and quality norms** (Lüpfert, 2013), new players along the value chain have to cope with. As quality and accuracy, especially but not only of the solar field and the solar absorber, have a huge impact on the economic 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 component 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 analyses. With the first installed measurement Crucero II (by GIZ and the Chilean Ministry of Energy, in Comuna de María Elena, Antofagasta) the lessons learned from this station should be transferred to new stations.
- 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 Chile, **a potential analysis of the CSP technology** in Chile is necessary. Such a potential analysis should not only include the north of Chile but also other potential regions. The solar resource in the North is highly promising, but there are also other regions (e.g. north of Santiago) that indicate a relatively high solar irradiation compared to other regions in the world. Besides the solar resource, also the demand for local dispatchable generation units should be analyzed in order to get a potential, regional demand. The results of this analysis could be a feedback of the **potential Chilean market size divided in several categories and regions**, which is necessary for the local and international players.
- The legal framework must ensure **a long lasting and a long horizon development** of CSP plants in Chile. As the mining companies are asking for long-term agreements with electricity suppliers that guarantee a consistent supply of energy, this could be a promising market chance for CSP. But especially with the first project, CSP must prove in Chile that they are able to deliver consistent and reliable energy.
- Due to the free trade arrangements and the lack of industrial capacity in Chile, foreign companies could directly enter the market. To strengthen the local industry, **joint ventures between national and international companies should be supported**, in order to increase the local share. If the local share is fixed by governmental boundary conditions, the developments along the value chain and the local value of the value chain must be monitored and the framework must be adapted (in both directions) 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 a CSP industry in Chile**.**

4. Estimated development of the market

In order to estimate the development of the Chilean 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 4-1.

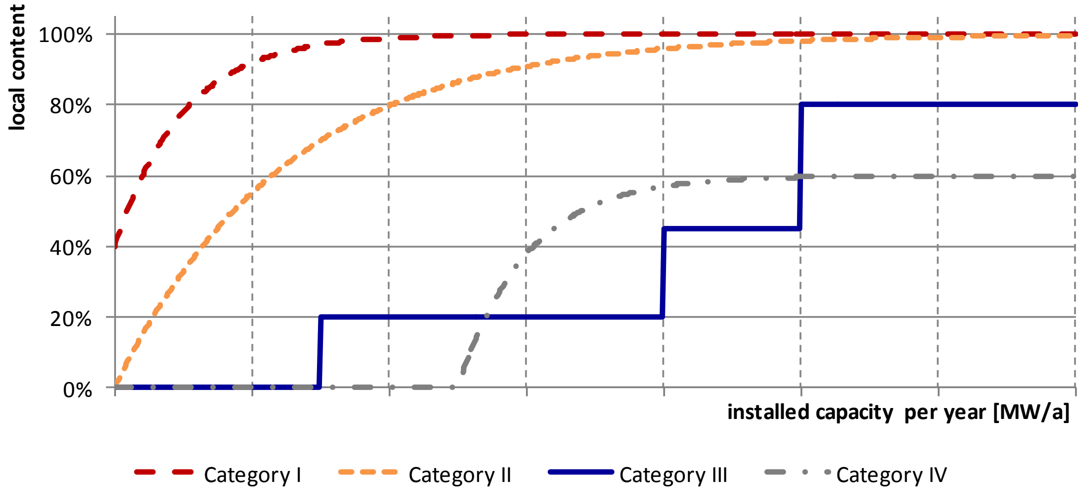


Figure 4-1: Different categories to quantify the local content of different CSP components, enolcon 2014

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 2.

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

Category I:

Within this category, all components are described that do not need special equipment or knowledge. These 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 are 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 II:

Within this category, all components are described that could be produced by local companies, but need special equipment's 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 III:

Within this category, all components are included that need specific adaptations 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 IV:

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 start 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 2. 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 2: 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 & electric	overall		x		
I&C				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	not applicable			
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
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	x			

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 CSP plants are identified that have a significant influence on the value of the plant. Therefore an evaluation of the investment costs for the whole CSP plant is shown in Figure 4-2, 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 (IRENA, 2012). The components are divided into the different sections, according to chapter 4.

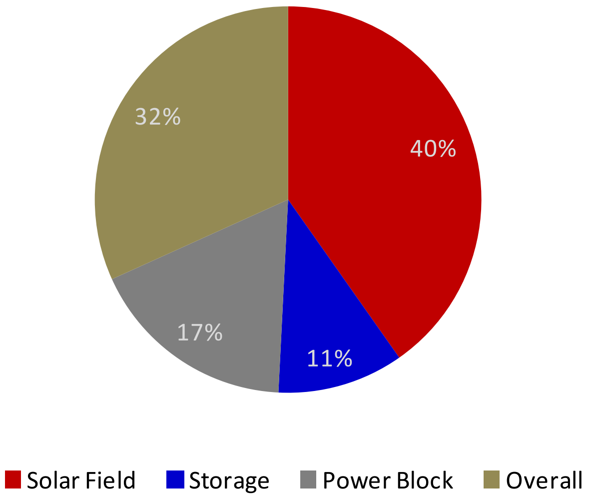


Figure 4-2: Estimated cost breakdown of a typical state of the art CSP plant, based on (IRENA, 2012)

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 publicly available information and direct company interviews. Some information is also available from foreign companies entering the mining sector, also included in this analysis (Vasters & Sonnenberg, 2011).

- **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. 6 - 9 % 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 (SAGEN, SASTELA, DTI, 2013), an equivalent

glass production between 90 - 130 MW per year is necessary for an economic 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 logistic 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 mirror system 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 economically 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 (Döhne & Erwes, 2012), the market concentration for steam turbine manufacturers is very high, resulting in only a few local market players in the whole region. Currently no turbine manufacturer is active in Chile.
  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 (Döhne & Erwes, 2012) especially locally produced electric 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.
- **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 EPC 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 and missing industrial capacities (especially steam turbines). Therefore, the sum of the following shares is not 100 %.

Category 1

The components summarized in category 1 represent approx. 20 % of the total value of the whole plant. This value is slightly higher compared to other countries. The share of the solar salt is included, compensating reductions due to the limited industrial capacity.

The estimated behavior of the local share is shown in Figure 4-3. 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 with increasing industrial capacities based on the market growth.

As especially the supervising and the quality management needs experienced workers, the last 10 - 15 % of the local share is only slowly increasing.

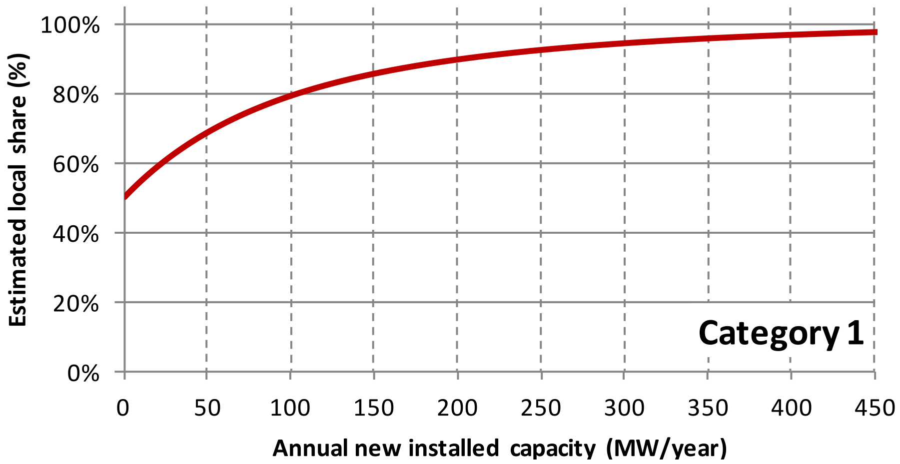


Figure 4-3: Estimated local share of category 1 components in Chile

Category 2

The components summarized in category 2 represent approx. 42 % of the total value of the whole plant, resulting in the highest share of all categories.

The estimated behavior is shown in Figure 4-4. 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 and increase their production capacity based on the increasing market.

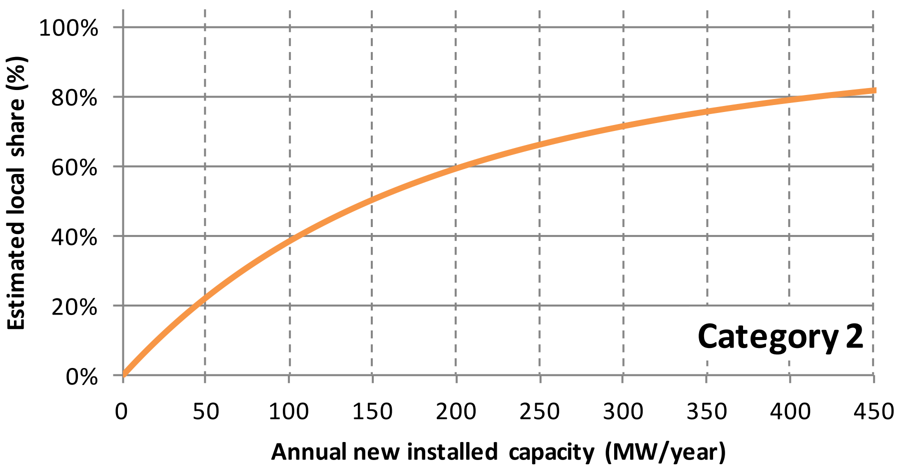


Figure 4-4: Estimated local share of category 2 components in Chile

The last 40 % 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 4-5. Compared to the other categories, no continuously 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. The behavior of this category is similar to other emerging markets with a huge solar potential like South Africa.

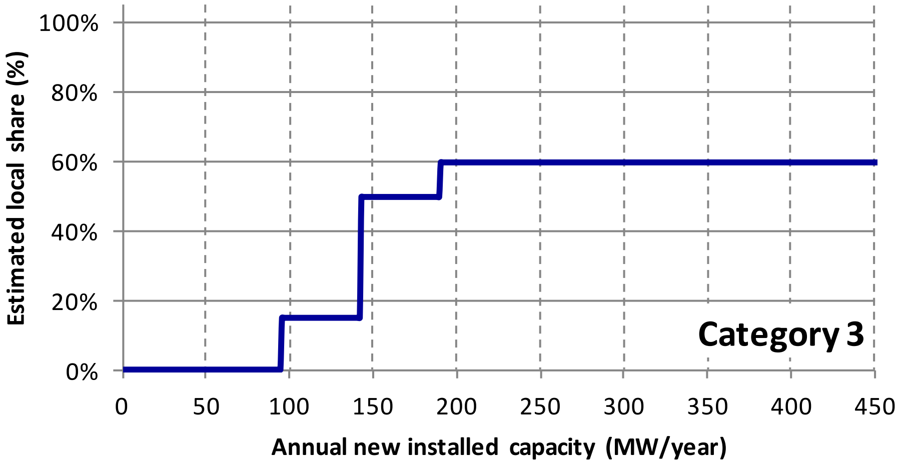


Figure 4-5: Estimated local share of category 3 components in Chile

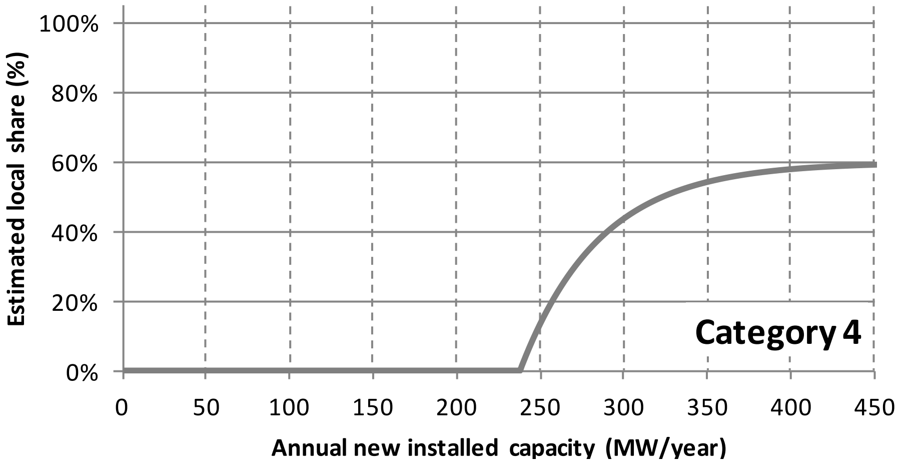
As the international market players are very competitive and experienced in this sector, especially concerning the EPC-business, a maximum local share of 60 % is expected.

Category 4

The components summarized in category 4 represent approx. 2 % of the total value of the whole plant.

The estimated behavior is shown in Figure 4-6. Within this category only highly specialized components are summarized. 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.

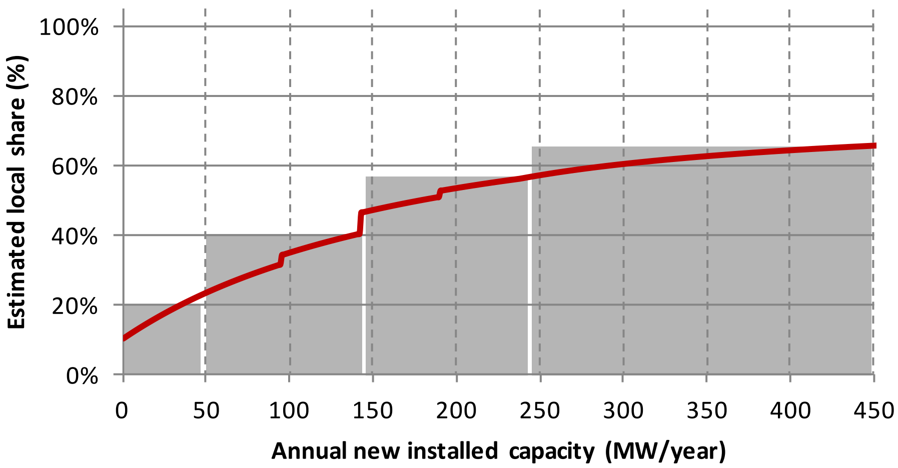
Figure 4-6: Estimated local share of category 4 components in Chile



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 4-7. Of course, this behavior is a rough estimation, based on the above mentioned assumptions.

Figure 4-7: Estimated local share of the CSP industry in Chile, 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 adaptations 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 150 MW of new installed capacity per year, the huge impact on the overall behavior is clearly visible. The local value could be doubled, if the (already existing) production lines and facilities are adapted to the needs of the CSP industry and the industrial capacity is extended.

With the future increase of the annual new installed capacity, also further adaptations within the related industry are necessary. With the implementation of new manufacturing lines and the investment in new facilities of international companies in Chile, the local share is further increased. With new installed capacities above values around 200 MW per year, local shares of more than 50 % 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 plants exceeds 250 MW per year, adaptations in all industry sectors related to the CSP value chain are necessary and suitable. With the implementation and adaptation 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 60 %, comparable to values that are expected in other emerging markets. As already mentioned, these values could only be achieved with ensuring a steady annually increase of the CSP capacity.

5. Summary and Conclusion for Chile

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 investments for new or updated production lines and for education and training of the own workers are necessary. Cooperation or joint ventures with already established and active market player also enable a fast entrance into the market, especially in “open markets” like Chile. Based on these co-operations Chilean and international market players could develop together new or improved components for the local market and later on also for the international market.

The Chilean market offers several possibilities and advantages compared to other CSP emerging markets:

- Excellent renewable resources with high DNI-values resulting in very good capacity factors for the plant, helping to decrease the specific energy generation costs.
- Increasing energy demand with a homogenous load profile, resulting in an increasing demand for dispatchable energy generation units. CSP with storage could cover this demand.
- Stable governmental and financial conditions, minimizing the risks for potential foreign investors.

Within this report it has been shown, that a local share of around 60 % could be achieved with an annual increase of approx. 250 MW or more. The local industrial capacity must be increased in order to reach these values. With its mines for Caliche Ore and Salar Brines the components for solar salts are locally available, resulting in a higher “initial” local content. It has been also shown, that without any adaptations or international joint ventures 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 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 need 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 investment security.

The motivation to invest in CSP for Chile is based on the need for additional energy generation units, delivering reliable and green energy by using the excellent solar resources. The price competition with other energy sources is one of the main challenges. Using thermal storage systems increases the capacity factor of the plant and reduces the LCOE. Together with the dispatchable energy and the local value that could be created, CSP offers a great opportunity for the Chilean energy market. **Summarized, the key focus for CSP in Chile must be the supply of secure and dispatchable renewable energy at a competitive price level.**

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

- 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 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 implementation of a CSP industry in Chile has a positive impact on all included actors, not only along the value chain but also for the electricity off-takers and the already existing energy production companies. Related actors like research institutes and project developers could also participate on this development. The boundary conditions for a sustainable development of the CSP industry in Chile are clearly given and together with experiences from other emerging countries a pathway to support this development could be defined.

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