CSP TECHNOLOGIES

RENEWABLE ENERGY TRAINING PROGRAM
MODULE 7 | CONCENTRATED SOLAR POWER (CSP)

ENVIRONMENTAL IMPACT

Fabrizio Fabrizi
(Head of Solar Thermodynamic Laboratory, ENEA, IT)

Remarks

The CSP technologies have characteristic environmental impacts, summarized under the following headings:

- water issues;
- HTF (and HSM) issues;
- land use and visual impact;
- energy and materials use;
- emissions;
- impacts on flora and fauna.

Water issues

Water uses vs environment impact

CSP plants are often designed to use water for cooling at the back-end of the thermal cycle, typically in a wet cooling tower. These water requirements can result in difficulties in arid areas, e.g. in the MENA region, being the region in the world experiencing the hardest water stress. Large scale implementation of CSP in Europe and the MENA region requires that additional water needs can be effectively met, or technologies with lower water use must be implemented.
A typical 50 MW parabolic trough plant uses 0.4-0.5 million m^3 of water per year for cooling: roughly the same as agricultural irrigation of an area corresponding to that occupied by the CSP plant in a semi-arid climate. The perspective of withdrawing large amounts of fresh water for CSP cooling is not appealing.

Water is also used for cleaning the mirrors to maintain their high reflectivity, though water use for cleaning is typically a factor of a hundred lower than that used for cooling. It may be more significant in desert areas where dust storms may require more frequent cleaning, and the associated water consumption is relatively higher when compared to precipitation.

Water use can be decreased by instead cooling with air, but this lowers the efficiency of the system. A study conducted by the US NREL indicates that the switch from wet to dry cooling in a 100 MW parabolic trough CSP plant can decrease the water requirement from 3.6 l/kWh to 0.25 l/kWh. Using dry instead of wet cooling increases investment costs and lowers efficiency, adding 3 - 7.5% to the levelised electricity cost.

Finally, there are some CSP plant designs that have inherently low fresh water requirements, such as gas turbine towers and parabolic dishes with Stirling engines.

Figure a. Wet cooling at Nevada Solar One CSP plant (http://www.basinandrangewatch.org/Water.html)

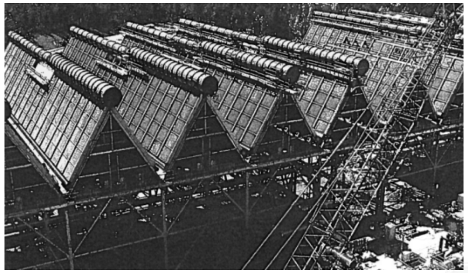


Figure b. Power plant air cooling (Spears, 2002)

FACT BOX: Desalination

HTF (and HSM) issues

Heat Transfer Fluids (HTF) vs environment impact

The environmental components that could be affected by leaks or emissions of HTF (heat transfer fluid) are: soil, groundwater and surface water, air and human presence. As a reference situation, the case of synthetic oil as HTF is taken and compared to other possible HTFs, more friendly to the environment.

Parabolic trough, linear Fresnel and parabolic dish technologies provide a widespread distribution of the receivers, i.e. tubes or motors in the solar fields and therefore a potential involvement of large tracts of land by possible leakages of HTF. This fact warns that the use of HTFs may be hazardous to the environment.

This aspect is less problematic for the limited area devoted to the TES (thermal energy storage) and to the process equipment. In this case, a proofing surface with containment walls will avoid a significant pollution towards the soil if some leakages of HTF or Heat Storage Medium (HSM) take place..

The Tower systems could be considered an intermediate case, where the height of the central receiver could facilitate the dispersion on a large area all around the tower. The accidental leakages could occur during circulation of the HTF in some parts not shielded by insulation, i.e. central receiver. In this case the pressurised fluid is sprayed outside and, due to the height of the tower the area of dispersion could be large.

Synthetic oil (reference case)

Nowadays parabolic trough plants in California and Spain exhibit some leakages of the synthetic oil used in the receiver tubes. There is also a prevailing HTF smell in the installations. Leakages have been more controlled by new interconnection elements (ball joints), while soil pollution can be recovered by bacteriological decontamination or by removing and substituting large amounts of ground. Where there are superficial ponds or not deep groundwater, the synthetic oil pollutes the soil and could pass very fast to the water, towards which it is highly toxic. This fact suggests that oil should be avoided in case of very vulnerable aquifers.

HTF (and HSM) issues /2

Alternative HTFs in use nowadays

The RTD of the past years has lead to various new systems that need not any more the synthetic oil, but directly use water/steam as HTF, as in DSG (direct steam generation), gases or molten salt mixtures in direct/indirect systems. The choice of the HTF has various constraints besides the environment safeguard: costs, performances and efficiency of the plants. This implies a compromise in order to comply with safe solutions.

Advanced HTF solutions

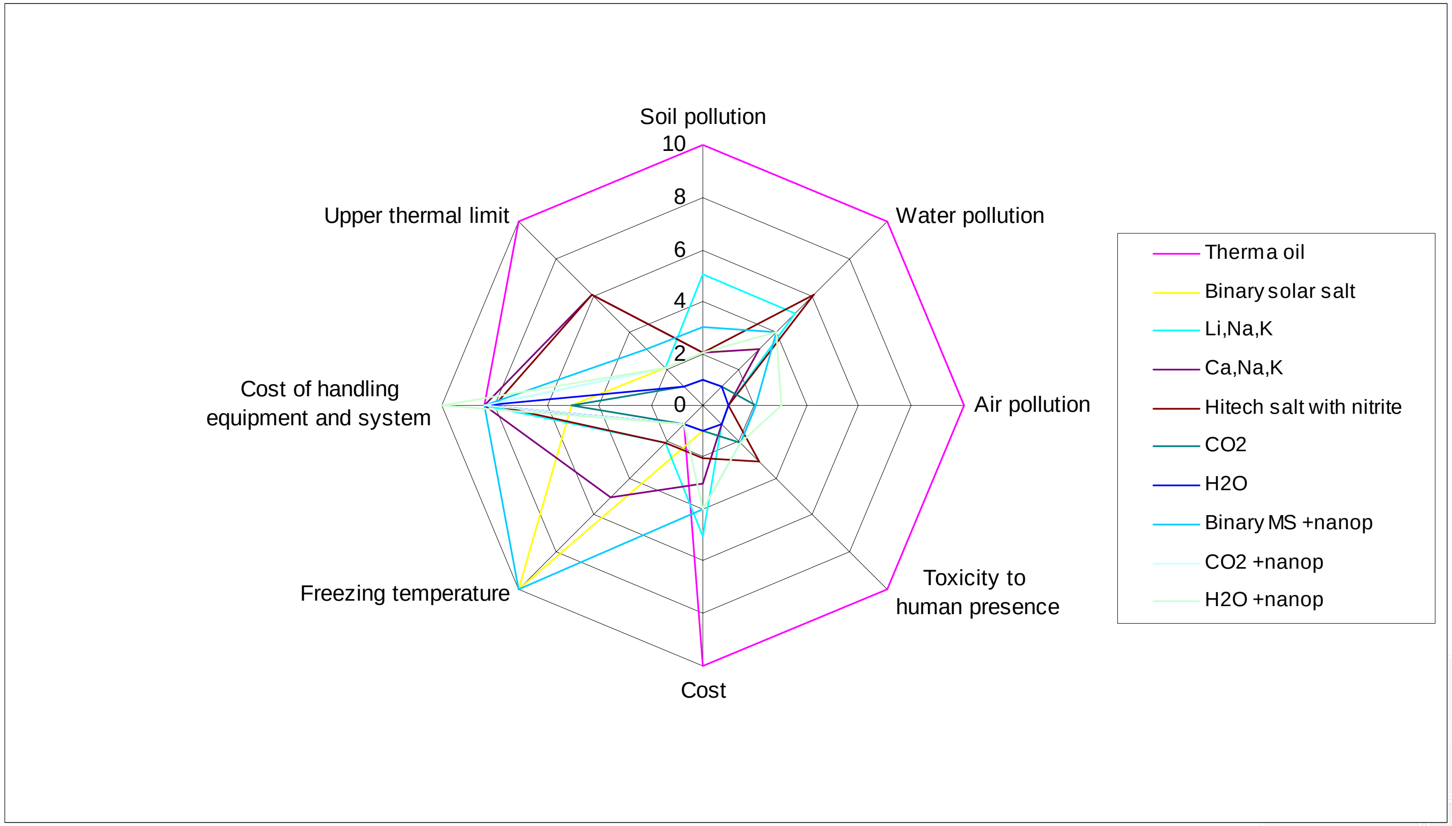
Other options involve advanced HTFs, including:

- pressurised gas, currently under testing, e.g. at the Plataforma Solar de Almeria, Spain. Additional work is needed to improve heat transfer in the receiver tubes, and to ensure control of the solar field, which is more complex than the reference oil design;
- molten salt directly used in the solar collectors field, thus simplifying the TES because HTF becomes also storage medium, e.g. in the Archimede demo plant, Italy. The used molten salt mixture, i.e. the less expensive "solar salt" nowadays used for TES, solidifies below 235°C; therefore auxiliary heating equipment and expenses are needed to protect the solar field against freezing. Other molten salt mixtures are under investigation to reduce the freezing point even down to 100°C.
- dense gas-particle suspensions: it is proposed to use dense gas-particle suspensions (approximately 50% of solid) in tubes as HTF; these tubes, set in a bundle, constitute the solar absorber (receiver), placed at the top of a central receiver system. This new HTF behaves like a liquid with extended working temperature: it stays almost liquid at any temperature (no freezing temperature) and permits to increase working temperatures up to 700°C and more. Moreover, it can be used as an energy storage medium because of its good thermal capacity. It is composed of any particulate mineral standing high temperature, thus deeply reducing the environmental impact and addressing the safety concern in comparison with standard HTF;
- adding nanoparticles to the above mentioned fluids, thus obtaining the so called nanofluids, would greatly enhance physical and transport properties, implying a positive impact on the environment;
- other attempts, in order to reduce the melting point for molten salt mixtures related to the use of special additives, have to be considered for the environment impact.

HTF (and HSM) issues /3

7.3.1.2 Heat transfer fluid characteristics

In the figure the various fluids are evaluated in the respect of a value scale (from 1 to 10) for their impact to the environment components and their technical and economic characteristics. Among all the possible HTFs, only the most commonly employed and/or studied ones have been selected, together with some less investigated but very promising nanofluids, i.e. fluids containing nanoparticles:



Land use and visual impact

To compare CSP land use to that associated with other energy conversion technologies, a basic estimate of land use has been made in EASAC study.

Land use refers to the area directly occupied by a power plant structure (in a CSP plant the collector/heliostat fields dominate), by extraction of fuel, or by plantations for biomass. It is presented in relation to the energy generated annually by each plant, and hence is expressed in units of $m^2/(MWh/y)$.

The **visual impact** gives the area over which a power plant disturbs the view, divided by the energy generated annually by the plant (and hence is also expressed in units of $m^2/(MWh/y)$)

The Table presents data for CSP technologies and, for comparison, for wind, biomass and lignite power plants. Visual effects are most noticeable in tower CSP plants where very bright points appear in the rural landscape. However, due to contemporary social attitudes the signal has been interpreted by the population as a technical novelty and a sign of progress, not causing rejection (so far).

One advantage of CSP plants is that they are often located in areas with limited amenity or aesthetic value. Desert land for solar plants could in many ways be seen as better than, for instance, agricultural land for biomass energy. The placement of power plants or fuel extraction (such as lignite) close to highly populated areas can be almost completely avoided. The areas globally suitable for CSP development far exceed present needs. Nevertheless, arid regions have environmental value, and contain some biotopes or species that are threatened. The harshness of the desert climate also makes it take longer for an arid biotope community to recover from the effects of disturbance. This calls for some caution.

	Land use [$m^2/(MWh/y)$]	Visual impact [$m^2/MWh/y)$]
Parabolic solar power, Spain	11	15
Solar tower power, Spain	24	1100
Photovoltaic power plant, Germany	56*	
Wind power	< 5	8600
Biomass plantation, France	550	
Open cast mining (lignite), Germany	60	
High voltage power transmission line across Europe	0.4	

Energy and materials use

In evaluating the sustainability of CSP plants it is useful to compare their energy balance and materials use over their life cycle to other power generation technologies. The life cycle assessment methodology used is proposed in the EASAC study. A life cycle assessment of CSP plants shows that the cumulative (non-renewable) primary energy invested in construction and operation of a plant over its lifetime is gained back as renewable power in less than one year of the assumed 30-year life. This gives an Energy Return on Investment (EROI) of about 30. The cumulative (non-renewable) primary energy needed to produce one kWh of electricity is comparable to that of wind power and orders of magnitude lower than for fossil-fired power plants, as illustrated in the Figure a.

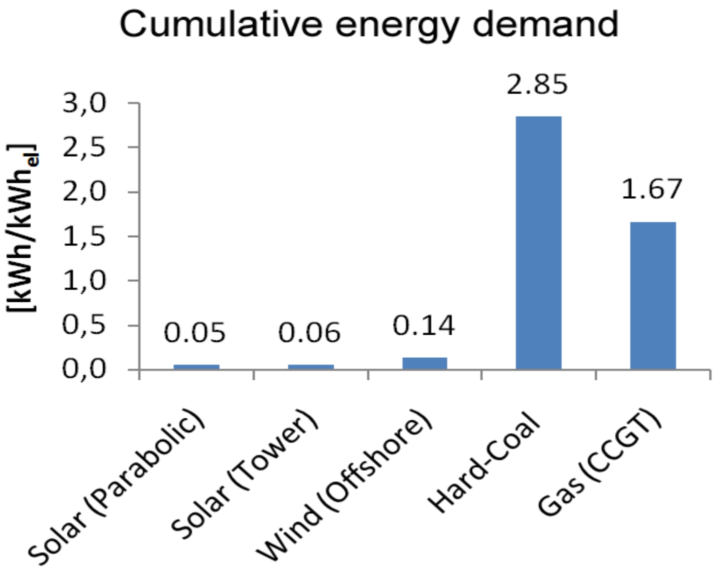


Figure a. The cumulative (non-renewable) primary energy over the lifetime of the plant needed to produce a unit of electricity from different power plants: parabolic CSP plant (May, 2005), CSP tower plant (Weinrebe, 1999), offshore wind farm (Wagner et al, 2010), hard coal- (GaBi, 2007) and gas combined cycle gas turbine (CCGT) power plant (Ecoinvent-Database, 2007).

Energy and materials use /2

CSP plants are more materials intensive than conventional fossil-fired plants as illustrated in Figure b. The main materials used are commonplace commodities such as steel, glass and concrete whose recycling rates are high: typically over 95% is achievable for glass, steel and other metals. Materials that cannot be recycled are mostly inert and can be used as filling materials (e.g. in road building) or can be land-filled safely.

There are few toxic substances used in CSP plants: the synthetic organic heat transfer fluids used in oil parabolic troughs, a mix of biphenyl and biphenyl-ether, are the most significant. They can potentially catch fire, can contaminate soils and create other environmental problems, and have to be treated as hazardous waste. Current research activities aim to replace the toxic heat transfer fluid with water or molten salts, or other fluids as illustrated in the specific chapter.

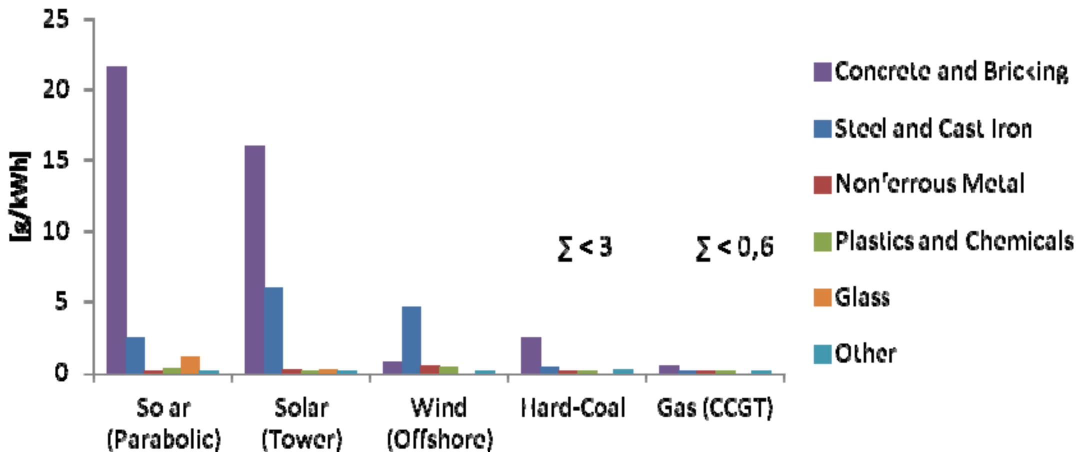


Figure b. Material intensity for different power plants: parabolic trough CSP plant with storage (May, 2005), tower CSP plant without storage (Weinrebe, 1999), offshore wind farm (Wagner et al, 2010), hard-coal power plant (Köhler et al, 1996) and CCGT power plant (Hoffmayer et al, 1996).

Emissions

The emissions of greenhouse gases are strongly linked to the cumulative (non-renewable) primary energy demand shown in Figure a and b. Greenhouse gas emissions for CSP plants are estimated to be in the range 15-20 grams CO_2-equivalent/kWh, much lower than CO_2 emissions from fossil-fired plants which are 400-1000 g CO_2-eq/kWh. Figure c presents data for a wider range of CSP technologies and drawings on a larger number of studies (IPCC, 2011) indicating greenhouse gas emissions of about 9 - 55 g CO_2-eq/kWh for large-scale CSP technologies.

The Figure c compares plants without salt storage (though the solar parabolic trough plant on which this figure is based includes a concrete thermal storage system). Using nitrous salts as heat transfer fluid and/or storage medium creates life cycle emissions of nitrous oxide (N_2O). Although the amounts are roughly 500-1000 times smaller than the carbon dioxide emissions associated with a CSP plant, they are not negligible as N_2O is about 300 times stronger than CO_2 as a greenhouse gas.

Comparative emissions of acid gases are also shown in Figure b. Again, coal-fired plants have the highest emissions, but in this case, natural gas-fired plants have values not much higher than the renewable technologies.

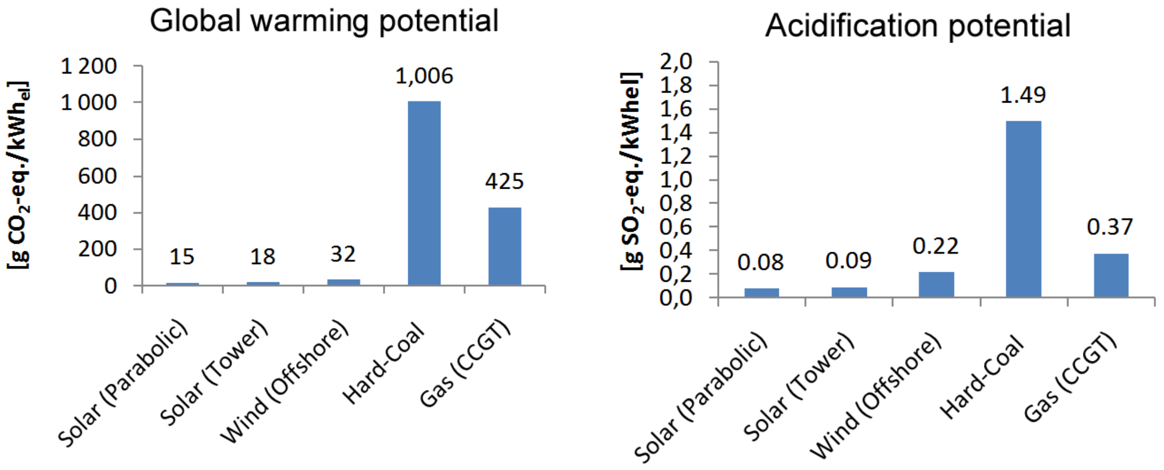
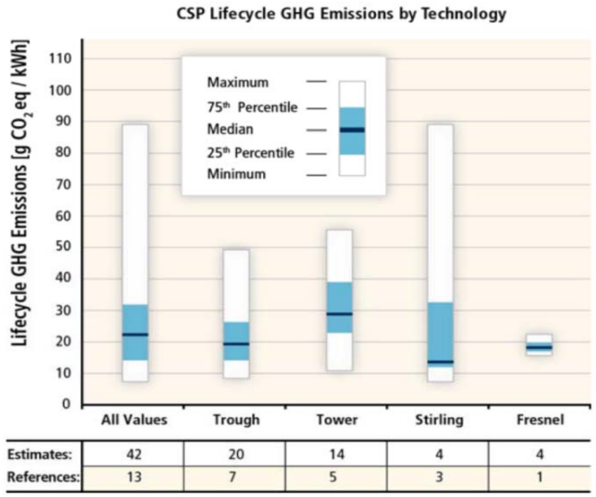


Figure a and b. Global warming and acidification potentials from selected studies of the different power plant systems: parabolic CSP plant (May, 2005), tower CSP plant (Weinrebe, 1999), offshore wind farm (Wagner et al, 2010), hard coal (GaBi, 2007), and gas CCGT power plant (Ecoinvent-Database, 2007).



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

Figure c. Greenhouse gas emissions of CSP technologies, including confidence intervals (IPCC, 2011).

Impacts on flora and fauna

Local impacts of CSP plants on the environment may be associated with traffic, building works, ecosystem disturbance and loss of ecosystem functions. Traffic, plant construction and surface treatment of parking plots cause indirect mortalities to local fauna at a level depending on the surface area of the facility and the land use type prior to plant construction.

Mortalities caused to vertebrates are the main concern in respect of the local environmental impact of CSP plants. Direct mortalities take place under two main circumstances: collision with top mirrors and buildings (the tower in particular), and heat shock or burning damage in the concentrated light beams. Birds rarely collide with CSP plants when visibility is good, but when vision is impaired casualties have been documented. A poorly illuminated solar tower can be hit by birds at night, but this is rare. Insects can also mistake the glass surfaces for water and be killed, or lose eggs they are carrying, in attempts to enter the surfaces.

If a plant is built on former agricultural land, available nutrients in the soil may facilitate growth of vegetation up to 1m in height below and between solar collectors. Under Mediterranean climates the vegetation can dry up and contribute to fire risk. Herbicides can be used to prevent plant growth, but they typically have toxic effects at some scale, persist in the soil profile and may be exported with runoff. Alternative treatments of soil surface that impair seedling establishment include compacting the ground, enabling the development of a surface crust, or adding gravel. The water used in mirror cleaning drips onto a narrow ‘wet band’ at the base of the collectors and can be a significant amount during dry summer months (particularly in desert areas), stimulating and/or maintaining plant growth.

Another impact related to plant construction and operation is the introduction of species previously alien to the area. Gardening, goods and equipment, and public works machinery all contribute to introductions. Some other species actively follow contractors and colonise their area of activity, gaining from the removal of local species from the disturbed land.

While CSP plants can have a number of effects on the local environment, in comparison to other technologies, particularly fossil-fired plants, they are relatively benign. The direct damage from solar plants is low: a monitored CSP tower plant operating since 2007 in Spain has so far (2011) only recorded 2 bird deaths. Even with a much larger implementation, environmental impacts will not be on the same scale of effects from fossil fuels, like the Deepwater Horizon oil disaster in the Mexican Gulf in 2010.

Conclusions

All power generation has some effects on the environment but it is evident that CSP plants on the whole have better environmental performance than today's fossil-fired technologies. Not using extractable fuels means that CSP is free of the impacts from coal mining, spills from oil rigs, leakage of methane from gas extraction etc. On the other hand, use of commodities such as steel, glass and concrete is relatively high, though most of these materials are readily available and have high recycling-potential.

Issues that need to be addressed are water requirements in arid areas, use of toxic synthetic oils as heat transfer fluids, and use of pesticides to restrict vegetation growth in heliostat fields. For all of these issues, technical solutions are available or under development. Environmental impacts vary among technologies and over time. Although some CSP technologies today are proven and commercialised, they are less mature than conventional fossil-fired power stations. This means that they can be expected to progress faster with innovation and improvements of efficiency and hence the environmental impact of CSP technologies, relative to fossil-fired power, is likely to get better over time.

Ref.s:

Concentrating solar power: its potential contribution to a sustainable energy future - EASAC policy report 16 - November 2011 - ISBN: 978-3-8047-2944-5 - www.easac.eu

Strategic Research Index from ESTELA. To be published by December 2012 - www.estelasolar.eu

THANK YOU