Concentrated Solar Thermal Power plants

The future of power supply in Europe?

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“I'd put my money on the sun and solar energy.

What a source of power!

I hope we don't have to wait 'til oil and coal run out before we tackle that.”

Thomas Alva Edison, 1847-1931

DECLARATION BY CANDIDATE

I hereby declare that this report is my own work and effort and that it has not been submitted anywhere for any award. Where other sources of information have been used, they have been acknowledged

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bbl	Barrel
CCGT	combined cycle gas turbines
CHP	cogeneration heating plants
CO_2	Carbon dioxide
CO_2/C	Carbon dioxide / Carbon
CO_2eq/kWh	Carbon dioxide equivalents per kilowatt hour
CSP	concentrated solar thermal power
DLR	Deutsche Luft- und Raumfahrzentrum German Aerospace Center
DNI	Direct normal irradiance
EREC	European Renewable Energy Council
EU	European Union
EU-NA	Europe – North Africa
EU-27	27 member states of the European Union
ETS	Emission Trading Scheme
FIT	feed-in tariff
GDP	Gross domestic product
GHG	Greenhouse gases
GW	Gigawatt
HDVC	High Voltage Direct Current
HTF	heat transfer fluid
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISCC	Integrated solar combined cycle
Kg	kilogram
kWh	kilowatt hour
kWh/m²/a	kilowatt hours per square meter per anno
kWh_t	kilowatt hour thermal
kW_{el}	kilowatt electric
l/MWh	liter per Megawatt hour
LCOE	levelized costs of electricity
LCPD	large combustion plant directive
LFR	Linear Fresnel Reflector
MENA	Middle East and North Africa
MPC	Mediterranean Partner countries

MW	Megawatt
MWel	Megawatt electric
MWh	Megawatt hour
PCM	Phase change material
PSA	Plataforma Solar de Almeria
PV	photovoltaic
RE	renewable energies
REN21	Global Network for Renewable Energies
RES	renewable energy sources
R&D	Research and Development
SRREN	Special Report on Renewable Energy Sources and Climate Change Mitigation
SM	South Mediterranean
TES	Thermal energy storage
TWh	Terawatt hours
US	United States
USA	United States of America
USD	United States Dollar
US$	US Dollar

1. Executive Summary

UN Secretary-General Ban Ki-Moon stated recently that: "*Countries that move quickly down a clean energy pathway will be the economic powerhouses of the 21st century.*" (UN Secretary-General Ban Ki-moon 2011). This report assesses a technology that could help to move this pathway down the road. The rediscovered technology Concentrated Solar thermal Power (CSP) is this possible technology. As part of this report, the technology itself including storage opportunities, a rare attribute of the renewable energy sources, is displayed and explained. The technology is divided into two general systems line concentrated systems and point concentrated systems. The major applications are parabolic-trough respectively tower systems. Parabolic-trough has the largest market application followed by the tower systems. For thermal storage, molten salt is the choice of art with the realisation of Andasol 1 and 2 and the newest plant Terresol (with 24 hours operation through molten salt storage) (Stromsta 2011). General sustainability aspects of the CSP are presented to show advantages and constrains of this promising technology. It shows that the price per kWh is still not in favour for this technology due to a small development of the young industry sector. Studies show promising potential in the future with a broader deployment of the technology. A constrain for this technology is the large water consumption due to steam process and the cooling of the steam afterwards. Dry cooling or a combination of dry and wet cooling show potential but with decreases in efficiency and therefore increasing kWh electricity prices. From a social perspective, the deployment of renewable energy sources means in general wealth generation like explained further in the report. On the other site, the electricity prices in the North African states are so low that an electricity generation by CSP is too expensive and an export of the electricity to the European states gets into focus as shown in chapter 7 (Dii 2011).

2. Introduction

A fundamental need of humankind is energy. Energy is needed to provide basic human needs as the IPCC states in the newest report “Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN)” signed by all members of the United Nations (IPCC 2011, 2). With this in mind, the huge conversion the world is facing in regard to energy production makes even more sense. Independence from fossil fuels which are a depleting source to renewable energies within human timeframes entails endless availability and or regeneration. Aside from the change in energy production for reasons of depleting sources, climate change is a need for change in energy production as well. The IPCC report SRREN says that: “*Recent data confirm that consumption of fossil fuels accounts for the majority of global anthropogenic GHG emissions* (IPCC 2011, 3)*”* and in relation with the goal to limit the global temperature increase to 2 °C as agreed upon at the Climate Conference in Cancun 2010 the global emissions for greenhouse gases like CO_2 have to decrease by 50 - 85 percent below 2000 levels by 2050 (Arvizu, et al. 2011, 7).

“As well as having a large potential to mitigate climate change, RE can provide wider benefits. RE may, if implemented properly, contribute to social and economic development, energy access, a secure energy supply, and reducing negative impacts on the environment and health (IPCC 2011, 3).”

Leading industrial regions such as Europe and China see this chance and are changing their energy production towards renewable energies sources. Political support is necessary for this change as the world energy prices are largely not taking into account the external costs of fossil fuel based energy and the benefits of renewable energies (Commission of the European Communities 2007, 7). Due to political support Germany is investing in large capacities for photovoltaic while China is going in huge steps towards the leadership for installed wind power capacity. Europe is investing largely in Renewable Energy Systems (RES) with additional generation capacities of 14 GW. "*RES now represents 10.3 percent of European generation capacit*y (Lewiner 2010)."

From a European perspective, this large increase of generation capacity is unfortunately not represented in the generation mix. *"Despite this construction of gas plants and wind farms, the European generation mix remained globally similar to the mix observed in previous years, with fossil fuel (52 percent) and nuclear (16 percent) still accounting for more than two thirds of total generation capacity in Europe* (Lewiner 2010)*."*

The European energy supply change is driven by the implementation of unstable RES such as photovoltaic and wind and not so much by base load generation like that of biogas and biomass Cogeneration Heating Plants (CHP). The fossil fuel capacity was built to focus more on peak load assets like combined cycle gas turbines (CCGT) with high efficiency rates. *"Together with this reality, plants decommissioning driven by the LCPD and nuclear phase-out laws has worsened the problem of security of supply in the future* (Lewiner 2010)*."*

An ideal technology based on RES for this supply dilemma is concentrated solar thermal power plant (CSP). In combination with storage capacity CSP is feasible to supply various loads determined by the size of the thermal storage. CSP is already available in different deployment systems from hybrid-systems to solar-only CSP plants. *"Some off-grid or remote-grid CSP systems are built, but large on-grid plants comprise more than 90 percent of overall CSP capacity (IEA 2010, p. 22)."* Large plants have shown more economic feasibility and promise further economy of scale developments with further deployment of the technology in the future. The International Energy Agency (IEA) projected in one of their scenarios a large increase in CSP deployment in the year 2020 and expects that solar CSP will be the fourth largest energy supplier of RES in the year 2050.

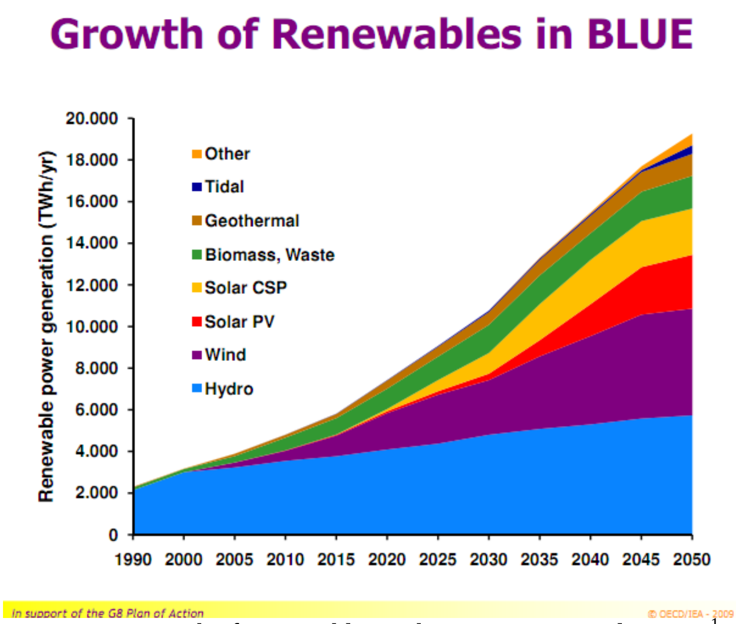

Figure 2.1 Growth of Renewables in the IEA Scenario Blue 2009[1]

The report will first explain the different technologies available and show that the focus so far in the industry lies on three technologies. Linear Fresnel, Tower and pass-trough are the technologies with the most promising developments, but other technologies will also be presented. Besides the capture technologies, this report will also describe the available storage technologies. The actual electricity generation with steam turbines is not part of this report since this technology is an established process and does not need any further description.

The following chapter will then describe the sustainable aspects of this renewable technology with all its environmental and social aspects as well as the economic aspects of the implementation in areas far away from the actual consumption. An assessment for the future importance of this technology for the South Mediterranean Countries (Morocco, Algeria, Tunisia) and the European Union in their energy policies will close this report and will conclude if CSP has the potential and support as a substantial energy supplier for the EU-NA region (European Union and North Africa).

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[1] (IEA Deputy Executive Director Richard Jones 2009)

3. Technologies

Arvizu et al define renewable energy sources as: "…is any form of energy from solar, geophysical or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. RE is obtained from the continuing or repetitive flows of energy occurring in the natural environment and includes resources such as biomass, solar energy, geothermal heat, hydropower, tide and waves, ocean thermal energy and wind energy (Arvizu, et al. 2011, 11)." This report focuses on the solar energy that is directly used. As biomass, hydropower, tide and waves, ocean thermal energy and wind energy are examples of indirect solar energy. Solar energy can be divided into three major technologies like shown below:

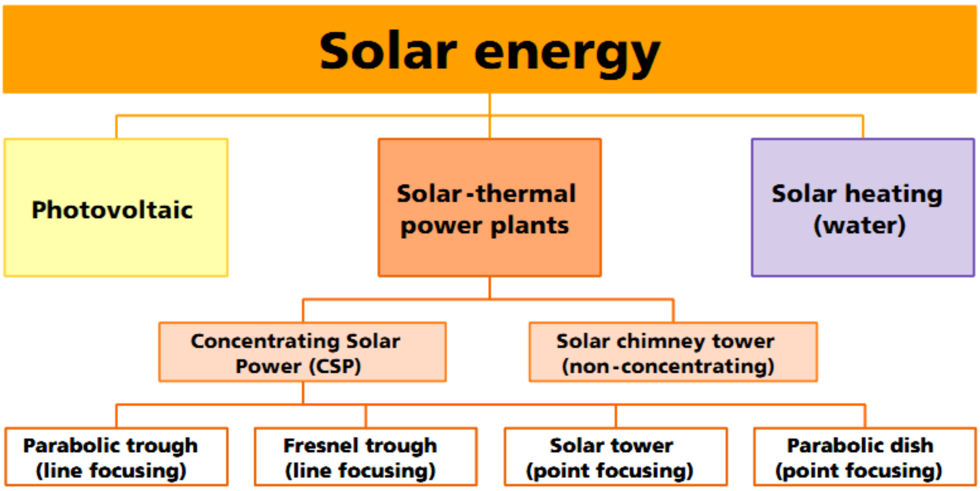

Figure 3.1 Solar energy technologies[2]

Solar energy consists of thermal radiation emitted by the sun. The radiation of the sun which reaches the Earth's atmosphere is called solar irradiance as defined by the IPCC. Solar technologies can use the un-scattered solar irradiance called direct irradiance or "beam" irradiance and the remaining and scattered irradiance diffuse irradiance. Both irradiances together are in sum the global solar irradiation (Arvizu, et al. 2011, 42).

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[2] (UBS - Wealth Management Research 2009)

The International Energy Agency states that: "Solar CSP needs solar irradiance to work, exactly "the direct component of solar irradiance". The direct irradiance is necessary for high-temperature solar energy systems because it can be concentrated on small areas using mirrors or lenses, whereas the diffuse component cannot. Concentrating the sun's rays thus requires reliably clear skies, which are usually found in semi-arid, hot regions (IEA 2010)."

Aside from clear skies and semi-aridity, hot regions also offer the necessary levels of high Direct Normal Irradiance (DNI) and are therefore distinguished as good areas for the application of CSP. The threshold levels for Direct Normal Irradiance for a CSP development are around 1900 kWh/m²/year to 2100 kWh/m²/year. *"Below that, other solar electric technologies that take advantage of both direct and diffuse irradiance, such as photovoltaic's, are assumed to have a competitive advantage (IEA 2010)."*

This high irradiance is used in concentrating solar power plants for "electricity generation by optical concentration of solar energy to obtain high-temperature fluids or materials to drive heat engines and electrical generators." (Arvizu, et al. 2011, 42).

The concentration in the CSP plant can be divided into two general system types: the first system deals with how the direct irradiance is focused on the receiver and the second system deals with what kind of receiver is used. Table 3-1 shows the different technologies in a Matrix-system and explains the special aspects of the systems.

Focus type / **Receiver type**		**Line focus** **Collectors track the sun along a single axis and focus irradiance on a linear receiver. This makes tracking the sun simpler**	**Point focus** **Collectors track the sun along two axes and focus irradiance at a single point receiver. This allows for higher temperature**
Fixed	Fixed receivers are stationary devices that remain independent of the plant's focusing device. This eases the transport of collected heat to the power block.	Linear Fresnel Reflectors	Towers
Mobile	Mobile receivers move together with the focusing device. In both line focus and point focus design, mobile receivers collect more energy.	Parabolic Troughs	Parabolic Dishes

Table 3-1 The four CSP technology families[3]

[3] (IEA 2010, 11)

3.1. Line concentrated

Parabolic trough power plant system is the oldest commercially available concentrated solar technology in the market. The first commercially installed power plants are located in the Mojave Desert in California, United States of America. They have now produced clean energy on a commercial scale for over 20 years (NREL 2010).

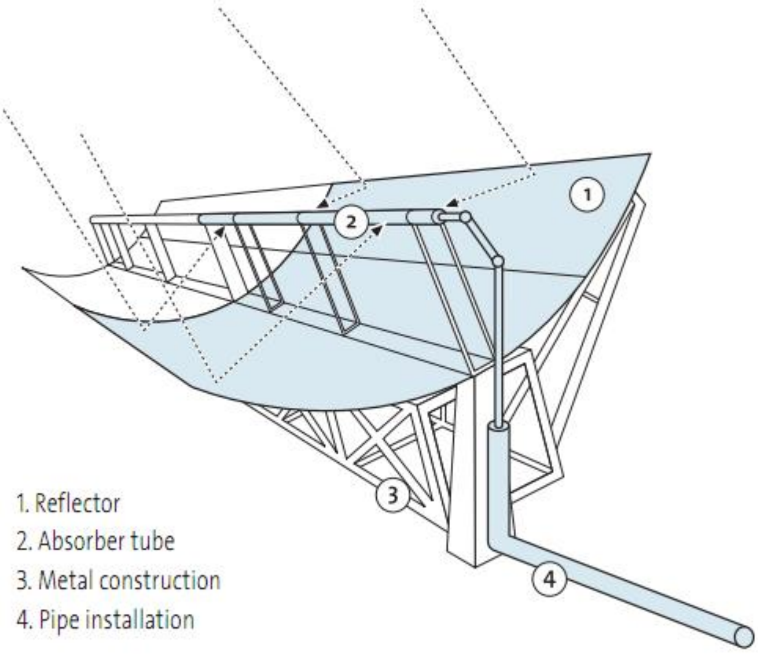

Figure 3.1.1 Parabolic trough mirror system[4]

The picture above shows a parabolic through mirror after the SKAL-ET principle in Almeria, Spain.

The basic structure of the parabolic trough power plants are long rows situated in a North-South axis. These rows follow the sun from East to West. The parabolic reflectors consist out extremely transparent silver coated glass. These coated glasses give the reflectors the possibility to concentrate the solar irradiation to 80-fold. Absorber pipes in the focal point of the parabolic reflectors receive the concentrated solar energy and heat up. The absorber pipes are made of steel which is in a

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[4] (Solar Millenium AG 2010, p. 13)

vacuum and heats special fluid up to a temperature of 400 °C. The heated fluid is pumped to a central heat exchanger where water is transformed into hot pressurized steam to drive a steam turbine. The steam turbine is then used like a conventional power generation system by producing electricity with a generator. The overall efficiency of this technology is about 15 percent in average and 28 percent in optimal conditions (Solar Millenium AG 2010).

Linear Fresnel Reflector (LFR) systems are a much simpler technology than the parabolic trough power plants. The system is made from small long mirrors (which can be curved) and reflect the sun to a tubular absorber receiver couple of meters above the mirror rows. To enhance the captured sun light, a second reflector system is installed on top of the receiver tubes. The average working temperature of these systems is between 450 – 500 °C above the operation temperature of parabolic trough systems (CSP Solutions Consult GmbH). LFR can be used for direct steam production and is therefore preferable for the steam usage.

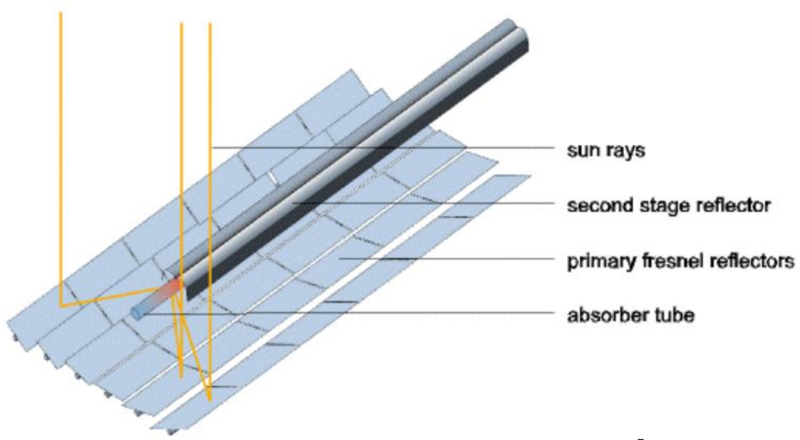

Figure 3.1.2 Linear Fresnel Reflector System[5]

The figure below shows the working principle of a LFR system. The water is heated up in three different sections to create supersaturated steam which can be used for electricity production or steam and process heat. The first step is the feed pump

[5] (Andreas Häberle, et. al. 2002, p. 1)

which pumps ambivalent water of around 30 °C into the system which is then pre-heated. The preheated water is then pumped through the internal pressure to the evaporation section, where the water is then evaporated and re-circulated to the evaporation section to increase the evaporation factor. Depending on the evaporation factor the steam is then injected in the superheating section where saturated steam is generated which is then used in the different industrial processes or in electricity generation with steam turbines.

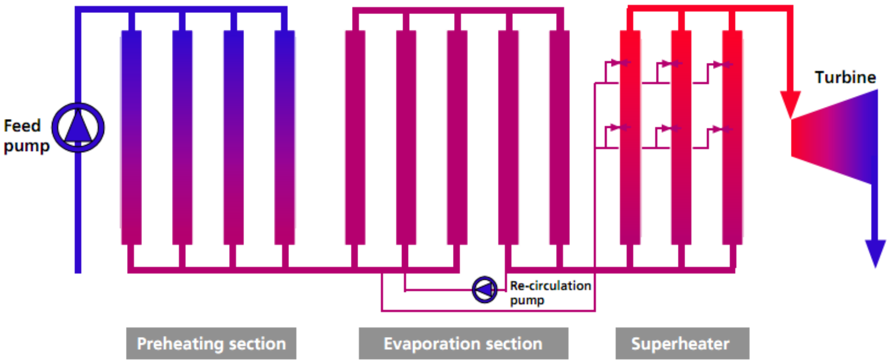

Figure 3.1.3 Linear Fresnel schematic diagram[6]

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[6] (Andreas Häberle, et. al. 2002, 2)

3.2. Point concentrated

The other main technology line of CSP is the point concentrated technology. The point concentrated technology is like the line concentrated technologies divided into fixed and mobile receivers.

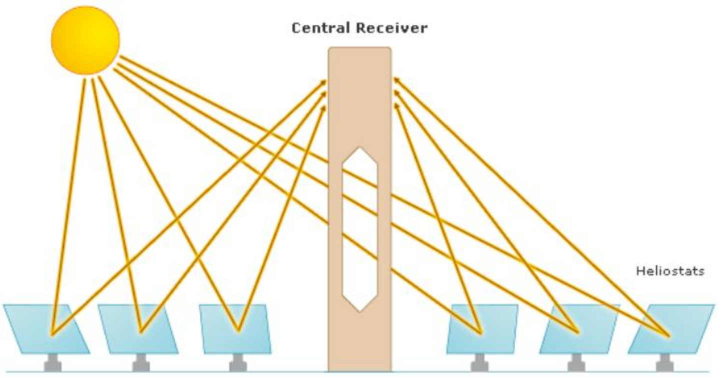

Figure 3.2.1 Operating scheme for solar tower[7]

Solar Towers are part of the fixed receiver systems and have in this field the biggest potential, because they are able to generate super saturated steam with temperatures of above 700 °C and up to 1000 °C. These high temperatures enable higher efficiencies with the steam turbines and therefore an overall higher efficiency of the power plant. The overall efficiency of solar towers is due to a 600-fold concentrated solar radiation between 20 and 35 percent. The solar thermal towers are operated with thousands of mirrors, so-called heliostats. These heliostats are simultaneously operated flat reflectors which are on double axes systems that reflect the solar radiation on one point in a high tower. Solar towers can be operated with a special kind of heating fluid but air or molten salts systems are more favorable for this technology, because this eliminates the need of additional heat exchangers which would further reduce the efficiency.

[7] (Abengoa Solar S.A. 2008)

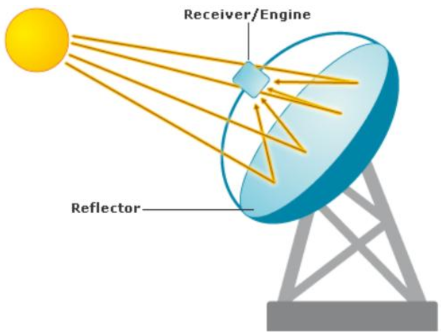

Figure 3.2.2 Dish-Stirling operating system[8]

Parabolic-Stirling power plants go a slightly different way to the so far explained technologies. Instead of using large scale steam turbines for electricity production, the Parabolic-Stirling technology creates electricity directly in combination with the stirling-engine. Compared to the other systems, the overall efficiency of the system is quite large with 20 to 30 percent solar irradiance to electricity. The area footprint of this type of CSP-technology is small compared to the other technologies like solar tower and parabolic-trough power plants.

The basic working principle of the parabolic-stirling technology is that the parabolic mirrors reflect the solar irradiance directly on a mobile receiver (a Stirling engine) quite close to the central part of the parabolic mirror. The reflectors heat a heating fluid in the Stirling engine up to a temperature of 750 °C. The Stirling motor or another micro generator then transforms the heat into electricity.

The direct heat transfer to the Stirling engine is the main advantage of the Parabolic-stirling technology; the small size of the system enables small scale applications for remote grids and decentralized energy production. A critical point of this technology is that the parabolic-stirling plants have a size of 10 and 50 kW_{el}. A virtual combination of the single power plants is necessary to create one large scale power plant. On the other hand, this small scale is also a possibility for economy of scale, since a lot of technical parts are identical in each plant and large production units are possible. This again allows lower production costs.

[8] (Abengoa Solar S.A 2008)

3.3. Other solar thermal power technologies

There are two additional solar thermal power technologies available: “Up and downwind” and the “solar lake”. These two technologies will be not explained here further, since these applications of solar thermal power plants are so far just design studies or in the feasibility status without the expectations of large deployment in the future.

3.4. Thermal energy storage systems

The Concentrated Solar thermal power plant technology depends on a constant solar irradiance. The advantage of CSP compared to solar PV is that the solar irradiance is not directly transformed into electricity but heat is captured and steam is generated from this heat. The additional step of steam generation gives this technology the possibility to use heat storages for constant energy production. The International Energy Agency, which is traditionally a supporter of fossil fuels, sees in this a large advantage: "*The storage and backup capabilities of CSP plants offer significant benefits for electricity grids. Losses in thermal storage cycles are much smaller than in other existing electricity storage technologies (including pumped hydro and batteries), making the thermal storage available in CSP plants more effective and less costly* (IEA 2010, 16) ."

Thermal storages can have different functionalities in a CSP plant. The major applications of thermal storages are so far the cover of clouds or a longer running time over the sunset.

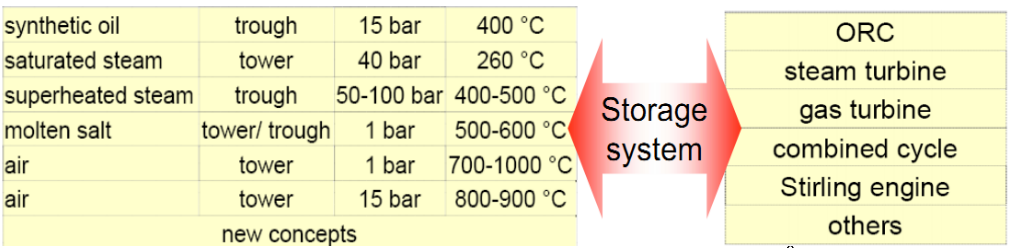

Figure 3.4.1 Bandwidth of necessary Storage Systems[9]

Figure 3.4.1 shows the dilemma of thermal energy storage systems. The future storage system technologies have to fulfill varying demands of the different solar thermal power plants operating principles. The Heat Transfer Fluids (HTFs) vary in combination with the collector system and the operating pressure of the system. Along with the operating pressure is also the temperature of the HTF which strongly

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[9] (Laing 2008)

varies from 260 °C in a saturated steam tower system with a 40 bar pressure circle to 1000 °C in a HTF air system in a tower collector system and 1 bar pressure. The systems described so far are just the collector systems with operating demands but the produced and stored heat also has to be used in an engine or turbine. This means again that the storage system also has to fit to the electricity generation cycle with its requirements such as operating temperature and pressure. All of these parameters make it difficult to design and develop a system that fits with all the applied solar thermal power systems. Currently, the researchers' and the industry's favorites are two systems which are: molten salt and solid thermal energy storages with concrete or Phase Changing Materials (PCM).

The technology of thermal energy storages (TES) are separated in two major systems. One system is the direct active thermal energy storage system where the HTF is also the storage medium. The other system is the passive thermal energy storage where the HTF is not the storage media. Another substance is used in the passive thermal energy storage.

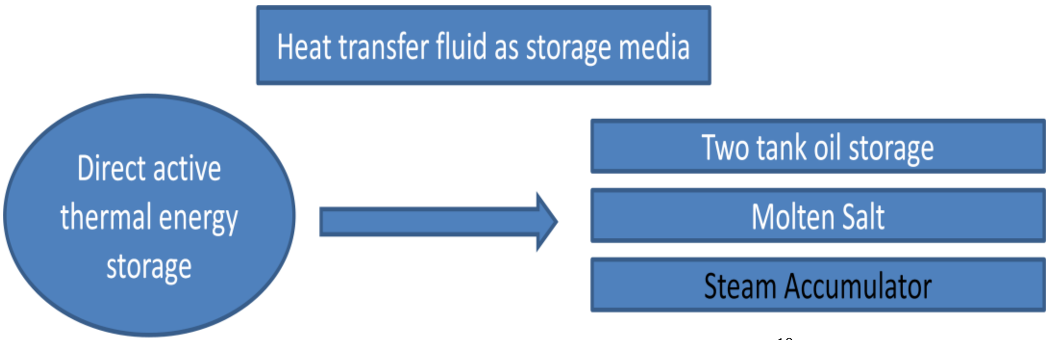

Figure 3.4.2 Direct active thermal energy storage[10]

The direct active TES are divided into two liquid systems and one gaseous system. The two tank oil and the molten salt direct system are not yet commercially available. Molten salt has the most promising features as a direct active TES system and can also be used as HTF with few disadvantages.

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[10] (Laing 2008)

The Steam Accumulator is the only commercially available direct active TES system. Steam is already used as a HTF in tower and pass-trough collector systems. The Steam Accumulator is used in most cases due to its high costs only in small sizes and just a short-term storage system to cover cloud interruptions. The idea is to store small amounts of steam to create a small buffer storage and to provide grid stability.

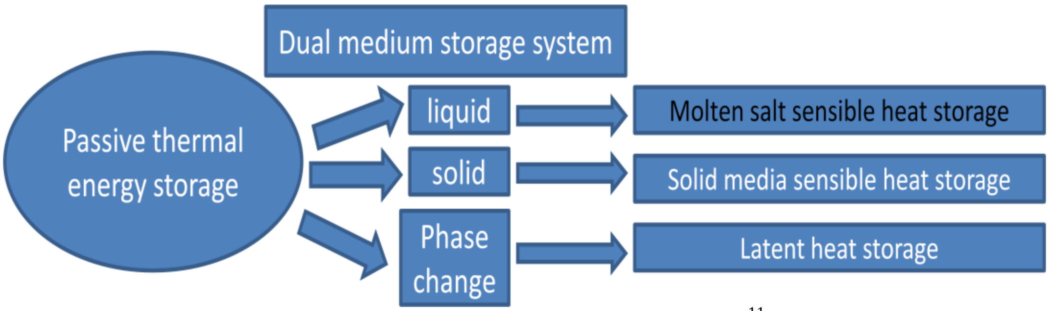

Figure 3.4.3 Passive thermal energy storage[11]

Passive TES can be separated into three forms of the storage medium. The liquid system is the only commercially operated system so far. The HTF transports the heat from the collector system to the heat exchanger of the storage system. The operation of the heat exchanger reduces the effectiveness of the system compared to the active TES. Even with this lower efficiency the use of the passive TES is the first choice. The first commercially available system with a large TES is the Andasol power plant in Spain. It uses the liquid system of molten salt sensible heat storage. In practice it is the system with the lowest price per kWh and with good efficiency.

Solid media sensible heat storages like concrete are under research by the German Aerospace Center. Doerte Laing from the DLR is together with Rainer Tamme a leading researcher in this field and developed together with the construction company Züblin from Germany a concrete storage which was used in a pilot phase at the PSA in Spain and Jülich, Germany. The idea was to use it in a large scale in Andasol but the project developers decided to use molten salt due its lower costs compared to concrete storages.

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[11] (Laing 2008)

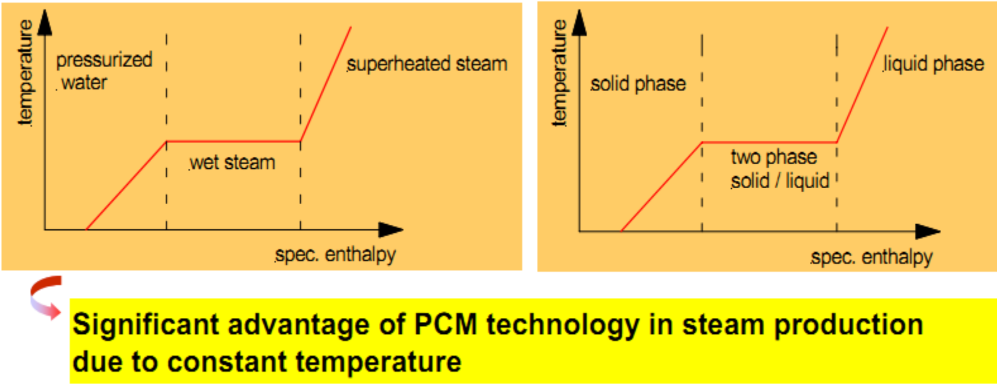

Figure 3.4.4 Advantage of PCM for steam production[12]

In the case of passive TES, PCM shows the most promising features for direct steam generation. Superheated steam is produced in three steps. The first step is to heat up pressurized water. In this phase of pressurized water the PCM has a solid phase and when the wet steam is created the PCM turns into a solid/liquid phase with a constant temperature. As soon as the wet steam gets superheated the PCM in the liquid phase heats the wet steam up to superheated steam. This means with the high temperature for superheated steam the liquid phase of the PCM is used. The heating up of the wet steam leads to the cooling of the PCM and a change of state to a solid/liquid phase with a constant enthalpy. As soon as the PCM cools down due to the loss of heat through the HTF steam, the PCM leaves the mid phase solid/liquid and becomes solid again and heats up the now low temperature pressurized water.

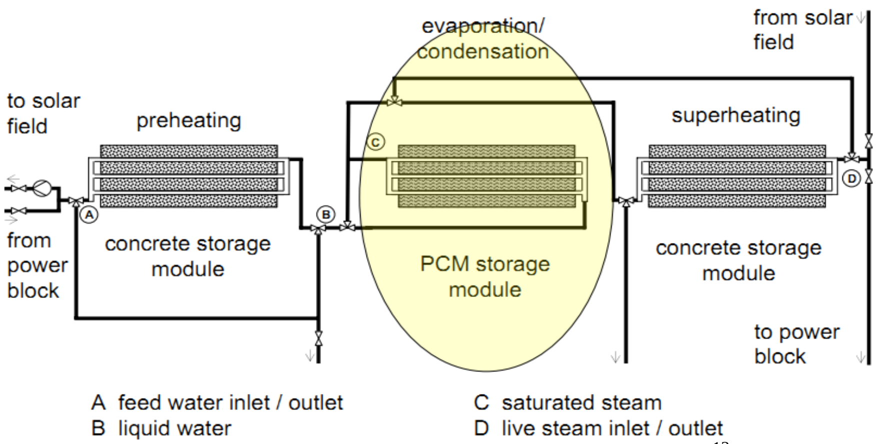

Figure 3.4.5 PCM and Solid Storage in Combination[13]

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[12] (Laing 2008)
[13] (Laing 2008)

The advantage of the aforementioned PCM storage media in combination with solid single phase concrete storage are shown in the figure above. Concrete storages are used for applications with a constant temperature level such as preheating and superheating. The phase of the HTF does not change in these steps while the temperature of the HTF is constantly increasing. The PCM storage has its advantages in the phase change of the liquid water to wet steam. The solid concrete storage can then heat up the single phase superheated steam.

Figure 3.4.6 Concrete thermal storage[14]

The above picture shows a concrete thermal storage module design by Züblin with a storage capacity of 100 kW and 400 kWh which means that the storage capacity operates for 4 hours on full load. The concrete block has a volume of 20m³ and was the first of its kind in a test-scale application close to Stuttgart, Germany. The research currently being conducted on PCM is finding an increase in heat conductivity due to its low but still acceptable heat conductivity level (Nuño 2009).

[14] (Nuño 2009)

The research follows the idea to increase heat conductivity of concrete by implementing metal tubes into the concrete blocks as shown in Figure 3.4.7. The steel tubes enable higher heat conductivity and with it higher efficiency. The implementation of steel tubes makes the concrete storage on the other hand more expensive and has to be further optimized to actually be able to be implemented on a commercial scale (Nuño 2009).

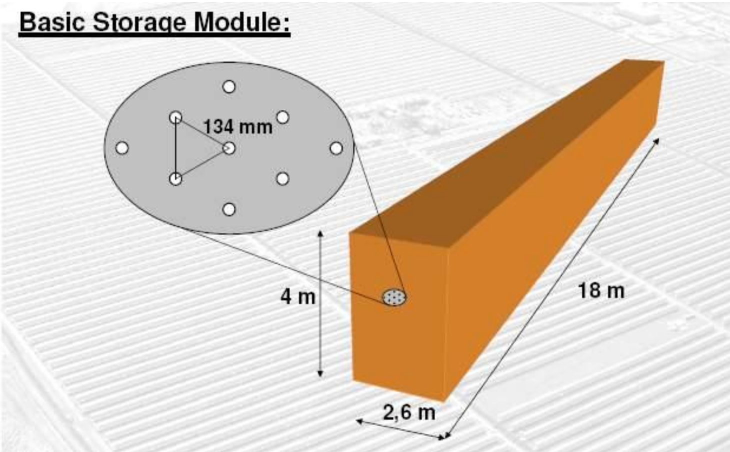


Figure 3.4.7 Concrete storage with steel tubes[15]

[15] (Nuño 2009)

3.5. Operating system of CSP including Storage

Figure 3.5.1 shows the operation principle of a parabolic trough power plant system including a thermal storage, in this case molten salt. The cold heating fluid is pumped to the parabolic trough power plant where it is heated up. The heated fluid is then pumped to a heat exchanger. The type of heat exchanger to be used depends on the load scenario which is used for the plant and the direct normal irradiance. The dependence on the direct normal irradiance is explained in the next break as excess heat case.

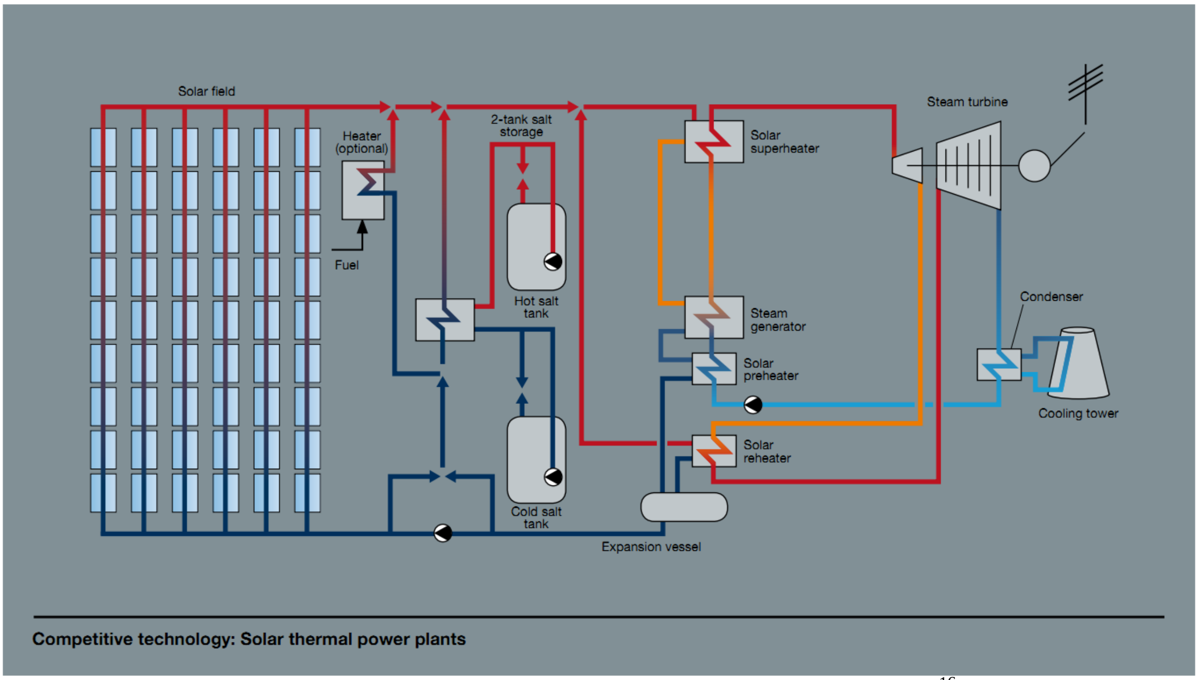


Figure 3.5.1 Working principle of a Solar thermal power plant incl. storage[16]

Figure 3.5.1 shows a typical solar thermal power plant with a solar collector field operated with synthetic oil. The oil is heated up in the collector field. The heated synthetic oil or so-called heat transfer fluid (HTF) is then transported to point 1. From there, it depends on the temperature where the oil will go. Normally, it goes to a solar super heater to create super saturated steam for power production in the steam turbine. After this point, the HTF floats down to the steam generator where it

[16] (Ferrostaal 2011, 14)

creates steam with its lower temperature. The next step is the solar preheater where the "low" temperature HTF preheats the cold and oxygen removed water. The HTF is then collected in the expansion vessel to depressurize the HTF and to feed it back into the system.

In the case of excess heat which cannot be used in the steam cycle, it is transported to a heat exchanger and there the available heat is used to heat up the cold salt from the cold salt tank. The heated up "cold" salt is then transferred to the hot salt tank. The cold temperature of this molten salt should be above 223 °C otherwise the molten salt "freezes" and gets solid. A re-melting process takes a high energy effort and should therefore to be avoided. For this reason the operating temperature of the cold salt tank is 292 °C which is considerably above its freezing temperature (Dracker und Riffelmann 2008).

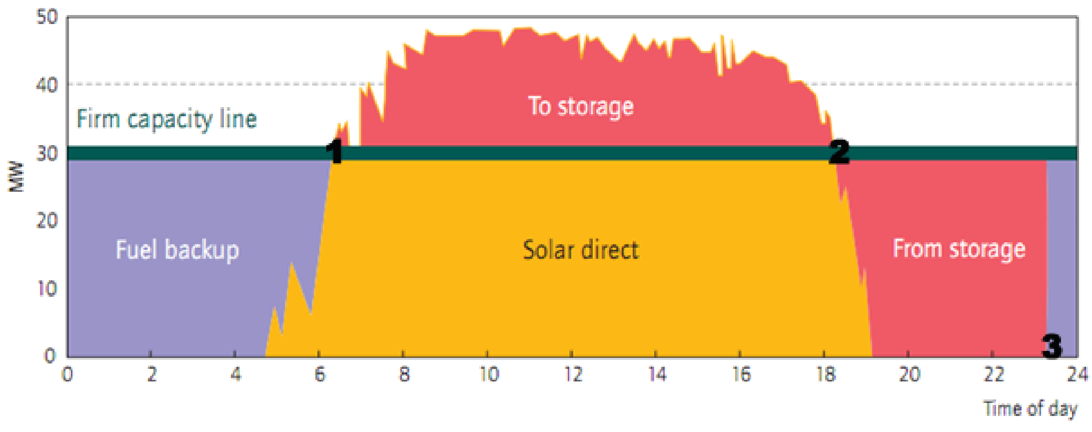


Figure 3.5.2 Storage and backup load of a CSP-plant[17]

The CSP plant design in Figure 3.5.1 shows also the possibility of including a fossil fuel based on a backup heater. By including a fossil fuel backup (usually gas-fired boilers) the necessary thermal energy storage capacity is significantly lower to operate in a base load scenario. Figure 3.5.2 then shows different operation systems of the CSP-plants in combination with a thermal storage and fuel backup. In the time

[17] (International Energy Agency 2010, 16)

from sunrise until reaching the firm capacity line at point 1, the parabolic trough power plant does not deliver enough energy to operate the steam cycle alone. To operate at the firm capacity of 30° MW, the steam cycle is supported by the fuel backup. Beginning from this time until 6 pm at point 2, the thermal storage of the CSP-plant is fed with the excess heat energy which is produced in the collector field of the solar power plant. From 6pm until shortly before midnight at point 3, the hot storage of the CSP-plant is used to generate electricity in the steam cycle process. The hot molten salt gives heat to the HTF in a heat exchanger and cools down in this process. During the cooling process the hot molten salt is transferred to the cold salt storage where the temperature level is lower than in the hot molten salt storage.

4. Sustainable Aspects

Solar CSP offers several advantages for sustainable development in the world. In the chapter Market Development, it is shown that just 3 industrial countries, the United States, Spain and Australia have sufficient solar irradiance for the application of solar CSP. Emerging countries such as South Africa, India and to an extent China will have sufficient area for the implementation of large scale CSP-plants. The other potential solar CSP areas are located in developing and developed countries which give the possibility for the world to apply the Millennium Development Goals of poverty reduction and clean water. This RES-technology gives us the possibility to apply in the early development stages of these economics clean energy production. The major energy production e.g. in the MENA-region could be exported to the European Union, where the current higher prices for expensive technologies could be paid. With further development of technology and economic growth in the region, more CSP plants could be built and the increase in demand could be covered by clean renewable energy.

"In short, CSP would be largely capable of producing enough no-carbon or low-carbon electricity and fuels to satisfy global demand. A key challenge, however, is that electricity demand is not always situated close to the best CSP resources."(IEA 2010, p. 10)

4.1. Economic

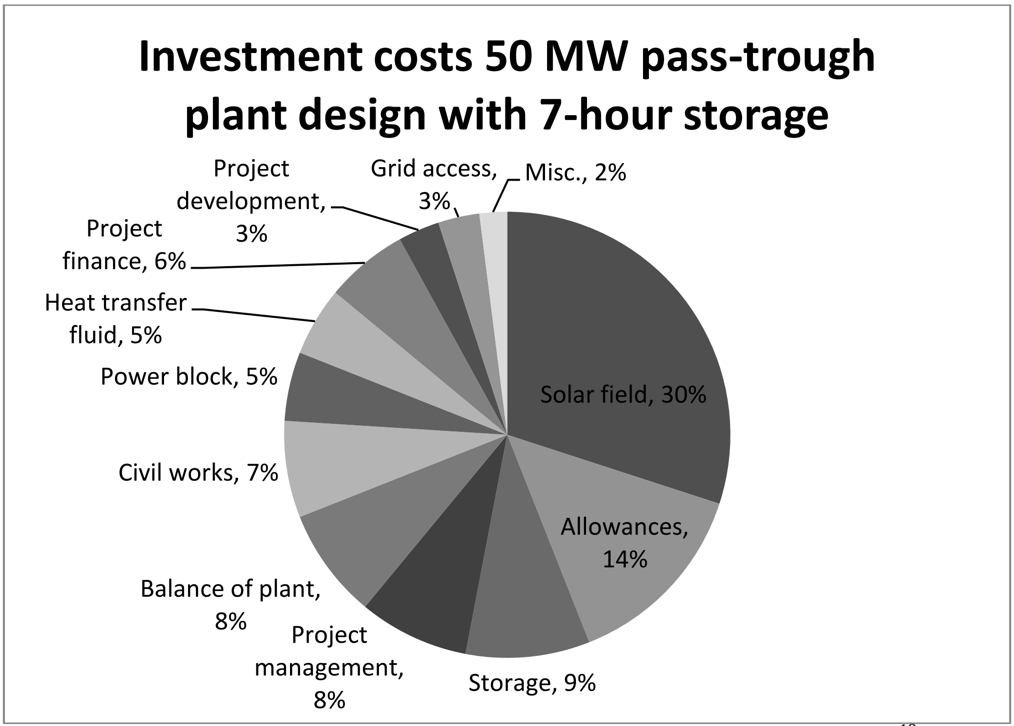


Figure 4.1.1 Investment costs of a 50 MW trough plant with 7-hour storage[18]

The diagram Figure 4.1.1 shows a typical investment distribution for a 50 MW through CSP plant in Spain with a seven hour storage capacity. The figure shows that the major investment was due to the solar field with the pass-trough collectors. This technology is more expensive than others, but has the highest deployment so far due to its higher efficiency. The figures indicate high shares for project management, project finance and development. In total they sum up to 17 percent of the overall costs for the realization of a plant. Together with 14 percent for allowances, they bring a large potential for cost reduction in the future when the projects are more commonly accepted and the systems are more proven.

[18] (IEA 2010, p. 27)

Operation costs for CSP plants can be separated in the following parts: *"...plant operation, fuel expenses in the case of hybridization or backup, feed and cooling water, and field maintenance costs* (IEA 2010, 28)."

Maintenance and operation for a 50 MW trough plant need about 30 workers for the operation of the plant and an additional 10 workers for field maintenance. Altogether the maintenance and operation costs can be determined *"...from USD 13 /MWh to USD 30 /MWh, including fuel costs for backup. As plants become larger, operation and maintenance costs will decrease (IEA 2010, 28)."*

The overall generation costs based on the levelized cost of electricity (LCOE) vary from source to source. A.T. Kearny states that CSP plants already have generation costs of 13 - 15 Eurocents/kWh today (A.T. Kearny 2010, 9).

The Global Network for Renewable Energies REN21 states for a CSP trough power plant in the size 50 - 500 MW, typical costs of 0.14 - 0.18 USD /kWh (REN21 2010, 26) which, under the current exchange rate, are substantially lower than the projection of the consulting company A.T. Kearny.

In the future A.T. Kearny expects generation costs of below 10 Eurocents in 2025 (A.T. Kearny 2010, 9). With the prices below 10 Eurocents, CSP would be much cheaper than off-shore wind today and would then be competitive with large-scale biogas or onshore-wind. Greenpeace International in cooperation with the European Renewable Energy Council (EREC) expects LCOE of 6 - 10 US cents/kWh under rapid market growth conditions in the long term for good sites and mode of operation (Greenpeace, EREC 2010, 55).

Arvizu et al conducted research for the following IPCC data: "The learning ratio for CSP, excluding the power block, has been estimated at 10 ± 5 percent. Specific LCOE goals for the USA are US cent2005 6 /kWh to US cent2005 8 /kWh with 6 hours storage by 2015 and US cent2005 50 /kWh to US cent2005 60 /kWh with 12 to 17 hours of storage by 2020. The EU is pursuing similar goals (Arvizu, et al. 2011, 57).” These estimations are considerably lower than the previous estimations and expectations but can be seen as reasonable from the independent researchers of the IPCC, which is a United Nations institution.

In our current political and economic system, each state-of-the-art technology has to compete with the most-cost effective technology as long as there is a restriction to this technology. The International Energy Agency recently released a study where the authors came to the conclusion that with the current feed-in tariffs (FITs) in Spain and France, solar CSP produced in North Africa could be economical feasible: *“Further, the current feed-in tariffs in Spain or France for large-scale, ground-based solar electricity would largely cover the costs of production of electricity in North Africa, assessed at EUR 150 /MWh on best sites, plus its transport to the south of Europe, assessed at EUR 15 /MWh to EUR 45 /MWh(IEA 2010, 21).”*

Solar CSP systems with combustible fuel as a backup system and/or thermal storages could be competitive with base, shoulder and peak load fossil fuel power plants in about 10 to 20 years. In some locations, CSP is already able to compete with CCGT-peak load plants (IEA 2010, 1). Competiveness in these regions can be reached by the nature of the design. In the semi-arid and hot regions, the peak and immediate loads are due to air-conditioning demand at lunch time which is the same time that the solar CSP reaches its peak generation capacity. “*This explains why the economics of CSP will remain more favorable for peak and intermediate loads than for base loads in the coming decade, unless or until CO_2 emissions are heavily priced. Competing energy sources have significantly higher generation costs for peak and mid-peak demand, while the cost of CSP electricity is about the same for peak and base load (IEA 2010, p. 28).”*

Figure 4.1.2 shows the cost development of CSP plants in dependence of the direct normal irradiance. In 2010, electricity costs on a good site including the cost of capital are around USD 200 /MWh and will decrease to a level of USD 50 /MWh in the year 2050 according to the estimations of the IEA. The production costs of electricity from CSP power plants are comparable at the moment with the production costs of small-scale wind turbines and are not feasible, at least for base load application. CSP, from an economic point of view, will be feasible for intermediate and peak loads in the year 2020 and for base load application in the year 2025 - 2030. The current application of CSP is driven by feed-in tariffs or the renewable energy portfolio standards.

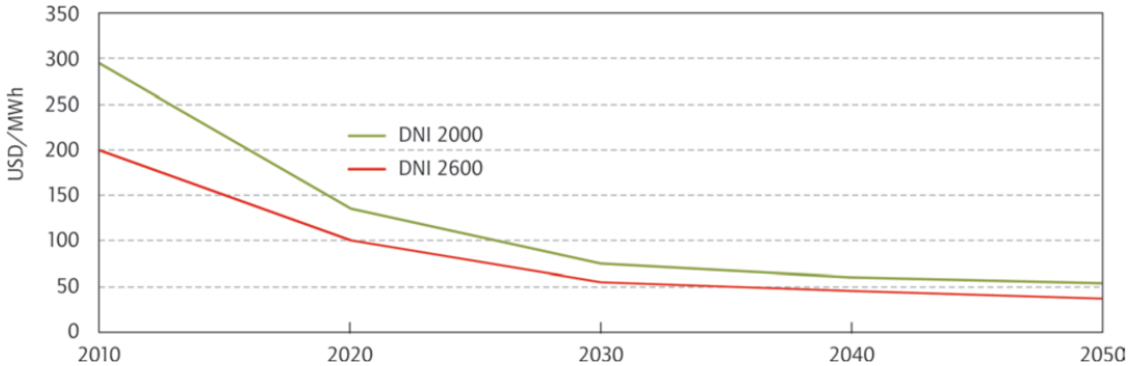


Figure 4.1.2 Projected evolution of the levelised electricity cost from CSP plants, in USD/MWh, under two different DNI levels in kWh/m /y[19]

The solar field produces heat for the same costs and therefore the thermal storage is the driver for the application scenario. Peak and delayed intermediate load applications will have the biggest application in the near future if a feed-in tariff is not applied to the power plant. The application of thermal storage will be due to its lower investment costs molten salt. Other technologies have better capacities but also higher prices and are thus less feasible (ABS Energy Research 2010, p. 3).

[19] (IEA 2010, 29)

	Tempera-tura Fría	Temperatura Caliente	Densidad	Conductividad	Calor especifico	Capacidad de almacenamiento	Coste por kg	Coste por kWht de almacenamiento	Coste para almacenamiento de 1000 MWht
	°C	°C	kg/m3	W / m K	kJ / kg °C	kWht / m3	€/kg	€/kWht	M€
Concrete	330	390	2200	1,5	0,85	31	0,1	7,1	7
Steel	330	390	7800	40	0,6	78	5	500,0	500
concrete + 7% steel tube							Current situation		32
concrete + 1% steel tube							Objective		10
Nitrate salts	291	384	1870	0,52	1,6	77	1,25	30,2	30
							Current situation		

Table 4.1-1 Cost benchmark[20]

	Tempera-tura Fría	Temperatura Caliente	Densidad	Conductividad	Calor especifico	Capacidad de almacenamiento	Coste por kg	Coste por kWht de almacenamiento	Coste para almacenamiento de 1000 MWht
	°C	°C	kg/m3	W / m K	kJ / kg °C	kWht / m3	€/kg	€/kWht	M€
Concrete	330	390	2200	1,5	0,85	31	0,1	7,1	7
Steel	330	390	7800	40	0,6	78	5	500,0	500
concrete + 7% steel tube							Current situation		32
concrete + 1% steel tube							Objective		10
Nitrate salts	291	384	1870	0,52	1,6	77	1,25	30,2	30
							Current situation		

Table 4.1-1 shows why the Andasol project can be implemented with nitrate salt or molten salts. The price of molten salts TES is 30 million Euros per MWh_t which is 2 million Euros cheaper than the concrete storage system technically available so far. The researcher aims for TES with 20 Euro/kWh_t specific installation costs. Molten salt has a small development potential and just by an economy of scale was able to reach this level. However, solid single phase concrete with steel tubes

[20] (Nuño 2009)

still has the research and development potential to reach a price level of 10 Euro/kWh_t

4.2. Life cycle assessment

Each technology also has a few drawbacks. Solar CSP plants will be mainly installed in arid or semi arid regions where the environment for CSP is well-suited for the purpose of electricity production due to the high direct normal irradiance in these regions. As these regions are mainly deserts and not suitable for agricultural purposes, land use conflicts are not a concern. The drawbacks from the surface footprint with 2 hectares per MW_{el} installed capacity are not considered essential from an environmental point of view *(IEA 2010, p. 10)*. Additionally, the Environmental and Energy Study Institute compared the land-use of CSP with coal and hydroelectric dams and came to the result that if the mining or reservoir sites are as well considered for the land-use, the land-use is even higher than for CSP (Environmental and Energy Study Institute 2009).

Water consumption on the other hand is considered critical as these regions are already water scarce. Most of the solar CSP-technologies require water for cooling and condensing processes in their plants. Parabolic trough and linear Fresnel reflector plants have with 3000 l/MWh high water requirements but are similar to nuclear power plants. Solar towers have with 2000 l/MWh a comparable water demand to coal plants and from a water demand and energy efficiency point of view, the combined cycle natural gas power plant is the most efficient technology of the fossil fuel based power plants with 800 l/MWh. On the other hand, parabolic Stirling dishes have no demand for water for cooling or condensation since these engines use a heating fluid directly for electricity production and are cooled by the surrounding air (IEA 2010, p. 17).

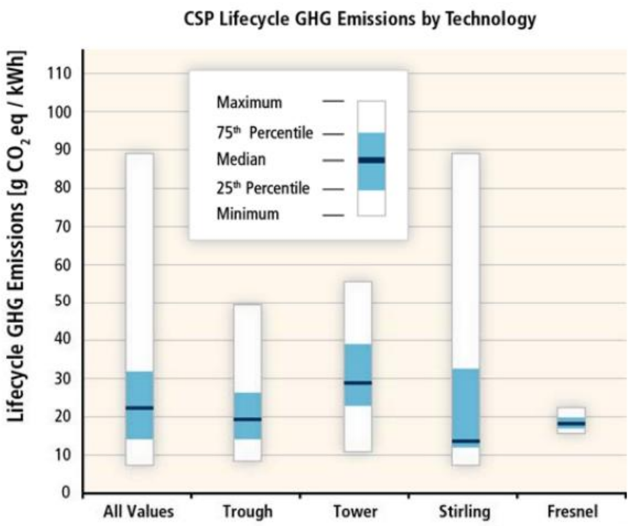
The challenge is now the development of efficient ways to reduce the water requirements for the solar CSP technology. Promising developments are done with dry or with hybrid dry/wet cooling systems (IEA 2010, p. 5).

The new developments of technologies are economically advantageous when compared to wet cooling systems since water is a highly valued resource in semi arid/arid regions. Wet cooling systems will increase the scarcity of water even more in the future with growing populations and the accompanying water requirements in combination with temperature increases. The new cooling systems have decreases in efficiency compared to wet cooling systems. The advantage is that the water requirement can be reduced substantially. Efficiency drops of 7 percent during electricity generation are expected. The costs of producing electricity will increase by 10 percent for parabolic trough and LFR-plants. Solar towers will have better performance records due to the higher operating temperature of the steam turbine.

Different operating systems for the purpose of cooling can decrease the performance penalty considerably. The installation of a wet/dry cooling system at a parabolic trough plant decreased the water consumption by 50 percent with a loss of just one percent of electricity generation (U.S. Department of Energy 2007). Water cooling systems are more effective than dry cooling systems but also more expensive in operation. The combined cooling systems have different favorable operating temperatures. In winter when the cooling demand is lower the dry cooling system is more cost-effective than the wet cooling system. The temperature delta of the ambient air and the steam is lower and so the cooling demand is lower. In summer with high ambient temperatures, additional wet cooling is applied and the cost benefits are optimized, since the consumption of the increasingly scarce resource water is reduced and it is used only for essential steps in the operation of the system.

Greenpeace calculates that every square meter of a CSP station could save between 200 and 300 kg of CO_2 every year, depending on how the plant is configured (Greenpeace 2009).

This statement shows along with the fact that a tree can save around 30 kg over its life, the huge potential for a carbon neutral society based on renewable energy production. The carbon footprint of each technology has a crucial part of each investment decision. The European countries have with the Emission Trading Scheme (ETS) an essential tool for a carbon neutral society already implemented. CO_2 credits have to be purchased in the future for each power plant which emits CO_2. Solar CSP with its low emission factor can benefit from carbon taxation even earlier before 2020.



	All Values	Trough	Tower	Stirling	Fresnel
Estimates:	42	20	14	4	4
References:	13	7	5	3	1

Figure 4.2.1 CSP Lifecycle GHG Emissions by Technology[21]

Arvizu et al states that the emission range for lifecycle greenhouse gas emissions have recently been estimated at 14 - 32 g CO_{2eq}/kWh produced electricity by CSP. These figures are about one tenth of the emission level of natural gas-fired

[21] (Arvizu, et al. 2011, 51)

power plants and are therefore from an environmental point of view more favorable than natural gas (Arvizu, et al. 2011, 50).

The German CleanTech Institut estimates the saving potential of CSP in 2010 between 3 and 27 Million tons of CO_2 (Deutsches CleanTech Institut 2009, 54).

From a carbon payback perspective, the CSP-technology is already a promising technology with minimum R&D efforts. The overall carbon balance, along with the low carbon footprint of the plant itself, is already outbalanced after half a year of operation. With an estimated lifespan over several decades like in the Mojave Desert in the USA, the carbon emissions for construction are covered and the overall net energy balance is highly beneficial (Deutsches CleanTech Institut 2009, p. 54).

4.3. Social

Solar CSP has, like all centralized large scale power plants, some constraints in the social aspect of sustainable development. The large scale power plants also need large scale investments with security which is normally provided by large companies, investors, or states. The idea of sustainable development founded by decentralized small scale energy production is possible only for parabolic dishes in this case. From a social point of view, this is a strong hindrance. However, solar CSP gives the world the opportunity to produce a renewable base load with low energy production costs and environmental restrictions if a dry/wet cooling is applied.

Aside from investment aspects, solar CSP also has developmental advantages. Besides the USA and Spain, the main region which is currently at the focus of CSP industry is the MENA-region. The Middle East and North Africa have as further explained in Chapter 6, large potential for the application of solar CSP. The North African countries are dependent on fossil fuel energy supply, which is further explained in Chapter 7. Therefore, the North African region is a good place for a renewable energy-based energy supply. Some North African states such as Algeria and Libya are not dependent on fossil fuel imports. Rather they are exporters whereas countries like Morocco are highly dependent on the import of fossil fuels in combination with highly increasing energy demands.

The potential of regional added value with the implementation of local based renewable energy supply is large. In a recently published report by the World Bank and the African Development Bank, they expect with their investment program that it would trigger the installation of 5 GW by 2020. In scenario C (Transformation) a total of 180,000 jobs and a local economic impact of 14.3 billion US$ would be generated. The scenario sees the development of a local industry for components and construction of CSP plants due to a strong market growth and the export opportunities to other CSP areas (World Bank, African Development Bank 2011).

The Kingdom of Morocco has realized this opportunity and is implementing projects based on Solar CSP. Egypt and Algeria are planning or constructing ISCC-plants with parabolic-trough solar CSP plants.

5. Application scenario

"While the bulk of CSP electricity will come from large, on-grid power plants, these technologies also show significant potential for supplying specialised demands such as process heat for industry, co-generation of heating, cooling and power, and water desalination. CSP also holds potential for applications such as household cooking and small-scale manufacturing that are important for the developing world."(IEA 2010)

The statement above from the IEA Solar CSP Roadmap is a clear statement of the development fields of CSP. These applications could be described further but are mainly self-explanatory and are therefore not further specified in this report. The author sees the biggest potential in the water desalination and small-scale manufacturing of parabolic dishes for the developing world as hot topics in the future since water and energy are essential resources of our daily lives. For further explanation due to limitation of this report reviewing the work of the research program (MED-CSD 2010) by the European Union is advised.

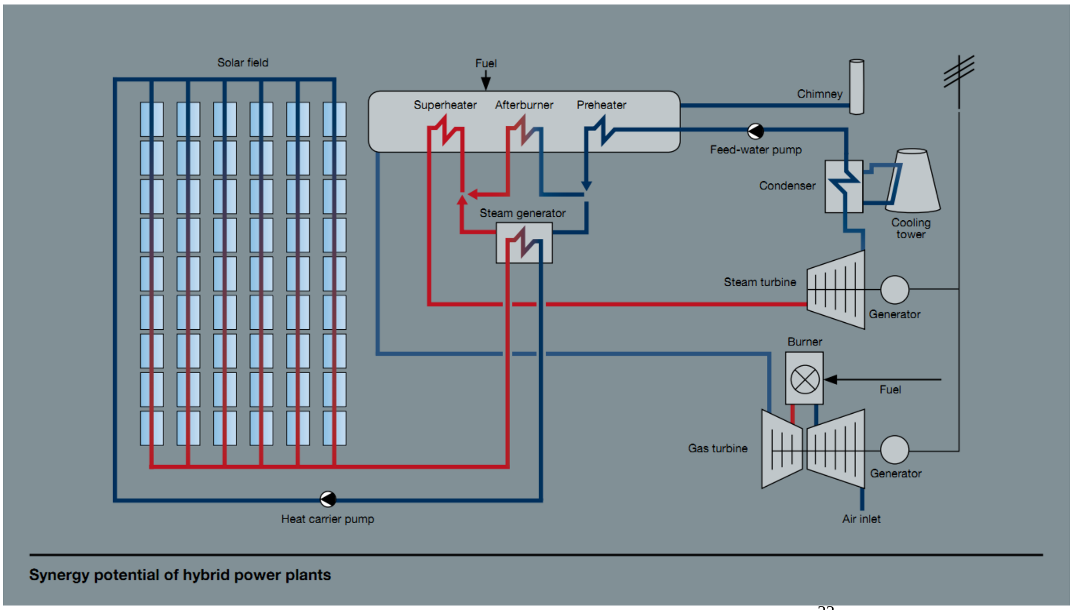


Figure 5.1 Fossil fuel hybrid solar thermal power plant[22]

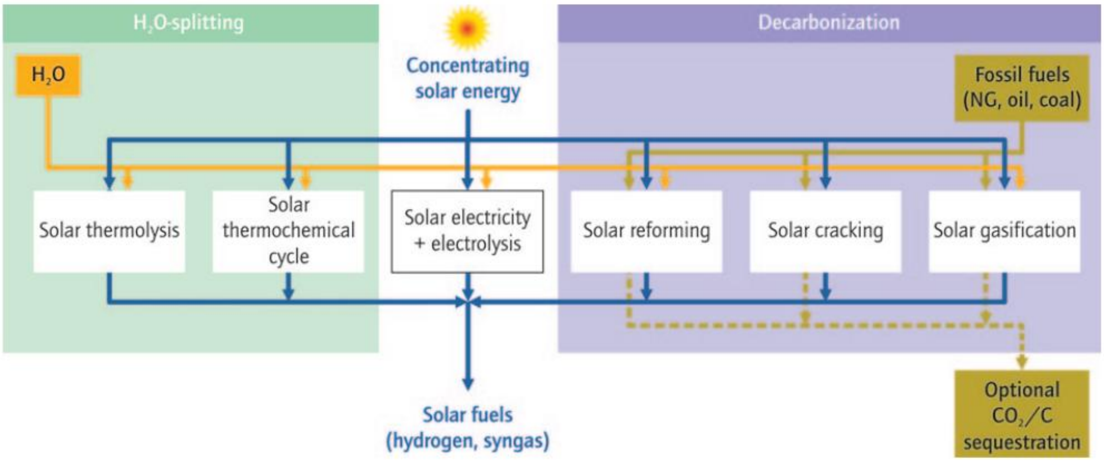
Integrated solar combined-cycle plants (ISCC) are another hot topic in the MENA region. Instead of using fossil fuels as backup technology, CSP is used as a cogeneration option. Countries such as Algeria, Australia, Egypt, Iran, Italy and the United States (in the state of Florida) invest in the solar CSP application. The range of capacity is between a few megawatts up to 75 MW as a fuel saving option since the fossil fuel is also intended just for steam production and could so substituted by CSP as a steam provider in these cases *(IEA 2010, p. 16)*.

Figure 5.1 shows the working principle of an ISCC plant in detail. The conventional fossil fuel combined cycle is supported by the collector solar field to create steam. By supporting the steam cycle the fossil fuel need can be reduced significantly. According to Schott Solar, the overall production costs are just slightly higher than that of conventional power plants. Yet, they offer the possibility to stabilize the production costs of the conventional natural gas system by reducing the fuel need.

With the expected increase of fossil fuel prices due to expanding demand, CSP-application gains more momentum in the future as was recently published by the IEA (IEA 2011) (Schott North America, Inc. 2010, 10ff).

[22] (Ferrostaal 2011, 14)

Besides electricity generation or heating and cooling purposes, the high energy produced from the concentration of solar power is also used in solar chemical processes. So-called solar fuels are created in this case with the help of the sun. The figure below shows the different possibilities for the creation of sun fuel. They are based on water splitting in solar thermolysis, solar thermochemical cycles for hydrogen generation or for the purpose of syngas production with optional CO_2/C sequestration based on fossil fuels. The water splitting with solar thermal processes will be more cost beneficial than the current application with electrolysis in 10 years (IEA 2010, 29).



Source: PSI/ETH-Zürich.

Figure 5.2 Different thermochemical routes to producing fuels with concentrating solar energy[23]

[23] (IEA 2010, 33)

Fertilizer production and coal-to-liquid are other possible applications of this universal energy provider: “Meanwhile, the first demonstration plants for solar-assisted natural gas reforming are built in southern Europe, California and the Middle East for manufacturing fertilizers. On some refinery sites, solar tower plants recycle the hydrogen that extracts sulphur from petroleum. Solar-assisted coal gasification for the production of coal-to-liquid fuels with a smaller carbon footprint is being developed in Australia, China, India, South Africa and the United States.”(IEA 2010, 23)

The Concentrated Solar thermal power plant technology is similar to the other sun-based RES dependent on high solar irradiance. The advantage of CSP compared to solar PV is that the solar irradiance is not directly transferred into electricity, but heat is captured and steam is generated from this heat. The capturing of heat enables delayed steam and with it delayed electricity production by the use of thermal energy storages (TES). TES enables this technology to be capable of base load and to produce constantly without breaks. The International Energy Agency, which is a traditional supporter of fossil fuels, sees in this a big advantage:

“The storage and backup capabilities of CSP plants offer significant benefits for electricity grids. Losses in thermal storage cycles are much smaller than in other existing electricity storage technologies (including pumped hydro and batteries), making the thermal storage available in CSP plants more effective and less costly (IEA 2010, 16).”

Thermal energy storages are cheaper when compared to battery solutions while also having a higher efficiency. The report therefore will present the different application scenarios for solar thermal power plants with a thermal energy storage system. So far, only the Andasol Project in Spain with its molten salt storage system is commercially available. The information of this report is therefore just a status quo analysis of a large and fast growing business with a lot of research and development effort. The major researcher for thermal energy storages is NREL in the United States of America and the German Aerospace Center (DLR), Germany.

The possible sizes of thermal storages largely vary. The major application and with it the size, is so far the cover of intermediate and peak loads. The storage size is limited to a few hours of cover as the competitive costs for intermediate and peak loads are more suitable for CSP-applications than for base loads. *"Thermal storage is further developed but in most cases remains limited to what is necessary to cover almost all intermediate and peak loads from solar resources only. CSP is not yet fully competitive with coal power plants for base load, as* CO_2 *emissions are not yet priced highly enough (IEA 2010, p 22)."*

Thermal storage varies largely as was previously mentioned. The following figures show the different sizes of thermal storages combined with different steam turbines for electricity production:

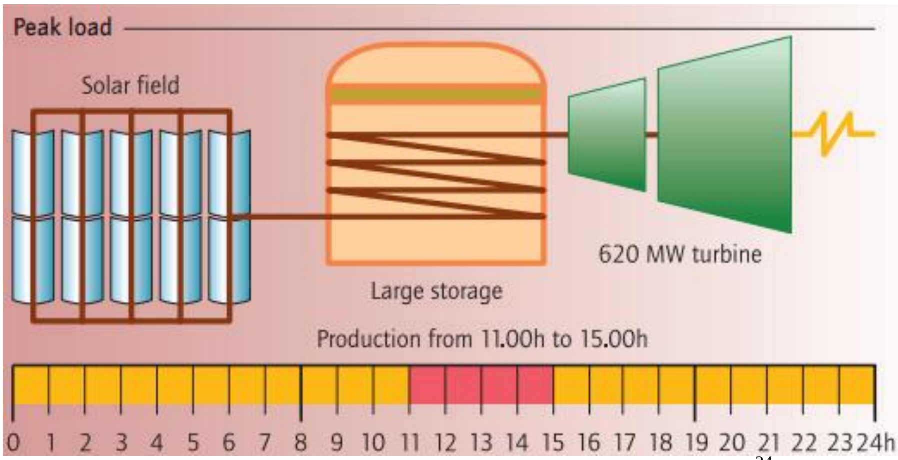


Figure 5.3 Peak load scenario with 4 hours operational time[24]

The first application is a peak load scenario. The solar field constantly feeds into the thermal storage. The thermal storage is of great dimensions as well as the steam turbine. Production time for this scenario at four hours is quite small, but the installed capacity of electricity generation at 620 MW is large. The production of

[24] (Julien Octobre and Frank Guihard 2009)

electricity at the high consumption times, which are around noon, is the main target of this application.

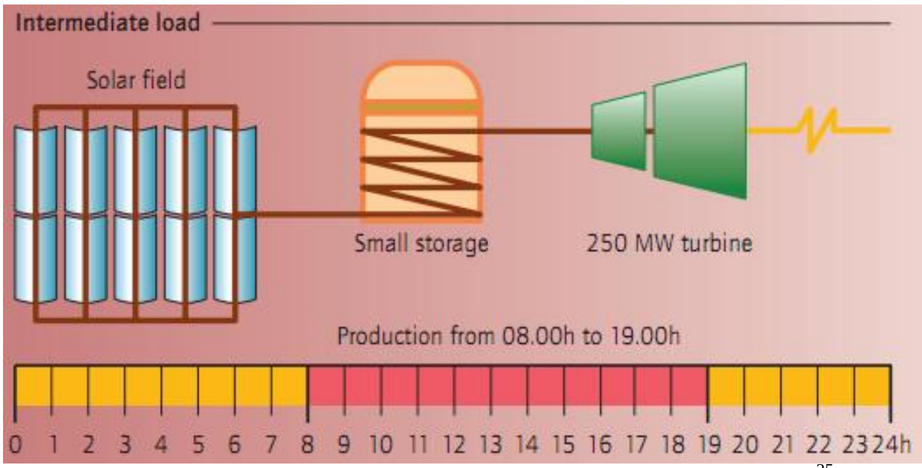


Figure 5.4 Intermediate load scenario with 11 hours operational time[25]

The intermediate load scenario power plant is equipped with a small thermal storage and a smaller sized 250 MW steam turbine. The small storage is used to cover clouds, which would otherwise interrupt heat production and ensure the operational supply of the steam turbine with steam. The operational time here is from 8 am to 7 pm which means that the sun irradiance is covering the main supply of heat and the heat storage can be sized reasonably small.

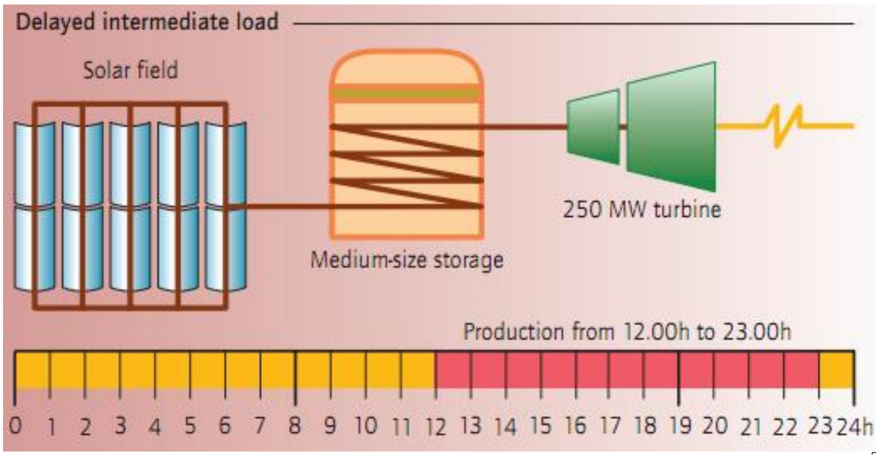


Figure 5.5 Delayed intermediate load configuration with 11 hours operational time[26]

Delayed intermediate load power plants have the same turbine deployed like the intermediate power plants. But the difference of the scenario before is the shift

[25] (Julien Octobre and Frank Guihard 2009)
[26] (Julien Octobre and Frank Guihard 2009)

of energy supply. The shift is enabled by the application of a medium-sized thermal storage. The thermal storage is filled up in the morning hours of the day and then used in the evening hours to supply the steam turbine.

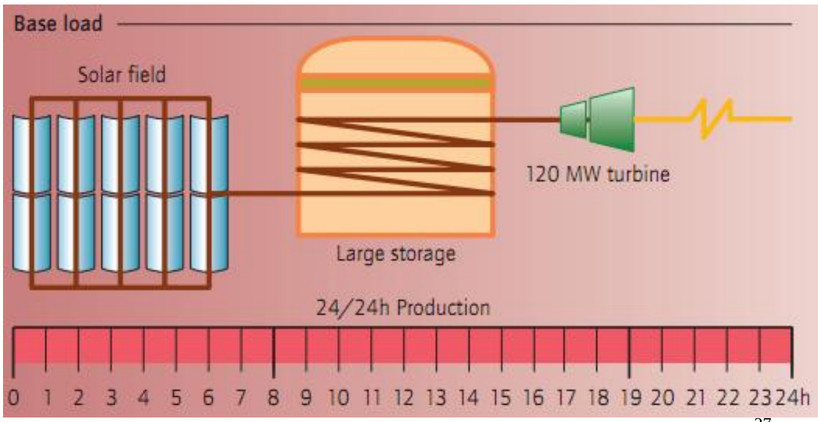


Figure 5.6 Base load configuration with 24 hours operational time[27]

Base load power plants have a large storage capacity in combination with a small generation capacity. As base load prices for energy are quite low due to low energy costs of fossil fuels, this application is the least favorable of all the different expressed scenarios.

[27] (Julien Octobre and Frank Guihard 2009)

6. Market Development

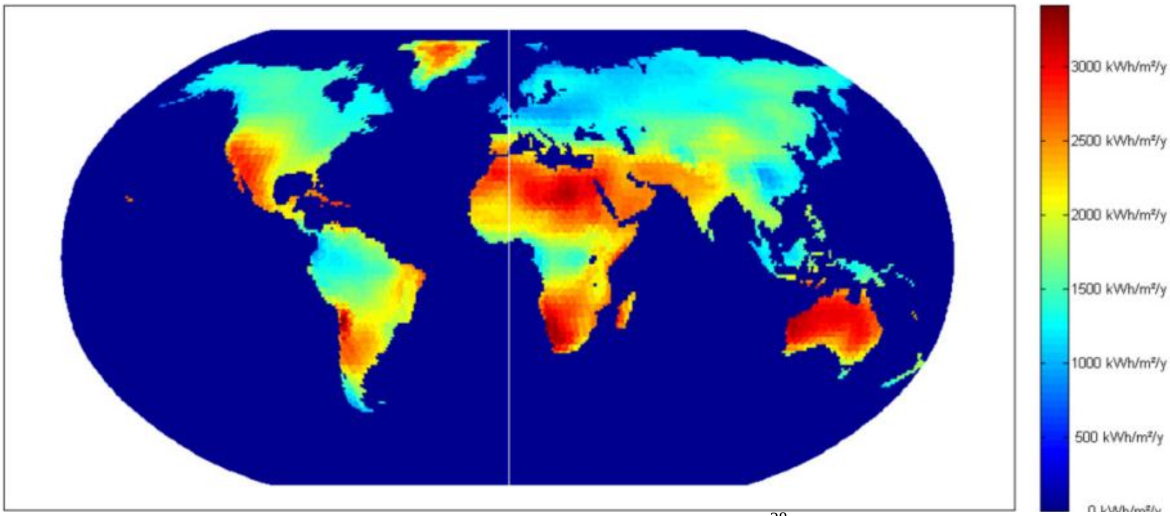


Figure 6.1: Global direct normal irradiance [28]

Figure 6.1 shows the world irradiance in kWh per square meter per anno. The dark red shifting down to yellow areas above and down the Sun Belt are the most promising areas for the application of Solar CSP. These areas have an annual solar irradiance above 2000 kWh/m²/a and are therefore economically feasible for solar CSP applications. The focus of current projects is in the United States, Spain and the MENA region due to feed-in tariffs, political support and renewable portfolio standards. An overview of the existing FITs can be found in the Annex of the report conducted by the Intelligence Service CSP Today (CSP Today 2011).

[28] (Breyer and Knies 2009) Data are based on DLR-ISIS of German Aerospace Center (DLR) and are derived from International Satellite Cloud Climatology Project. Areas of at least 2000 kWh/m²/y are needed for CSP plants due to economic constraints

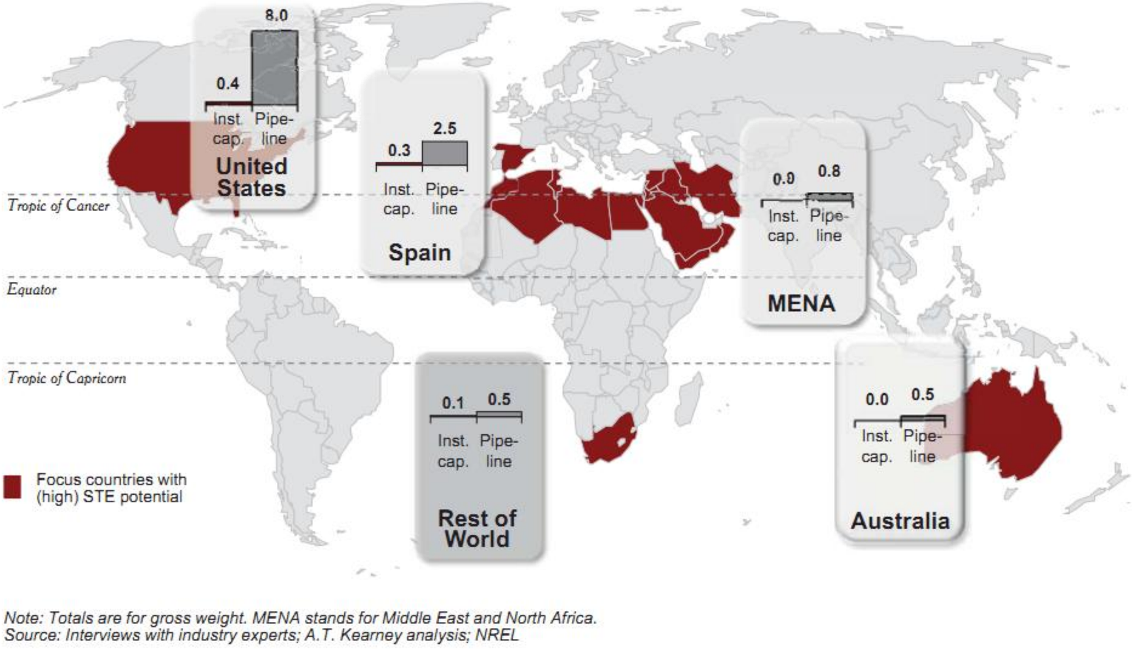


Figure 6.2 Existing and planned CSP-plants capacity through 2015[29]

The Figure 6.2 shows that the market development in the last two decades was quite small. Worldwide there is an installed capacity of around 1.7 GW which equals two larger fossil-fuel based conventional power stations. The current market development is based on projects in Spain and the United States. The proposed large market MENA is currently not under such high development as the circumstances and the environment for this technology are yet not developed. Spain and the United States have political visions and support the CSP technology with feed-in tariffs or with Renewable Portfolio Standards.

From a technology point of view there is not yet a leader in the CSP production line. Parabolic troughs are so far more favored but have not so much development potential and will therefore be phased-out in the long term by Linear-Fresnel, Power tower for centralized and dish-stirling for decentralized applications and for other applications without any water impacts (REN21 2010, 32).

[29] (A.T. Kearny 2010, 12)

7. Significance for Europe and North Africa

As mentioned in the introduction, the world energy supply is facing huge changes. The European countries have demand increases but due to energy efficiency measures, they are lower than in the past. Besides Europe, the North African countries will have huge demand increases without tackling the energy efficiency effects due to low fuel prices in these countries. The focus of this chapter is therefore placed on North Africa. In 2006, Trieb and Klann researched as part of an internal report for the German Aerospace Center the energy demand of the MENA-region (Middle East and North Africa). They stated that the MENA-region will have by 2050 the same energy demand as Europe did in 2006. This means huge energy demand increases in the next decades. As the analysis will show, these countries already have problems in satisfying their energy needs and will enlarge these needs by four times as explained later on in this chapter. This increase brings opportunities and barriers for the future energy supply of this region (Trieb and Klann 2006).

The European Commission published at the end of 2010, the strategy "Energy 2020 - A strategy for competitive, sustainable and secure energy" in which the Commission stated that the European Union is "*the world's largest energy importer,"* and that "*the EU is likely to be more vulnerable to supply risks as a result."* (EUROPEAN COMMISSION a 2010, 5). In context with large energy demand increases in neighbouring countries, this effect becomes even more dramatic.

Therefore, the Commission proposed to "*strengthening the external dimension of the EU energy market* (EUROPEAN COMMISSION a 2010, 7)*."* With the construction of additional interconnections at the borders of the European Union the external dimensions of the energy market is intended to be strengthened (EUROPEAN COMMISSION a 2010, 11).

Examples of these enhancements are the Desertec and the Medring initiatives or the Mediterranean Solar Plan as they also play a role, which affects the European Union member states (EUROPEAN COMMISSION a 2010, 16).

Enabling these initiatives requires market integration and regulatory convergence through bilateral agreements or common declarations like the Barcelona Declaration. According to the European Commission, the focus is in the Mediterranean region with the North African states along with the Middle East (EUROPEAN COMMISSION a 2010, 18).

Figure 7.1 MENA-region[30]

The MED-EMIP project of the European Union recently published their final report. It contains a brief overview of different statistical aspects of the so-called South Mediterranean region (SM). SM-region consists of the countries Morocco, Egypt, Libya, Algeria and Tunisia. The last two countries, Algeria and Tunisia, get a brief closer description in this chapter. The SM-region produces a GDP of 542 billion US-Dollars and has a population of 158 million inhabitants. The total electricity consumption of these economies is 189.5 TWh, which means that the average per capita GDP is 3,432 US$ and the electricity consumption 1,200 kWh (MED-EMIP 2010, 186). For a comparison, the average per capita GDP in the EU-27 is 23,530 € and the average electricity consumption 6,733 kWh (European Union e 2011).

[30] (CIA 2010)

Type	Egypt		Libya		Tunisia		Algeria		Morocco	
	Capacity									
	MW	%	MW	%	MW	%	MW	%	MW	%
Fossil fuels	19701	86.2	6196	100	3233	97.5	8271	97.3	3449	65.2
Steam turbines	11571	50.6	1747	28.2	1090	32.9	2740	32.2	2385	45.4
Gas turbines	916	4.0	2094	33.8	1308	39.5	4490	52.8	615	11.6
Combined cycle	6949	30.4	2355	38.0	835	25.2	825	9.7	380	7.2
Diesel	265	1.2	0	0			217	2.6	69	1.3
Hydropower	2842	12.4	0	0	63	1.9	230	2.7	1729	32.7
Other RES	305	1.3	0	0	19	0.6			114	2.2
Total capacity	22848		6196		3315		8503		5292	

Table 7-1 Installed capacity in South Mediterranean area modelled after (MED-EMIP 2010)

The MED-EMIP project also conducted the generation capacities for the North African countries. **Error! Reference source not found.** shows that the countries Libya, Tunisia and Algeria have a fossil-fuel based electricity generation capacity of around 100 percent. Morocco and Egypt have both Hydropower and minor shares of other RES in their portfolio. Morocco, with a share of 32.7 percent, has a significant portion of clean energy base load. The table shows that nearly 50 percent of the total installed capacity in the North African countries is installed in Egypt. With 22.8 MW from a total installed capacity of 46.154 MW.

The high share of steam turbines and combined cycle turbines gives opportunities for in the Application scenario described ISCC-plants. A first approach in this direction is done in Algeria and Egypt which are both in cooperation with the World Bank to apply the co-generation of steam by natural gas and CSP (World Bank, African Development Bank 2011).

The report will show two example countries in the MENA-region. The report is able to display the differences of these countries in the electricity sector between them and in comparison to the European generation mix.

Tunisia

Tunisia's electricity market is dominated by the public company "Sociéte Tunisienne de l'Electricité et du Gas" (STEG). The company operates 70 percent of the electricity generation capacity in the Tunisia in the year 2009 (Market Observatory for Energy (T) 2010).

Power plants in Tunisia

Status	Fuel	Capacity in GW
Operating	Natural gas	1.3
	Oil	1
	Other	0.7
TOTAL OPERATING		3
Planned	Natural gas	0.4
	Other	1.3
TOTAL PLANNED		1.7

Table 7-2 Electricity – Installed and planned generation capacity[31]

The generation capacity is currently 3 GW installed capacity which is reasonable small. The generation capacity equals around three to four power plants in Western Europe. Another 1.7 GW capacity is in development whereas 1.3 GW are not further specified and the rest is natural gas fuelled.

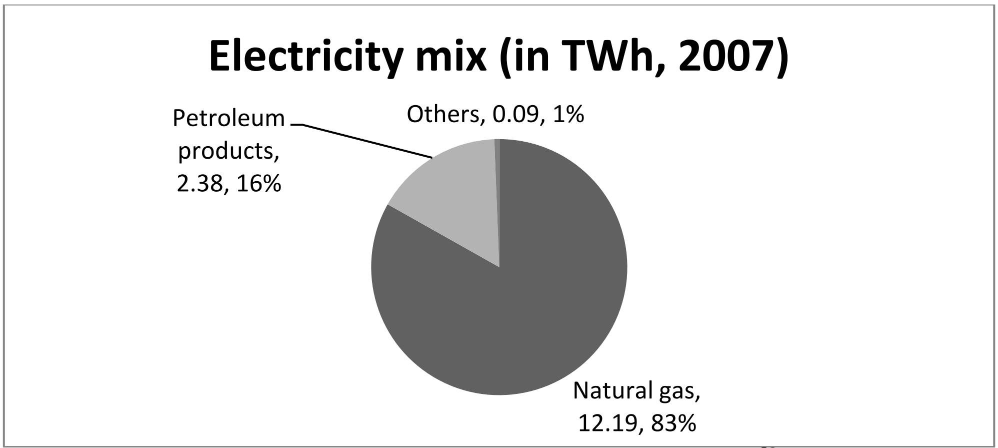


Figure 7.2 Electricity generation mix Tunisia 2007[32]

The electricity mix for the year 2007 shows that Tunisia is focused in the electricity generation sector with 83 percent on natural gas.

[31] Petroconsultants SA found in (Market Observatory for Energy (T) 2010)
[32] OECD/IEA found in (Market Observatory for Energy (T) 2010)

Algeria

According to the Market Observatory for Energy of the European Union, the Algerian government stands by a commitment of a larger share of RES in the energy sector (Market Observatory for Energy (A) 2011), whereas this commitment is not reflected in the generation capacity of Algeria. The generation capacity of 7.5 GW out of a total generation capacity of 8.3 GW is clearly dominated by natural gas as major fuel supply. Other non-renewable as well as renewable fuels, are existent but have a minor share in the generation capacity.

Generation capacity		
Status	**Fuel**	**Capacity (GW)**
Operating	Natural gas	7.5
	Waste heat	0.4
	Hydropower	0.2
	Diesel/Distillate	0.1
	Oil	0.1
	Total	**8.3**

Table 7-3 Generation capacity Algeria[33]

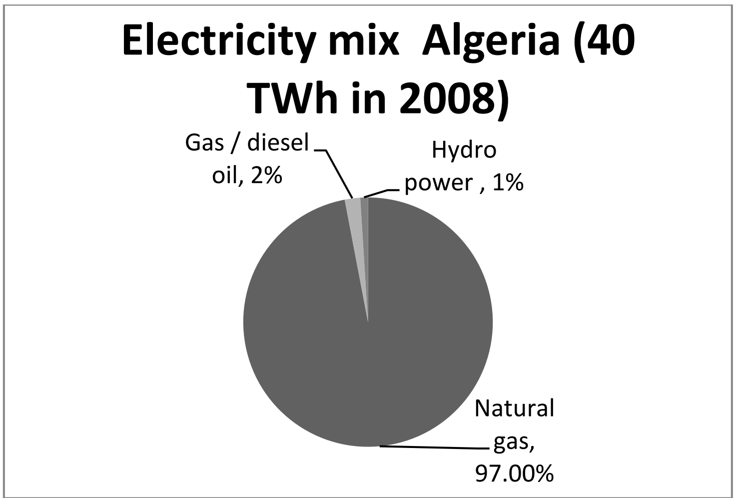


Figure 7.3 Electricity mix Algeria 2008[34]

Figure 7.3 Electricity mix Algeria 2008 shows that the generation capacity shown in

Generation capacity		
Status	**Fuel**	**Capacity (GW)**
Operating	Natural gas	7.5

[33] Petroconsultants SA found in (Market Observatory for Energy (A) 2011)
[34] OECD/IEA found in (Market Observatory for Energy (A) 2011)

Waste heat	0.4
Hydropower	0.2
Diesel/Distillate	0.1
Oil	0.1
Total	**8.3**

Table 7-3 does not mirror with the electricity mix of Algeria. The electricity generation is provided up to 97 percent by natural gas plants. One percent of the electricity generation is generated by hydropower.

For a comparison of electricity generation by source in power stations of the EU-27 in 2008 is as follows:

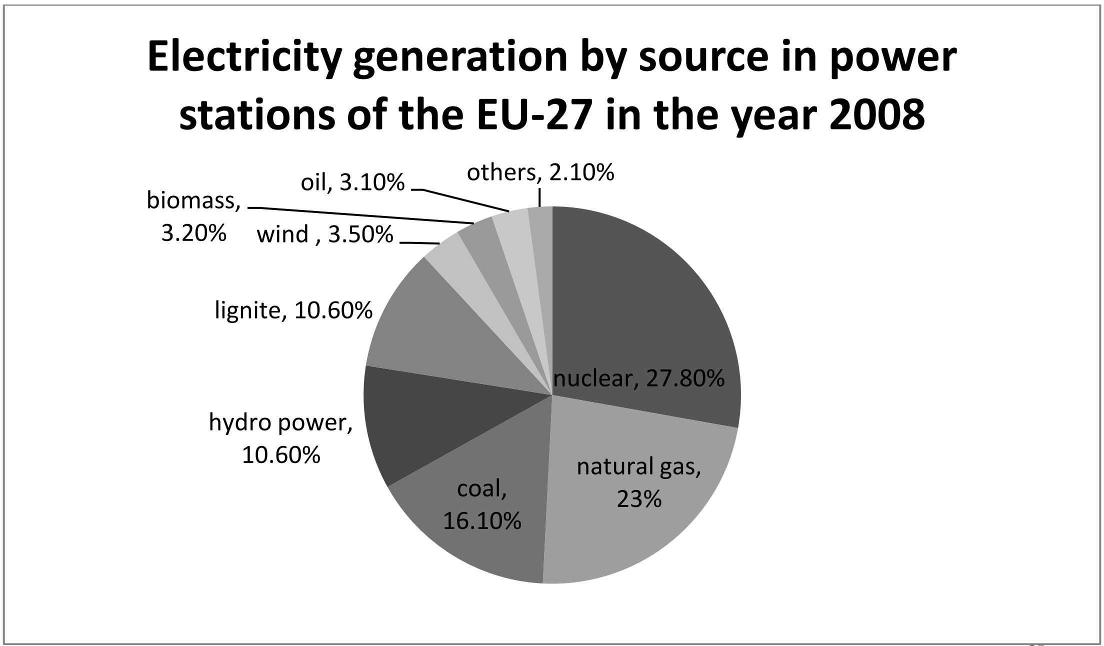


Figure 7.4 Electricity generation by source in power stations of the EU-27 in the year 2008[35]

Figure 7.4 shows that the European electricity mix is diversified but still relies on large amounts of fossil fuels. On the other hand the share of renewable energies is respectable with at least 17.3 percent for a developed region.

Source for electricity	2008	2020	2030
Gas	70%	70%	
Coal	=>10%	Increase expected	
Nuclear	-	3%	
Oil	10%	6%	
Renewables	=<10%		
Thereof Hydro	94%	41%	
Total	350 TWh	680 TWh	1200 TWh

[35] (European Union e 2011)

Table 7-4 Energy mix Mediterranean Partner Countries[36]

The table above shows the expected electricity generation increase over the next two decades in the Mediterranean Partner Countries. In two decades, the expected demand of electricity is nearly four-fold compared to today. The increase in demand comes along with a high uncertainty for the electricity mix. This uncertainty is supported by the low system average rate in the area. Table 7-5 shows the dilemma in the Mediterranean Partner Countries (MPC) the bandwidth of average electricity price for the end-customers is as low as 2 Eurocents/kWh in Egypt and goes up to a maximum of 7 Eurocents/kWh in Israel. The highest electricity price is still 2 Eurocents lower than the average electricity price for the industry and 9 Eurocents for households in the EU-27.

Country	**System average rate (SAR) in Eurocent/kWh**	
Egypt	2	
Israel	7	
	Households	Industry
EU-27 average	16	9

Table 7-5 System average rate in bandwidth MPC-EU 200837

These low energy prices imply that energy efficiency measures and behavior changes are difficult to implement as the fiscal incentive is not there. Therefore the proposition of the European Union to include external costs of energy such as environmental, social and healthcare costs is desirable (European Union b 2009). By including these costs aside from the reduction of energy subsidies which are worldwide at a level of around $250-300 billion (United Nations Development Programme 2000) per year, a real market price for conventional fuels can be established and the artificial market situation due to the subsidies will become obsolete.

[36] (MED-EMIP 2010, 7)
[37] (MED-EMIP 2010, 7)

By reducing the subsidies, real competition between the different technologies is activated and the non-competitive technologies and fuels get phased-out of the market (Greenpeace and EREC 2010).

The European Solar Thermal Electricity Association estimates that the CSP-technology is already competitive with conventional technologies in the year 2020: *"According to this possible schedule, a large proportion of the plants to be initiated before 2020 (likely those to be initiated closer to that date) will be able to generate electricity at prices below the contemporary alternative fossil fuel electricity from their start-up date* (ESTELA 2009)*."*

The energy supply of Morocco is currently not fully supplied by the country itself. The mentioned problem of supply security is a symptom already shown in this case. Morocco imports over 4.3 TWh annually from Spain to satisfy the energy demand of the country. The other countries of the region have an out-balanced electricity balance, whereas Egypt is for the moment still a net exporter but with a falling balance every year (MED-EMIP 2010, 66). The countries' commitment to renewable energies is yet not fully reflected in the generation capacity as also stated by the MED-EMIP report: "*The 2010 share of solar and wind based electricity generation stands a minimum of 0 percent in Lebanon and a maximum of just below 1 percent for Egypt. There has been considerable talk and many public announcements of RE capacity addition. Unfortunately, these are most often not reflected in the official power capacity expansion plans of the power utilities (covering the next ten years), nor supported by any budget plan* (MED-EMIP 2010)*."*

Energy policy

With the joint decision of the European Parliament and of the Council of 23 April 2009 the European Union stated to follow the goal to limit the "*overall global annual mean surface temperature increase not to exceed 2 °C above pre-industrial levels,…*" and to reduce the greenhouse gas emissions to at least 50 percent below the 1990 levels by 2050. (European Union a 2009)

The European Union is one of the leading areas for the implementation of renewable energies. The increase of RES in North Africa is due to the low energy prices in affect of energy subsidies distorted and not representing the real costs of conventional fuels. Conventional fuels have volatile price levels due to supply disruptions in the world market for example. The REN21 report 2005 indicated a doubling of the oil prices in less than two years to over 60 USD/bbl. They followed up by stating that there is an essential economic risk in primarily relying on imported energy as can be observed in Morocco (REN21 Renewable Energy Policy Network 2005, 7).

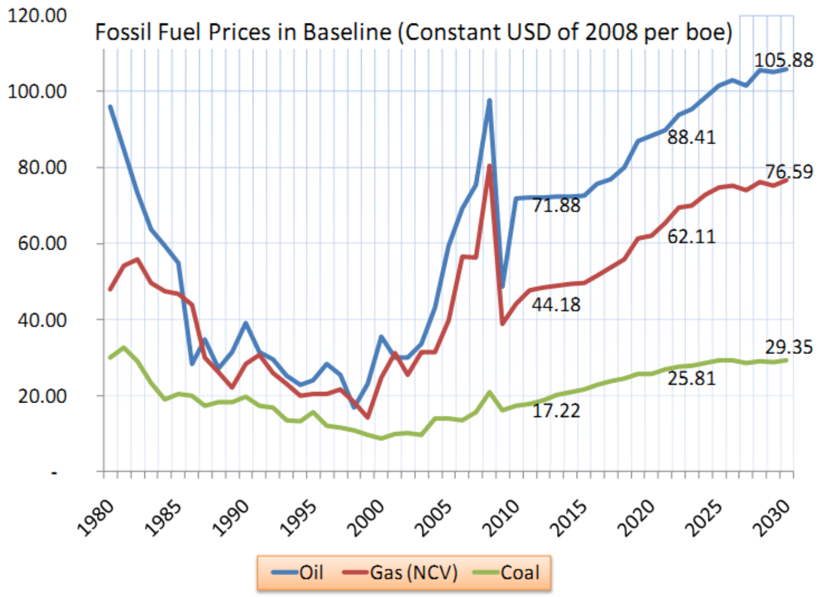


Figure 7.5 World fossil fuel prices[38]

[38] (European Commission b 2010)

The spot price for the oil sort WTI Cushing was on the 10th of June 2011 101.93 USD/bbl according to the news network Bloomberg (BLOOMBERG L.P 2011). The European Union expected this price level in the baseline scenario for the “EU energy trends to 2030 - Update 2009” just in the year 2030. This shows that the prediction for oil prices is highly volatile and difficult to estimate. Prices of natural gas, a major fuel in North African countries as shown in above, are reflected in the oil price due to a limitation of world market prices for natural gas (gas price link). Natural gas is also an unstable product with volatile prices. The dependence on one fuel together with highly volatile prices for this fuel endangers the local economies and presents risky energy security (Greenpeace, EREC 2010).

The United Nations characterizes energy security as: “…availability and distribution of resources, as well as variability and reliability of energy supply…” they propose that it “may also be enhanced by the deployment of RE. (Arvizu, et al. 2011, 18)” They enlarge the portfolio of energy sources and reduce so the vulnerability to world energy price volatility. As renewable energy sources have in the most cases just a large initial investment and no need for constant fuel, foreign exchange flows can be redirected to create a regional added value (Arvizu, et al. 2011, 18).

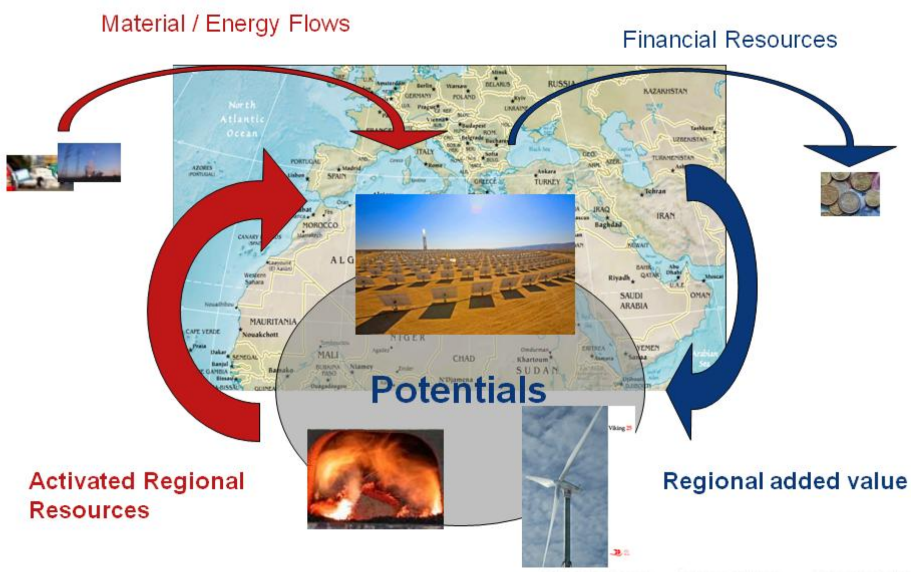


Figure 7.6 Regional Material Flow Management approach after IMAT

Aside from energy security, RES also offer the possibility to produce energy in a sustainable way and are a way to mitigate with climate change (Arvizu, et al. 2011). To fight climate change is a global challenge which offers opportunities to the world. The SRREN report defines opportunities as "*circumstances for action with the attribute of a chance character. In the policy context that could be the anticipation of additional benefits that may go along with the deployment of RE but that are not intentionally targeted. These include four major opportunity areas: social and economic development; energy access; energy security; and climate change mitigation and the reduction of environmental and health impacts.* (Arvizu, et al. 2011, 17)*"* However barriers are defined as "*any obstacle to reaching a goal, adaptation or mitigation potential that can be overcome or attenuated by a policy programme or measure* (Arvizu, et al. 2011, 20)*."*

Nevertheless, increasing the RES share in electricity generation in the SM-region will be a difficult task due to uncompetitive generation costs by subsidies of conventional fuels (Resource and Logistics 2010, 9). In the current environment for RES, most of the projects are implemented on a project-to-project approach as can be observed e.g. in the Algerian ISCC-plant or the implementation of CSP in Morocco (Appleyard 2010). This will be not enough to tackle the large increases in energy demand and the fight of climate change as well as the loss of regional added value. The MED-EMIP project comes to a negative result in that: "*This neither provides enough capacity to contribute in a significant way to the annual power demand increase in the region, nor does the capacity suffice to produce excess power for export. The delivery mechanism and existing framework conditions for RES based electricity production in the MPC are nowhere close to those in the EU-27* (MED-EMIP 2010)*."*

As shown in the EU-27, the investment in renewable energies brings large economic benefits for the economy due to job creation and the redirection of monetary subsidies away from conventional fuels which flow outside of the country towards renewable energy sources and investment in the country itself. An example would be in Morocco in which the country purchases electricity from Spain rather than producing electricity on its own by CSP. Conventional fuel exporting countries like Algeria and Tunisia (CIA 2010) could extend the revenue from oil and gas exports, rather than selling it on the local market on low market levels and increase so the revenue for the wealth of the population. But these propositions need a fundamental change in energy politics of the North African states as well as the European Union and the International financial Institutions such as the World Bank and African Development Bank.

The following paragraphs will show what kind of policy framework is already existent to promote renewable energies in North Africa in a European context and what should be done to promote and extend it further. This framework with legal binding objectives and support is a necessary part for a positive development of renewable energies as for example the development of a CSP-plant needs about 6 years from the idea to the implementation (Environmental and Energy Study Institute 2009).

Arvizu et al declare, "Since the early 2000s, the energy supply has become more carbon intensive, thereby amplifying the increase resulting from growth in GDP per capita (Arvizu, et al. 2011, 7)." This is not a sustainable manner for the development of our world. And it does not comply with efforts of the European Union to provide sustainable energy to all citizens (EUROPEAN COMMISSION a 2010, 20).

The European Union has a mutual interest in the development of renewable energies in the neighbouring countries, as it is a way of energy security for the European economy. Consequently, *"the external dimension of EU energy policy must be consistent and mutually reinforcing with other external activities of the EU (development, trade, climate and biodiversity, enlargement, Common Foreign and Security Policy and others). There must be synergies between energy objectives and other policies and instruments including trade, bilateral agreements, and development cooperation instruments and vice-versa* (EUROPEAN COMMISSION a 2010)*."*

The European Union started as a result the Mediterranean Energy Partnership. The partnership has the aim to promote renewable energy sources and energy efficiency along with an integrated energy network with the Mediterranean countries outside and inside the European Union. In Article 10 of this declaration, the ministers recommend "r*eflecting on the possibility of extending the ongoing sub-regional co-operation initiatives in the field of electricity in the Maghreb region to natural gas, as well as extending gas cooperation in the Mashreq to the area of electricity with the objective to facilitate the development of fully integrated and interconnected Euro-Mediterranean electricity and gas markets;…* (EURO-MEDITERRANEAN MINISTERS 17. December 2007)*."* The integration of the two electricity markets is an essential step forward for CSP deployment in the North African states and a sustainable energy supply in the region.

The European Parliament published in February 2011 an astonishing report about "EU Subsidies for polluting and unsustainable practices." The report stated that investments in renewable energies can improve the economic situation and add jobs in the short, mid and long term for Europe (European Parliament 2011). What is considered for Europe can have the same effects for North Africa as well. So, the European Commission had published in 2010 the plan for *"a major cooperation with Africa on energy initiatives in order to progressively provide sustainable energy to all citizens* (EUROPEAN COMMISSION a 2010, 20)*."*

To provide sustainable clean energy, the environment for the implementation has to change fundamentally. The foundation of clean development is already provided but the implementation itself still needs elementary policy support to increase the share of RE in the energy mix (IPCC 2011, 3).

The Institute Resource and Logistics identified for the European Union in an Identification Mission of the Mediterranean Solar Plan the barriers for the deployment of RES in the Mediterranean Partner Countries:

- *Poor knowledge of renewable energy sources and their potential, by the private sector, the general public and policy makers in the MPCs.*
- *The relative small number of domestic electricity supply companies which would be sufficiently robust or able to support the development of industrial clusters.*
- *Lack of differentiation in existing regulations and incentives between energy production sources or between the different segments (Resource and Logistics 2010, 9).*

These barriers can be overcome in a simple way by information campaigns in the targeted countries which have already shown some results as Morocco is already deploying RES while planning to increase the share substantially (Rzepka 2011).

Aside from the barriers, the Resource and Logistics institute report also had the outcome that the economies give greater responsibilities to energy and financial operators for the deployment of RES in the Mediterranean region. Therefore, the governments have to set a stable and secure framework, so that the actors in this market sector have a long-term interest in the deployment of RES (Resource and Logistics 2010, 10).

RES can't be seen individually and just as a whole. Every RES has advantages and disadvantages. The advantages and disadvantages of CSP are shown in this report. As a holistic approach, Greenpeace and EREC have worked out demands for a large-scale deployment of RES to increase the RES-share in the energy mix.

- *Phase out all subsidies for fossil fuels and nuclear energy.*
- *Internalise external (social and environmental) costs through 'cap and trade' emissions trading.*
- *Establish legally binding targets for renewable energy and combined heat and power generation.*
- *Reform the electricity markets by guaranteeing priority access to the grid for renewable power generators.*
- *Provide defined and stable returns for investors, for example through feed-in tariff payments.*
- *They conclude that the successful deployment of RES need:*
- *A clear, bankable pricing system.*
- *Priority access to the grid with clear identification of who is responsible for the connection, and how it is incentivised.*
- *Clear , simple administrative and planning permission procedures.*
- *Public acceptance/ support.*

The major point is a clear, bankable pricing system. While a solid pricing system is foremost important, the other three parts are essential as well (Greenpeace and EREC 2010).

Furthermore, the European Union has to provide support for the North African countries which cannot provide such high levelized support schemes such as FIT° or Carbon Trading like Europe has, since the income of the population and the price level of conventional fuels are far below the European Union. For that reason the European Union has to "a*vail all EU carbon mechanisms for the benefits of both Mediterranean sides in purpose of improving the economics of the projects under MSP and fulfilling the obligations of the EU developed counties towards GHG emis-*

sions reduction under Kyoto Protocol and beyond (Mediterranean Solar Plan Expert Group 2010)*."*

In Directive 2009/29/EC for the greenhouse gas emission allowance trading scheme the European Union already provides in Article 41 this proposed tool for the neighbouring countries like the Mediterranean Partner countries: "*Third countries neighbouring the Union should be encouraged to join the Community scheme if they comply with this Directive. The Commission should make every effort in negotiations with, and in the provision of financial and technical assistance to, candidate countries, potential candidate countries and countries covered by the European neighbourhood policy to promote this aim. This would facilitate technology and knowledge transfer to these countries, which is an important means of providing economic, environmental and social benefits to all* (European Union c 2009)*."*

The Emission Trading Scheme of the European Union (EU-ETS) is one tool for the support of CSP and the RES sector in general. However, Arvizu et al came to the result that the "m*ost successful solar policies are tailored to the barriers imposed by specific applications*, *and the most successful policies are those that send clear, long-term and consistent signals to the market.* (Arvizu, et al. 2011, 49)*"*

Such tailored support systems were already communicated in 2008 where the European Community wrote in the Green paper "TOWARDS A SECURE, SUSTAINABLE AND COMPETITIVE EUROPEAN ENERGY NETWORK" the establishment of a Mediterranean Energy Ring to link the Mediterranean area and North Africa with Europe to enable these countries to feed-in renewable energies into the integrated European Network. (European Community 2008)

In 2010, this initiative received further support through the strategy paper 2020 by the European Commission. There it says that the relations with large energy-consuming and in particular emerging and developing countries are of growing significance. Furthermore, it requests the universal right for energy access to eradicate extreme poverty by 2015 as requested in the Millennium Development Goals.

In order to ensure that this does not harm other policy goals, sustainable development needs to be at the core of both energy and development policy, such as proposed in the Green Paper on Development Policy. Europe should be in a position to rely on significant additional energy supply sources and routes by 2020. (EUROPEAN COMMISSION a 2010)

Paragraph 171, 3 of the European Treaty gives the legal bias for the cooperation with the MENA region: "The Union may decide to cooperate with third countries to promote projects of mutual interest and to ensure the interoperability of networks."

Later on in Article 194 of the Treaty it says that: "in the context of the establishment and functioning of the internal market and with regard for the need to preserve and improve the environment, Union policy on energy shall aim, in a spirit of solidarity between Member States, to:

(a) ensure the functioning of the energy market;

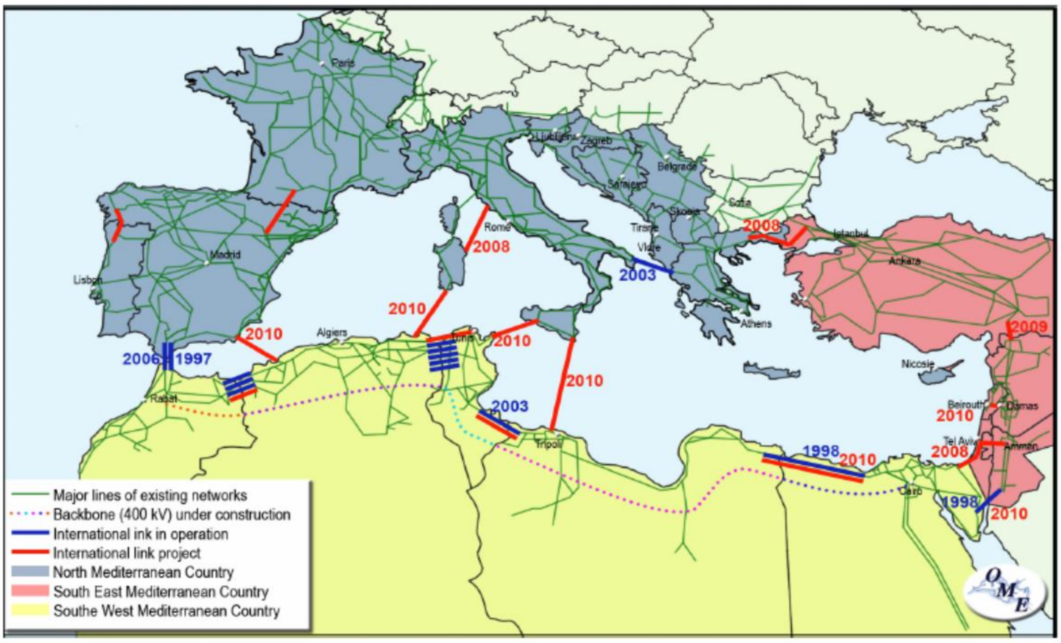
(b) ensure security of energy supply in the Union;

(c) promote energy efficiency and energy saving and the development of new and renewable forms of energy; and

(d) promote the interconnection of energy networks. (European Union 2008)

So it can be concluded that the European Union can support projects in the Southern Mediterranean Region to promote RES in the European Union and to ensure meeting the goals of the strategy paper "Energy 2020". The internal goal to reduce the GHG emissions by at least 50 percent by 2050 and to diversify the energy supply routes of the European Union (European Union a 2009).

Because of this diversified energy supply, the European Union has to strengthen the infrastructure of the energy connections. The connections: Algeria – Spain, Algeria – Italy, Tunisia – Italy, Spain and Morocco are the first that need to be strengthened. As well as the interconnections between the countries itself, the focus should be on the South-Western Mediterranean countries Morocco, Algeria and Tunisia (EURO-MEDITERRANEAN MINISTERS 17. December 2007, 16). Under the current political environment in Libya, such an interconnection for the time being is not feasible. The countries mentioned before have a stable government or have already the change in the political system behind them. For example, Egypt has the political change but the country is still unstable.



Source: OME

Figure 7.7 Existing and potential future connections[39]

Figure 7.7 Existing and potential future connections shows the proposed interconnections which should be built by the European Union to promote RES deployment in the SM-region and thusly enable the export of clean and stable electricity by CSP-applications to the European energy network.

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[39] (Resource and Logistics 2010)

The current energy network of the European Union was constructed mainly in the 50s and 60s of the last century. The design is to suit centralized energy generation by large power stations fuelled by conventional fuels such as coal, gas and nuclear. The change to RES forces a re-design of this system where the electricity is generated in large amounts at one point, and then transported to another point where it is consumed. RES produce decentralized electricity at many different points, which then needs to be transported to the customer in a local area (Greenpeace, EREC 2010, 40).

The aim should therefore be to use CSP as a peak load supply. CSP has the same generation costs of the thermal energy in all load scenarios as was explained before. CSP has the same steam cycle as gas power plants; it can therefore be used instead of gas power plants to deliver minute-based electricity demand. Being linked with a European super grid as was proposed in the strategy paper "WORLD ENERGY [R]EVOLUTION - A SUSTAINABLE WORLD ENERGY OUTLOOK," it was calculated that the costs for such a European super-grid with connections to the African continent as was shown in "Figure 7.7 Existing and potential future connections" would costs €100 billion. This includes 11 high voltage direct current (HDVC) connections in Europe. They would transfer large amounts of RE through Europe and another €90 billion for the interconnection with Africa (Greenpeace, EREC 2010, 46).

This seems to be a high amount, but compared to the $250-300 billion the world spends for conventional fuel subsidies per year this long term investment for many decades is small (United Nations Development Programme 2000).

As the generating prices for RES are so far uncompetitive due to the subsidies and the lack accounting for environmental externalities, they need a policy framework which guarantees higher prices or out-balances the inequalities (Resource and Logistics 2010, 9). Such a tool is the feed-in tariff (FIT) which is defined as: *"Feed-*

In Tariffs encourage entrepreneurs to produce electricity through renewable sources by guaranteeing that the entrepreneurs' electricity will be bought at a guaranteed rate and for a fixed period by the established utility companies." (World Future Council 2010)*"* But, as Greenpeace and EREC correctly report, a mix of FIT, international finance and emission trading is necessary to deploy RES in the SM-region (Greenpeace, EREC 2010, 21)

Such a mix should include more advanced international financing schemes such as: investment funds, guarantee funds by the European Union or by granting loans at subsidized rates and on favourable terms by the European Investment Bank and the World Bank. Europe must offer incentives to the SM-Region to deploy RES in their energy mix if Europe wants these countries to export electricity besides natural gas and oil to the European Union. The financing of such projects including the granting of FIT for such projects by the European Member states such as Italy, Germany and France are not only essential but also an interesting mechanism for the deployment of RES in the region. The financing will give these countries an individual power supply and significant opportunities for their economy to develop in a sustainable manner. The export of electricity gives the countries further exportable products and would generate revenue out of development aid.

8. Conclusion

Technology	Optical efficiency	Annual solar-to-electric efficiency	Land occupancy	Water cooling (L/MWh)	Storage possible	Possible backup/ hydrid mode	Solar fuels	Outlook for improvements
Parabolic troughs	**	15%	Large	3 000 or dry	Yes, but not yet with DSG	Yes	No	Limited
Linear Fresnel receivers	*	8-10%	Medium	3 000 or dry	Yes, but not yet with DSG	Yes	No	Significant
Towers (central receiver systems)	**	20-35% (concepts)	Medium	2 000 or dry	Depends on plant configuration	Yes	Yes	Very significant
Parabolic dishes	***	25-30%	Small	none	Depends on plant configuration	Yes, but in limited cases	Yes	Through mass production

Table 8-1 Comparison of main CSP technologies[40]

Solar CSP is a promising technology with some potential of improving since this technology was founded in recent years in a revival as a future energy supplier. The deployment of solar CSP is limited to special regions all over the world but could supply the whole world if a sufficient electricity grid is developed. Table 8-1 Comparison of main CSP technologies" shows a good summary of the different solar CSP technologies currently implemented in the world. Parabolic dishes seem to have the best opportunity of instalment since the technology is in all specification, more advanced than the other technologies. From a market perspective, the parabolic troughs, with a market deployment of 93 percent is the best technology with growing potential for towers and LFR. Parabolic dishes are unable to draw support even with the advantages on paper. The future of solar CSP depends on the scenario of good to very good. The IEA sees CSP as a "*cost-effective technology that will lower CO2 emissions.*"

[40] (IEA 2010, p 31)

Fossil fuels supplies are decreasing by their natural state of being fossil-based. Renewable energy sources like Concentrated Solar Thermal Power Plants are a promising technology for the future of world energy supply. They are clean and do not produce CO_2 during their operation. So-called clean technologies like CCS and nuclear power still need fuel supplies and still emit CO_2. CSP is a promising large-scale alternative, which could provide large amounts of energy at competitive costs.

Like any sun-based technology, CSP need solar irradiance to heat up and operate an electrical operation by an engine. When there is no solar irradiance, there will be no heating up of the HTF and thus no electricity production. Thermal energy storages fill this gap by providing heat over the time of no solar irradiance. This gap could be from a short-term or minute-based cover like the steam accumulator towards night-covers for a few hours' worth of storages for instance with concrete or like in the Terrasol project like recently published enable a 24 hour operation with molten salts. Molten salt is now well-managed technology, but currently the prices for fossil fuel are too low to operate CSP with base load. CSP can provide delayed power production at comparable costs with the help of TES as it is explained in the report. Especially the cases of peak load production with its high electricity prices on the spot market are currently interesting for the CSP plants with TES. TES are the kicker technology for the success of CSP-plants. The future will show if TES will be affordably priced and therefore enable base-load operations with CSP or if CSP will remain a niche product.

To conclude the technical part of this report, Concentrated Solar Power plants with Thermal Energy Storages is a promising technology with large potential for improvement for a future with a zero-emission power supply for a healthy and sustainable world energy supply.

The global scenarios conducted by the international organizations like the IEA show a large development of CSP in the future. The production level of CSP worldwide is following the ETP BLUE Map scenario "*2,200 TWh annually by 2050 from 630 GW of local capacities (no exports taken in account). CSP is expected to contribute 5 percent of the annual global electricity production in 2050 in this scenario* (IEA 2010, 19)." The advanced scenario in the CSP Global Outlook 2009 of the IEA SolarPACES, the European Solar Thermal Electricity Association and Greenpeace estimated even a global CSP capacity of 1,500 GW by 2050.

The energy political impact of CSP is still uncertain. The report shows that there are advantages on the sustainable aspect site with job creation and low environmental impact if a combination of wet and dry cooling is applied. Europe should see the support of CSP-deployment in the SM-region as development aid that gives even revenues for Europe back. Europe needs to diversify the energy supply for security reasons. Why not diversify with a clean energy supply in an energy carrier that will gain more importance in the next decades? CSP has various application scenarios for electricity generation and for advanced application like sun fuels. Jose Barroso, President of the Commission of the European Union said that: "*However, some projects that would be justified from a security of supply/solidarity perspective, but are unable to attract enough market-based finance, may require some limited public finance to leverage private funding.* (European Council - The President 2011)*"*

If we want to eradicate poverty, we have to reduce the amount of people without access to electricity. REN21 stated in 2005 "Roughly 1.6 billion people worldwide do not have access to electricity in their homes, representing slightly more than one quarter of the world population. (REN21 Renewable Energy Policy Network 2005, 7)" CSP can help to reduce this amount in a poor region like the North African states and the Sub-Saharan region and as I quoted Thomas Alva Edison at the beginning of the report "I'd put my money on the sun and solar energy.

What a source of power! I hope we don't have to wait 'til oil and coal run out before we tackle that.” We have to start now before it is too late. At least for the sun-power CSP it is getting difficult as the largest planned project Blythe with a total capacity of 1 GWp is changing from CSP to PV due to more favourable financing conditions but the developer also says with an increasing PV share the potential of CSP will rise due to grid-stability features (Solar Trust of America 2011). As mentioned in the executive summary the aim should be to become the powerhouse of the 21st century, it is not depending on the technology involved rather than that it is a clean technology such as renewable energies, energy efficiency and energy savings.

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VI. Annex

Attached in the pdf.

CSP FIT GUIDE

CSP TODAY SEVILLA 2011

5th International Concentrated Solar Thermal Power Summit

November 29-30, Sevilla, Spain

CSP is Evolving - Increase competitiveness and exploit new opportunities to develop a profitable & commercially successful business

CSP TODAY SEVILLA is the number one networking and knowledge centre for the industry and the most influential CSP-focused event in the world. In association with the launch of this event, we are pleased to present you with the CSP Feed-in tariffs Guide.
For more information,
visit: www.csptoday.com/csp/fit

The International Energy Agency already envisages that with the right support, **CSP could provide 11.3% of global electricity by 2050**.

As part of this year's **CSP TODAY SEVILLA 2011** event, we have compiled a useful CSP feed-in tariffs and incentives guide to help you spot the best opportunities. This document contains vital information on the schemes available to the concentrated solar thermal industry around the world and will keep on being updated.

Table of Contents

Available solar incentives at a glance

Authority/Regulator	Type of Incentive/Mechanism	Currency/ kWh	Tariff
USA			
State Government/US Treasury Department	Tax credits		Vary from state to state
US Department of Energy	DoE Loan Guarantee Program		$10 bn of the total sums available under the programme are targeted to renewable and/or energy efficient systems and manufacturing
Federal Government	Tax credit bonds		N/A
	MTC for creation of expansion of manufacturing facilities		N/A
South Africa			
National Energy Regulator of South Africa (NERSA)	REFIT 2011 for CSP trough ≥ 1 MW with storage	Rand/kWh	R 1.836 - Not accepted yet; tariffs are proposed for revision through a discussion paper submitted by the energy regulator
National Energy Regulator of South Africa (NERSA)	REFIT 2011 for CSP trough ≥ 1 MW without storage	Rand/kWh	R 1.938
India			
Central Electricity Regulatory Commission (CERC)	Solar Tariff (FY 2010-11)	Rupees/ kWh	Rs. 15.31 - Tariffs also vary at a State level in: Gujarat, Rajasthan, Maharashtra, Jharkhand and Madhya Pradesh
Central Electricity Regulatory Commission (CERC)	Solar Tariff (FY 2010-11)	Rupees/ kWh	Rs. 15.04
Morocco			
Moroccan Agency for Solar Energy (MASEN)	Tender offer framework		Masen has currently set two tariffs, one for peak and a lower one for offpeak for the CSP Ouarzazate plant which might be a base for future projects
Spain			
Ministry of Energy and Mines	Royal Decree 661/2007- Fixed regime: fixed a tariff for the first 25 years	Euros/kWh	€ 0.27
Ministry of Energy and Mines	Royal Decree 661/2007- Fixed regime: after 25 years	Euros/kWh	€ 0.22
Ministry of Energy and Mines	Royal Decree 661/2007- Variable regime	Euros/kWh	Market price + premium with lower limit and cap of: floor of €0.2712/kWh and a cap of €0.3673/ kWh
Ministry of Energy and Mines	Royal Decree 661/2009 - Updated Feed-in-tariff with two options	Euros/kWh	1.Regulated tariff : €0.28 first 25 years; €0.23 from then on. 2. Organized electricity market: €0.27first 25 years; €0.21 from then on (top cap €0.36; lower cap €0.26)
Italy			
Ministry of Economic Development / Ministry of Environment and Territory / Gestore dei Servizi Energetici	Decrees No. 387/2003; DM 11/04/2008: Feed-in tariff for CSP	Euros/kWh	0-15% €0.28; 15-50% €0.25; 50% and greater €0.22. The tariff depends on the net productionthat (not attributable to solar) - See annex 6 for more details
Portugal			
Portuguese Government/Directorate General for Energy and Geology (DGEG) / Portuguese energy agency Adene	Decrees No. 312/2001; No. 189/88; No. 225/2007 :Special Production Regime based on formula	Euros/kWh	Average indicative tariff for CSP installations <= 10MW: €26.3 - €27.3 (valid for 15 years)
Portuguese Government/Directorate General for Energy and Geology (DGEG) / Portuguese energy agency Adene	Direct subsidy payments (PRIME-Programme) and tax incentives		N/A
Greece			
Regulatory Authority for Energy	Decree L3468/2006	Euros/MWh	As from June 2010: Solar thermal energy €264.85; Solar thermal with storage system (at least 2h at nominal load) €284.85

USA

Summary of the various incentive mechanims in the USA

Type of mechanism	Description	Example of Use
ITC	Tax credit on a percentage of the total capital investment in a renewable energy project.	30% of CSP use projects constructed before 2017.
PTC	Tax credit for electricity generated by qualified energy resources and sold by the taxpayer to an unrelated person during the taxable year.	Can now be exchanged for a grant from the US Treasury Department.
Accelerated	Depreciation Enables greater tax write-offs at early stages of project to help cover initial start-up costs.	Five years for solar property.
Loan Guarantee	Government guarantees the full repayment of a loan, which helps projects attract debt financing at lower rates.	Provided by US DoE.
CREBs	Tax credit bonds on which the companies do not pay full interest. The federal government provides the bondholder with a tax credit that covers 70% of the interest earned.	Increased funding of $1.6 bn under ARRA.
MTC	Incentive for the creation or expansion of manufacturing facilities producing clean energy components and systems.	Provides a 30% credit for investments in advanced energy manufacturing projects.
Sales or Property Tax Reduction/Waiver	Governmental or bank financing at terms below commercial rates.	Arizona has a sales tax exemption for CSP components.
R&D Support	Helps drive more rapid technological improvement.	DoE-funded R&D partnerships.

Spain

The Spanish STE Regulatory Framework

Incentives and government support The main government support for CSP is the FiT. These are payments made by grid operators or utilities to renewable energy generators for the energy they supply to the grid. Grid operators are legally obligated to enter into long-term contracts (25 years) under which they will pay a fixed amount for each unit of renewable energy produced, which is above the average wholesale energy price. Spain was the first country to introduce a FiT for CSP. The original FiT offered a rate of €0.12/kWh for electricity produced at CSP plants with up to 50MW of capacity.

The FiT was increased to €0.18/kWh in Royal Decree 436 in 2004 and then to €0.27/kWh in 2007. The Royal Decree (RD) 661 in 2007 fixed a tariff of €0.269375/kWh for the first 25 years, and then drops to €0.215498/kWh. Under RD 661/2007, CSP producers could claim the FiT in two different ways. One of them is the fixed regime, in which they receive the amounts given above. Alternatively, they could claim the FiT under the variable regime. This means that they received the market price of electricity plus a premium.

Under the variable regime there is a floor of €0.2712/kWh and a cap of €0.3673/ kWh. This is the tariff that has been granted to all the current projects in the planning and construction stages in Spain. It separates the tariff from the market reference price, which is linked to oil prices.

R.D. 661/2007 (May)

- It established a FIT of 27 c€/kWh (or pool price + 25,4
- c€/kWh) for plants <50 MW

R.D.L 6/2009 (May)

- It made a selection of the eligible plants for the former FIT
- Criteria : Permits, financing, component acquisition,
- 4500 MW applied and 2400 MW registered
- Limitation in connection dates: Phases I, II, III, IV (2011-13)
- 36 months for completion. Dec-2012 for ph. I, II and III and Dec-2013 for ph. IV

R.D. 1614/2010 (Dec.)

- It maintained the FIT for all the plants registered under the
- R.D.L. 6/2009 process
- It limited the operating hours of these plants according to their respective designs to prevent for future capacity enlargements

New R.D. still to be negotiated

- It will cover the period 2014 - 2020.
- Goal: approximately 5.000 MW in operation by 2020
- Criteria and technology breakdown still to be defined

South Africa

2009 REFIT and 2011 Revised REFIT with projected CPI adjustments for years 2012-2013

YEAR	REFIT 2009	REFIT 2011	REFIT 2012	REFIT 2013	PERCENTAGE CHANGE 2011/2009
TECHNOLOGY	R/kWh	R/kWh	R/kWh	R/kWh	
Wind ≥ 1 MW	1.25	0.938	0.945	0.952	-24.9%
Landfill Gas ≥ 1 MW	0.90	0.539	0.550	0.562	-40.1%
Small Hydro ≥ 1 MW	0.94	0.671	0.675	0.680	-28.6%
CSP trough ≥ 1 MW with 6 storage	2.10	1.836	1.845	1.854	-12.6%
CSP trough ≥ 1 MW without storage	3.14	1.938	1.953	1.967	-38.3%
CSP central receiver (tower) ≥ 1 MW with TES 6 hrs	2.31	1.399	1.408	1.417	-39.4%
Photovoltaic ≥ 1 MW ground mounted	3.94	2.311	2.325	2.338	-41.3%
Biomass solid ≥ 1 MW (direct combustion)	1.18	1.060	1.084	1.108	-10.1%
Biogas ≥ 1 MW	0.96	0.837	0.862	0.887	-12.9%

TARIFF INDEXATION

South African CPI as published by South African BER annually, will be used to adjust the REFIT in the PPA for annual economic fluctuations. The adjustment will only be applied to the 'operation and maintenance' and fuel portions of the previous calendar year REFIT. The Capex portion will remain constant for the duration of the PPA.

The formula for annual REFIT CPI adjustment in the PPA will take the following form: REFITj+1 = Capex2011 + (FOMj + VOMj + FUELj) x (1+ RSA_CPIj/100) (1)

Where:

j - calendar year ≥ 2011

REFITj - PPA tariff in year j

CAPEX2011 - Capex, R/kWh

FOM - Fixed Operation and Maintenance in year j, R/kWh

VOM - Variable Operation and Maintenance in year j, R/kWh

RSA_CPIj - Actual South African CPI for year j

Forestry trees must be replanted into order to complete the carbon cycle in the Atmosphere

All forestry trees and residues to be used for electricity generation will be collected from fields where there is plantation, not from industrial plants

REFIT POWER PURCHASE AGREEMENT

- The Regulator will facilitate the conclusion of the REFIT PPA and the associated commercial agreements necessary for buying and selling power between a REFIT IPP and the Buyer.
- REFIT agreements will be approved by the Regulator in the licensing process of the preferred bidders
- The term of the PPA is 20 years as agreed in REFIT Phases 1 and 2.

STAKEHOLDERS INPUTS REQUESTED

- Stakeholders are requested to provide comments on the following:

(a) Financial assumptions used for the calculation of the REFIT.
(b) REFITs and qualifying principles.
(c) Any other comments or proposals to the Regulator related to this Review of Renewable Energy Feed-In Tariffs Consultation Paper.

REFIT REVIEW

The revised tariffs will apply to new REFIT IPP projects to be commissioned after the promulgation of the revised tariffs.

India

Regulatory Initiative: CERC-RE Tariff Regulations

Comprehensive RE tariff regulations by CERC

Tariff Support

- Tariff design ensures assured return with full cost recovery during debt repayment period
- Fixed Levelized tariff for useful life: 25 years

Tariff Visibility

- Solar PV: Tariff for FY10-11 shall also be applicable for FY11-12, PPA to be signed on or before 31.03.11
- Solar Thermal: Tariff for FY10-11 shall also applicablefor FY11-12 and FY12-13, PPA to be signed on or before 31.03.11

Regulatory Initiative: Solar Tariff (FY 2010-11)

Norm	Solar PV	Solar Thermal
Capital Cost	Rs. 16.90 Cr/MW	Rs.15.30 Cr./MW
CUF	19%	23%
Tariff	Rs. 17.91 /kWh	Rs. 15.31 /kWh

Reverse bidding experience of NVVN: Invited bid discount from CERC determined rate for FY10-11 Rs.15.31/kWh (34 ct/kWh) for solar thermal, has yielded prices in the range of Rs. 10.49 to 12.24/kWh (23 to 27 ct/kWh)

Regulatory Initiative: Solar Tariff (FY 2011-12)

Norm	Solar PV	Solar Thermal
Capital Cost	Rs. 14.42 Cr/MW	Rs.15.00 Cr./MW
CUF	19%	23%
Tariff	Rs. 15.39/kWh	Rs. 15.04/kWh

Solar PV and Thermal Tariff of SERCs

Norm	Solar PV	Solar Thermal
Gujarat	Rs. 12.54 / kWh Or Rs. 15 for first 12 years, Rs.5 from 13th to 25th year	Rs.9.29 / kWh Or Rs. 11 for first 12 years, Rs.4 from 13th to 25th year
Rajasthan	Rs. 12.58 / kWh	Rs. 15.32 / kWh
Maharashtra	Rs. 15.61 / kWh	Rs. 15.24 / kWh
Jharkhand	Rs. 17.96 / kWh	Rs. 13.12 / kWh
Madhya Pradesh	Rs. 15.35 / kWh	Rs. 11.26 / kWh

Morocco

Morocco has a high energy demand, which is increasing and is forecast to continue growing steadily. The country has developed a strategy to address energy security in light of the fact that the country's energy

balance is dominated by imported fossil fuels. With no fossil-fuel production capacity, Morocco has to import all its fuel requirements and wishes to achieve sovereign security of fuel. Key elements of this strategy include: diversifying and optimising the energy mix around reliable and competitive energy technologies, in order to reduce the share of oil to 40% by 2030; making energy efficiency improvements a national priority; and integrating into the regional energy market, through enhanced cooperation and trade with the other countries of North Africa and the EU. On 2 November 2009, the government unveiled a Moroccan Solar Plan aimed at achieving a 42% renewable energy target by 2020. It hasa 2,000MW long-term target for solar power, including CSP, by 2020, intended to meet 14% of the country's energy needs.

Together with Jordan, Morocco is one of the two most deregulated markets in the region for electricity. It has established a single authority, the Moroccan Agency for Solar Energy (MASEN), to run tenders. Our primary sources confirmed that Morocco is a positive example of the tender offer framework or market. It is competitive, and not the preferred option for investors, but it is functioning. The framework is a result of government policy not to introduce feedin tariffs because it could put threaten public finances, which did happen in Spain, as described above. In addition, the country has the regulatory framework in place to allow energy products from solar power to be exported, thereby making it of interest to both developers and investors.

MASEN has established two tariffs, one for peak and a lower one for offpeak or base load, for the CSP Ouarzazate plant.

Implementation Potential

Public policies and the institutional set-up in Morocco are very supportive for this project (Ouarzazate plant). The Government has in recent years undertaken a substantial effort to promote renewable energy, establish an adequate legal framework, set up a dedicated agency for energy efficiency and renewable energy development, and set up an institution specifically dedicated to implementing the Solar Plan (MASEN).

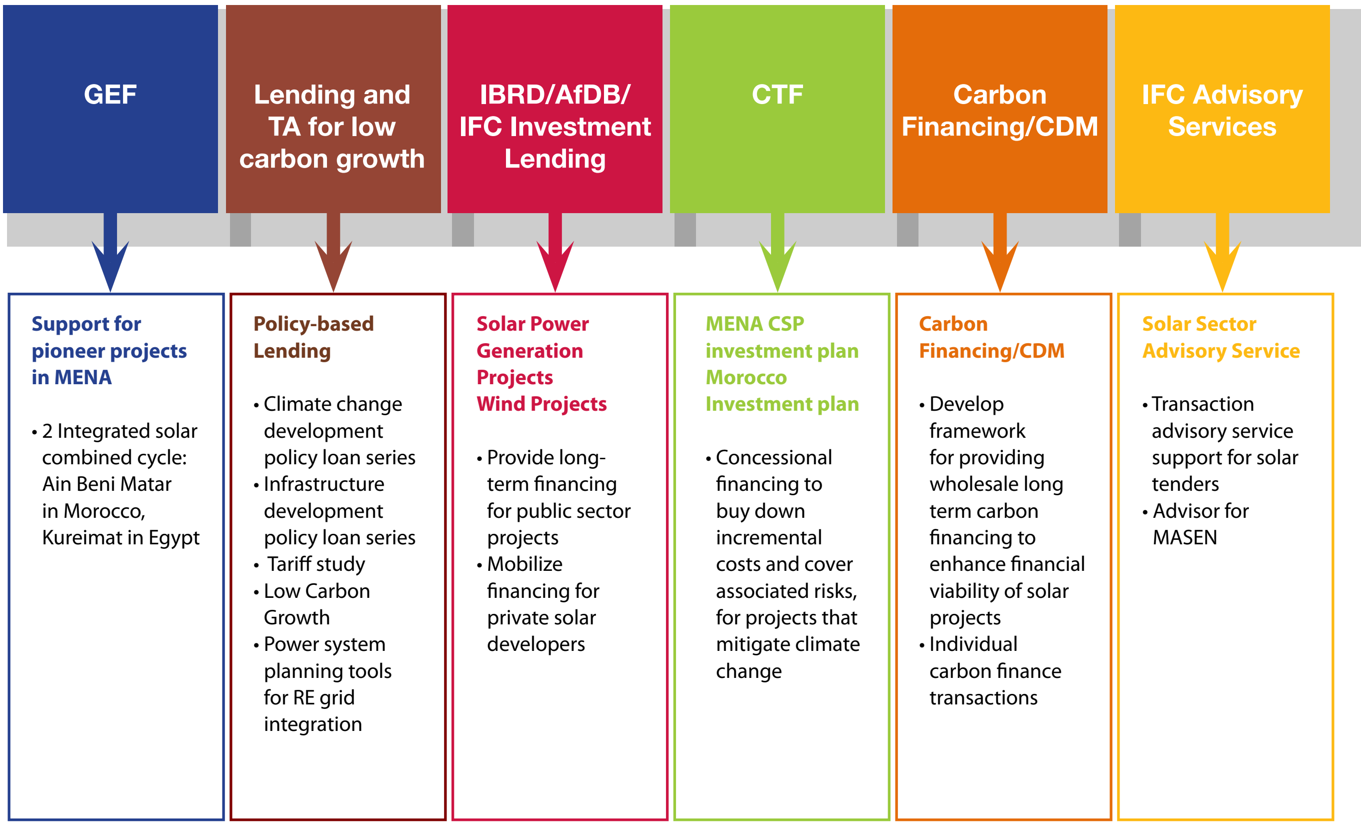
A renewable law 13-09 was approved in 2010. It provides a legal framework for the creation and operation of facilities producing electricity from renewable energy sources. It allows public and private corporations to compete with ONE, the publicly owned utility, in the production of electricity from renewable energy and have access to the electricity transmission system operated by ONE.

The Government is also undertaking extensive efforts to implement cost-reflective energy pricing and is launching energy conservation programs that will ease the transition to cost-reflective pricing by keeping consumer electricity steady.

Sustainability of Transformation

In addition, the World Bank and the African Development Bank are engaged with the Government to enhance the overall sector policy framework and advance reforms aimed at improving the sector's commercial environment and financial sustainability. The Government recognizes that ONE operates under tight financial constraints and has demonstrated its willingness to gradually increase tariffs toward covering costs, and provide budget and other support in the meantime. A study aimed at proposing a cost-reflective structure for electricity tariffs has been launched. In parallel, a study was also launched to define the missions of a new regulatory authority to be created.

As illustrated below, the World Bank and the AfDB are leveraging a set of actions aimed at building capacity within Morocco and providing the adequate incentives for policy reforms enabling a higher penetration for renewable energy.



Utilizing Different Instruments Together to Make a Transformational Impact

IFI (International Financial Institution) and Donor Coordination: Given the importance of solar energy in Morocco's development agenda and its significance to mitigating climate change, a number of IFIs and donors are assisting the Government of Morocco implement its national solar plan. There is already considerable coordination as well as collaboration of these efforts. This is exemplified by the various sources of financing expected for the Ourazazate I.

Leverage: The CTF (Clean Technology Fund) co-financing will directly lead to the development of up to 160MW of CSP capacity that is estimated to cost about $1 billion in investments. The $197 million allocation from the CTF will be leveraged about 7 times.

Portugal

RES POLICY

The Portuguese Government promotes RES principally via guaranteed feed-in tariffs for renewable electricity, direct subsidy payments (PRIME-Programme) and tax incentives. Beginning in 2005, a tendering/concession process has also been established. Subsidy payments and tax incentives have been largely, though not entirely, used for smaller-scale renewable energy applications. Feed-in tariffs and tendering schemes, used principally for larger-scale renewable applications.

RES TARGETS

Mandatory targets set by the Directive on the Promotion of the use of energy from renewable sources

- 31% share of RES on the final consumption of energy in 2020.
- At least 10% share of renewable energy in final consumption of energy in transport by 2020 .

RES POLICY INSTRUMENTS

Support for Electricity

Feed in tariff

The Decree-law 33_A of 16th February 2005 modified the system of feed-in tariffs, establishing a new calculation system. The formula for calculation of the feed in tariffs takes in account the technology, the environmental aspects and the inflation rate through the index of prices to the consumer. There are also some minimum and maximum tariffs, according to the variations of load on the grid.

Resource	Technology	Support level [€cents/ kWh]	Feed-in tariff or premium?	Duration [up to years that an investor is entitled to support]
hydro	small	7.5	feed-in tariff	20 years
wind	onshore	7.4	feed-in tariff	15 years
wind	offshore	7.4	feed in tariff	15 years
biomass	solid	11	feed in	15 years
biomass	gasification (biogas)	10.2	feed-in tariff	15 years
PV		31-45	feed in	15 years
CSP	Up to 10 MW	26.3-27.3	feed-in tariff	15 years
Wave		26 -7.6	feed-in tariff	15 years

The Decree-law 225/2007 introduced new tariffs for emerging technologies, such as wave energy and Concentrated Solar Power providing the legal basis for government use of public maritime areas for producing electricity from sea-wave power.

The present Portuguese feed-in law also describes a specific procedure that aims at minimizing local opposition towards new wind projects. In consideration of the crucial role of wind power within Portugal's energy strategy and the immense increases in installed capacity required to meet Portugal's wind energy targets. Under this procedure, municipalities in which a wind farm is located will automatically benefit from the remuneration the operator of the wind project receives. Altogether, the municipality receives a share of 2.5 percent of the monthly remuneration paid to the wind project operator. As expected, municipalities have responded with support for wind power projects in their territory. Local resistance against new installations has consequently remained negligible. A comparable procedure for other renewable technologies does not exist under the Portuguese regulation, and most other countries with feed-in tariffs have not experimented with this approach to minimizing local opposition to new renewable energy projects.

Tendering procedures

- Were used in 2005 and 2006 in connection to wind and biomass installations.
- In 2006, a call for tenders was launched for CSP power plants using forest biomass.

Europe

Regulatory Incentives for Solar Thermal Energy

Country	Decree	Value
Greece	L3468/2006	Original: For solar energy from units other than photovoltaic smaller than 5MW (250€/MWh Mainland; 270€/MWh Non-interconnected islands); larger than 5MW (230€/MWh Mainland; 250€/MWh Non-interconnected islands) Valid for 2009: For solar energy from units other than photovoltaic smaller than 5MW (264,84€/MWh Mainland; 284,84€/MWh Non-interconnected islands); larger than 5MW (244,84€/MWh Mainland; 264,84€/MWh Non-interconnected islands) As from June 2010: Solar thermal energy 264,85€/MWh; Solar thermal with storage system (at least 2h at nominal load) 284,85€/MWh
Cyprus		Financial incentives. Subsidies of capital cost and license aquisition cost. Support in cost of ancillary services. Use of system tariffs and losses. 0,26€/Wh for the first 20 years the system is in operation.
France	No. 2000-108	STE ha no specific support. More emphasis placed on biomass, wind and PV.
Malta		No specific reglatory support mechanisms for STE. (Appropriate for unshore wind and some on biogas and PV).
Portugal	No. 312/2001 No. 189/88 No. 225/2007	Special Production Regime based on formula. Average indicative tariff for STE installations <= 10MW: 267-273 €/MWh (valid for 15 years)
Italy	No. 387/2003 DM 11/04/2008	Feed-in-tariff for STE is dependent on the net production that is not attributable to solar: [0-15% 0,28€/kWh; 15-50% 0,25€/kWh; 50% and greater 22€/kWh].
Spain	RD 661/2007 RD ley 6/2009	Feed-in-tariff with two options: Regulated tariff [28,4983 c€/kWh first 25 years; 22,7984 c€/kWh from then on]; Organized electricity market [Reference bonus 26,8717 c€/kWh first 25 years 21,4973 from then on; top cap 36,3906 c€/kWhM lower cap 26,8757 c€/kWh]