All facts about Concentrating Solar Power (CSP) in 5 pages

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CSP in 100 words
Concentrating Solar Power (CSP) is the technology of solar-thermal power stations.
In conventional power stations the combustion heat of coal, natural gas or oil, or the heat from a nuclear reactor is used to produce high pressure steam. The steam feeds a steam turbine that is coupled to a power generator. In a solar-thermal power station, the rays of the sun are focussed through mirrors on to the boiler of such a conventional power station. The heat of the sun replaces the fire: CSP-plants are sustainable thermal power stations. Often the solar heat is stored, so that also after sunset power can be delivered to the grid.

1. CSP Technology

This review gives a summary of the technology as it is applied on a daily basis in CSP-plants (a.k.a. solar-mirror plants or solar-thermal power plants), [Ref.1].

Mirror systems.
The rays of the sun are focussed through mirrors and release their heat to an absorber, which then rises enormously in temperature. The mirrors have to turn constantly to compensate for the rotation of the earth.
There are four types of CSP-mirror systems:

1. Parabolic Trough mirrors: these focus on one focus line, are positioned North-South and rotate on one axis.
2. Linear Fresnel mirrors: these focus on one focus line and rotate on one axis
3. Solar Towers with a field of heliostat-mirrors which rotate on two axes and focus on one focal point.
4. Solar dishes that focus on one focal point.

Absorbers to catch the radiation
The absorbers are covered with a spectral-selective layer to avoid radiation loss.
The absorber tubes in the focus line of the parabolic-trough mirrors operate at 400°C. They are thermally insulated by means of a vacuum-drawn glass tube. The absorber part of a linear Fresnel field consists of a strongly curved secondary mirror and an absorber tube usually operating at 300°C without vacuum insolation. The absorber at the top of a solar tower is either a thick-walled boiler, a vessel in which fluid salt is heated up to 565°C, or a ceramic air heating system that reaches temperatures of up to 680°C. In the absorber of a solar dish a Stirling engine converts heat into mechanical energy.

Heat transport and storage
The current parabolic trough plants apply a silicon oil or liquid alkali-nitrate salt to transport the heat from the absorbers to the steam boilers. In linear Fresnel systems, steam is produced directly in the absorber tubes.
Storage of heat enables CSP-plants to generate steam also after sunset. In trough mirror plants the temperature varies between 300 and 400°C. In solar tower the temperature varies between 290 and 565°C, thus over a larger range.
Energy storage in the form of heat at high temperature is cheap and the losses are much smaller than for conventional energy storage through pumping water into high level lakes.

Conversion of heat into electricity.
The heat is used to produce superheated, dry steam. This steam expands in steam turbines which drive electric generators. The steam is reheated halfway through the expansion in the turbines. Linear Fresnel plants work with wet steam and turbines that can handle wet steam. In the absorber of a solar dish a Stirling engine converts heat into mechanical energy.

Cooling.
Solar-thermal power plants are usually cooled through cooling towers in which water is evaporated. Increasingly, plants are cooled with air because insufficient quantities of water are available.

The seasonal problem of solar energy
In the winter, the yield of solar radiation is lower than in summer. The closer to the equator, the smaller the difference but also in North Africa the difference is considerable. The only way to have sufficient power available through the year is chemical storage of surplus solar energy in summer, for example as hydrogen. Electricity from CSP-plants (and also from PV-plants) is then used to produce hydrogen through electrolysis of water. A possible alternative is the use of the very high temperatures of solar towers to split water into hydrogen and oxygen in a series of chemical reactions. In winter, hydrogen can be reconverted into electricity in fuel cells or gas turbines, where residual heat can be supplied to heat grids, connecting to houses.

Guarantee of delivery.
For a small additional investment, gas burners can be added so that absolute security of supply can be guaranteed to the grid operator.

Required land area.
The energy conversion of solar radiation to electricity of a CSP-plant and a PV-plant is similar, about 20%. A CSP-plant of 100 MW without heat storage in a country with a desert climate requires a mirror surface area of about 1 km^2 and a land area of about 2 km^2. A solar plant that is comparable in performance to a modal coal or nuclear power plant (i.e. a CSP-plant of 1GW with sufficient heat storage for 16 hours delivery at full capacity) requires a land area of about 50 km^2 or 7x7 km. Such a plant supplies 10^9x365x24x3600 Ws/y= 3x10^{16} J/y = 30 PJ/y.
The total consumption of energy in the whole world (coal, oil, gas, uranium and renewable) is 6x10^{20} J/y. If we would want to supply this with CSP then we would need 6x10^{20}/(3x10^{16}) = 20000 plants of 1GW, that would cover one million km^2 of desert land. This is equal to the land area of Egypt.

Long distance transport of electricity
Electricity can be transported over large distances through High-Voltage Direct-Current (HVDC) technology. The energy losses during transport of electricity for example from Southern Morocco to Central Europe are 10-14%.

2. Comparing CSP (solar mirrors) and PV (photovoltaic, solar panels).

Advantages of CSP vs PV
- Delivery of electricity when required thanks to storage of heat.
- Sustainable alternative for coal and nuclear power plants.
- Shorter energy-payback period.
- Less pollution in producing the installation.
- Smaller impact on rare chemical elements.
- Better integration into the local economy of developing nations.
- Possibility to produce cheaper green hydrogen.

Disadvantages of CSP vs PV
- Only profitable in countries where the sun is shining often and strongly.
- Only possible in large and expensive installations.

3. The contribution of CSP to the global energy supply

In November 2018, 90 CSP-plants in 11 countries supplied 5 GW electricity in total [Ref.1]. Under construction is a capacity of 1.4 GW in 9 countries.
In figure 1 the total global generating capacity is given for four climate-neutral technologies: nuclear, wind, solar-PV, and solar-CSP. In addition, the total primary energy consumption is shown in the same units. In 2017, this was 14050 Mtoe (million tonnes oil equivalent) or 587 exaJoules. Converted to Watt = Joule/second, the units on the vertical axis of figure 1, the global total energy consumption in 2017 was 18600 GW.

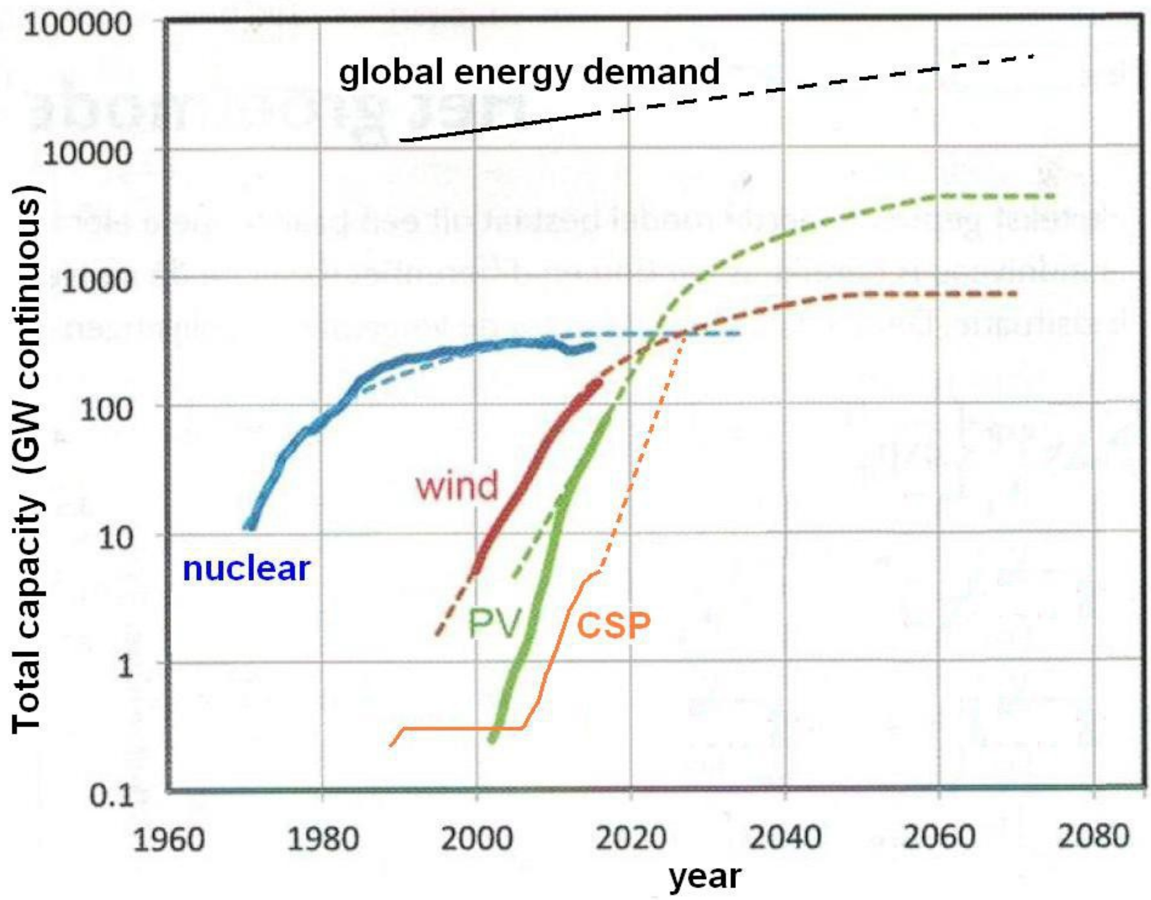

Figure 1. Total installed capacity of the four climate-neutral energy sources with greatest global potential. The curves for wind and solar-PV have been corrected for their restricted capacity factor. The vertical axis is logarithmic.

In the perspective of global energy consumption the contribution of CSP is still small; also compared to solar-PV and wind energy the contribution of CSP is modest. The explanation for the rear end position of CSP is that, for many reasons, the growth of CSP started much later than that of PV and wind. In authoritative scenarios for a global non-fossil energy supply, CSP is considered indispensable because CSP is the only solar energy capable of delivering power around the clock.

The cost of CSP
The Levelized Cost of Electricity (LCOE), which is the sales price per kWh at the plant gate, depends strongly on the geographical location, the climate and interest rates.
As an example we give the NOOR1 trough-mirror plant in Ouarzazate (Morocco). This started in 2015 with a capacity of 146 MW with 3 hours heat storage capacity and air cooling. This plant has a 25-year delivery contract for 1.62 Dirham/kWh (14.4 €cent/kWh). This price is still considerably above that of conventional gas- and coal plants.

In the last decade, the CSP-sector has consolidated in a number of companies in Spain, the USA, Germany and, to a lesser extent, some other countries. This provides the basis for a learning curve towards lower kWh cost, as has already been the case for rival technologies such as solar-PV and wind. Results are starting to show: in the UAE construction recently started of a combined solar tower/trough mirror plant that will generate 700 MW for a sales price of 7.3 $cent/kWh. A unit cost reduction of more than a factor 2 in 5 years! The perspective for further reduction is amply available.

The best business case for an energy company is a combined CSP/PV plant. During the day, cheap PV power is supplied to the grid, while the heat from the mirrors is stored. During the night the steam turbines of the CSP plant run on heat from storage. This way a base load solar power station is created that could replace all fossil plants without the need for nuclear.

4. A plea for political support for CSP.

Why is political support needed for CSP?
Of all sustainable energy sources solar energy has, by far, the largest potential. CSP is the only technology that can supply solar electricity continuously and is therefore able to replace coal plants. CSP thus is the best technology to solve the climate problem.
As long as the kWh price of solar-thermal plants is higher than that of power plants on fossil fuels, all governments should legislate to force, or at least tempt, companies and banks, to invest in CSP.
The alternative is large scale introduction of PV, together with battery storage for electricity during the day, to enable supply after sunset. For the moment, this approach is more expensive than CSP and a much larger use of PV has unnecessary environmental problems with scare materials.

Opposition.
The development of CSP has gone in fits and bursts. After a hopeful start around 1990 with 300 MW in trough plants in California (Kramer Junction) no plant was built for 15 years (see fig 1). But from 2006 onwards growth has accelerated. Still, there has not been a specific technological breakthrough to trigger this growth; it might just as well have happened in 1990. If that had been the case, now, in 2018, a much more delivery-secure solar power would have been available rather than the fickle wind energy. The stagnation in the period 1990-2006 was the consequence of a few unfortunate political decisions and especially the conscious and unconscious opposition by promotors of small scale energy ideology (“Robinson Crusoe romantics”).

Measures at the national level.
Solar-thermal energy has the prospect to become profitable soon in 90 countries, the so called “sunny countries”. Developed countries with strong solar radiation like Australia and South-Africa should adopt the successful 'obligatory portfolio standards laws' of California and Nevada or stimulate CSP-investment through a ‘feed-in’ law that has been very effective in the cost reduction of solar panels and wind turbines.
Oil and gas exporting countries in areas well-endowed with sunshine should invest their income in CSP-plants and migrate their power production from oil and gas to solar. This is starting to happen in the UAE and Saudi-Arabia. In this way, oil and gas that otherwise is used for own power production becomes available for export. These countries could also become exporters of solar power.
Governments of OECD-countries with less sunshine should stimulate their national energy companies to invest in CSP in sunny countries.

Measures at the bi- and trilateral level.
Sun-poor OECD countries en sun-rich developing countries could cooperate (e.g. the Netherlands and Morocco) with companies from both countries investing in solar in the South and wind in the North. Both countries then present themselves as a single party for the achievement of international climate goals to mutual benefit [Ref.2], solar energy in the South being cheaper and more reliable than wind in the North, for example in the North Sea.

Gas exporting and trading countries like Algeria, Libya and Qatar could work together with e.g. the Netherlands in order to spend part of their gas revenues in investment in CSP.
These countries could start a cooperative agreement in which CSP investment is coupled to a preferential access to gas, thus making the 'Gas-Rotonde' into a 'Gas-CSP-Rotonde'.
Dutch energy companies could build CSP plants in Southern Europe with HVDC (high-voltage direct current) cables to the Netherlands. In this way, the Netherlands could satisfy an important part of its EU obligation for sustainable energy production.

Measures at EU and ME/NA level.
Large scale solar energy is an important part of the Mediterranean Union [Ref.3]. EUROSUNMED is a cooperation between companies and universities for the development of PV and CSP [Ref.4]. A Solar Mobilization Fund, SMF, [Ref.6] with one billion (10^9) euro initial capital could be created as a trustworthy business partner for companies that invest in CSP in sunny countries that are seen as less stable politically. The SMF would purchase electricity and water from the operators of solar plants and sell it at competitive local prices to local grid operators. Any losses of the SMF could be covered by the European and (to lesser extent) ME/NA governments, or by the European electricity consumers. Since CSP is close to being profitable, the effectiveness of the SMF can be considerable.

Measures at the global (UN) level.
If the world were to decide to invest one percent of its GDP in solar-thermal plants, all coal, gas and nuclear power plants could be closed down in 20 years [Ref.6]. The most important source of CO_2 emissions would then have been shut down and the largest attack on our climate would have been beaten off.

Delivery-secure solar energy, i.e. CSP, must come on to the political agenda!
The global annual CO_2 emission should have come down already a long time ago, but the opposite is the case. The scientific reports are alarming. In all global scenarios that describe a credible transition to a world economy where global warming is limited to 2ºC or less, CSP plays a prominent role. This form of sustainable energy is therefore also relevant for the Netherlands and needs to be supported by all parties.

Literature and websites
1. Complete overview of CSP plants in operation and under construction:
http://www.nrel.gov/csp/solarpaces/ and
http://en.wikipedia.org/wiki/List_of_solar_thermal_power_stations
2. Dutch-Moroccan Solar Energy Plan (Nederlands, Français, English)
https://www.gezen.nl/wp-content/uploads/2018/12/Dutch-Moroccan-Solar-Energy-Plan.pdf
http://www.gezen.nl/wp-content/uploads/2018/12/Plan-d-energie-solaire-neerlandaismarocain-2-.pdf,
3. The Union for the Mediterranean Region unites the 28 EU-states and 16 countries from ME/NA see http://en.wikipedia.org/wiki/Union_for_the_Mediterranean
4. Euro-Mediterranean Cooperation on Research & Training in Sun Based Renewable Energies, http://eurosunmed.cnrs.fr
5. The International Solar Mobilization Fund, see http://www.gezen.nl/wpcontent/uploads/2018/12/The-International-Solar-Mobilization-Fund-2-kopie.pdf
6. E.H. du Marchie van Voorthuysen, *Two scenario's for a Solar World Economy*, Int. J. Global Environmental Issues Vol. 8, No. 3, 2008, or: http://www.gezen.nl/wpcontent/uploads/2018/12/ArtikelIJGlobalEnergyIssues.pdf