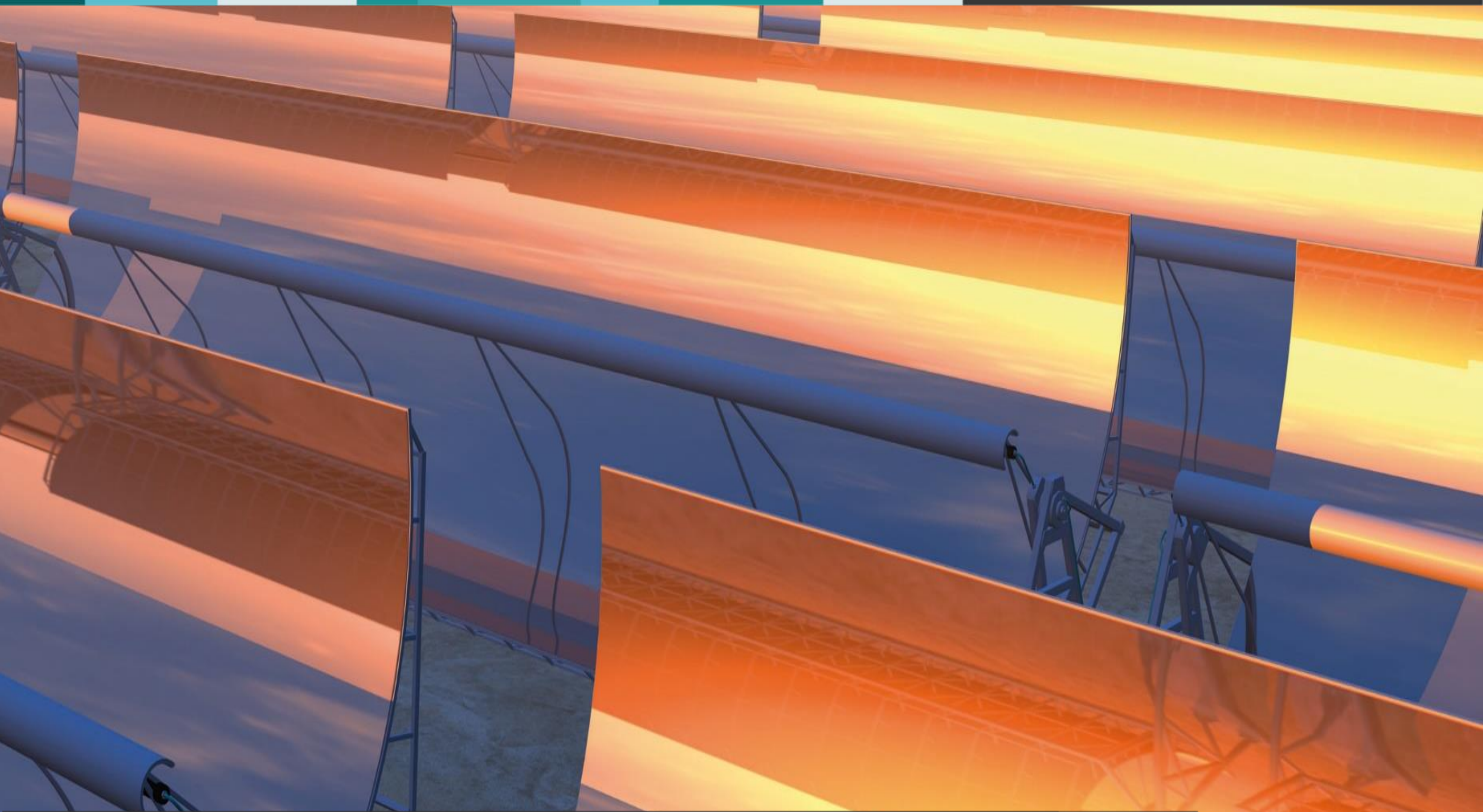
ISSN 1831-9424

European Commission

CLEAN ENERGY TECHNOLOGY OBSERVATORY



CONCENTRATED SOLAR POWER AND HEAT IN THE EUROPEAN UNION

2022

STATUS REPORT ON TECHNOLOGY DEVELOPMENT, TRENDS, VALUE CHAINS AND MARKETS

Joint Research Centre

EUR 31255 EN

Contact information
Name: Nigel TAYLOR
Email: nigel.taylor@ec.europa.eu

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC130811

EUR 31255 EN

PDF ISBN 978-92-76-57686-0 ISSN 1831-9424 doi:10.2760/080204 KJ-NA-31-255-EN-N

Luxembourg: Publications Office of the European Union, 2022

How to cite this report: Taylor, N., Georgakaki, A., Letout, S., Kuokkanen, K., Mountraki, A., Ince, E., Shtjefni, D., Joanny, G., Eulaerts, O. and Grabowska, M., *Clean Energy Technology Observatory: Concentrated Solar Power and Heat in the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets,* Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/080204, JRC130811.

Contents

Foreword

This report is an output of the Clean Energy Technology Observatory (CETO). CETO's objective is to provide an evidence-based analysis feeding the policy making process and hence increasing the effectiveness of R&I policies for clean energy technologies and solutions. It monitors EU research and innovation activities on clean energy technologies needed for the delivery of the European Green Deal; and assesses the competitiveness of the EU clean energy sector and its positioning in the global energy market.

CETO is being implemented by the Joint Research Centre for DG Research and Innovation, in coordination with DG Energy.

Acknowledgements

The authors are very grateful to Piero De Bonis (RTD), Piero Carlo Dos Reis (CLIMA) and Philip Hawkins (CLIMA) for the review contributions received, and to Thomas Schleker (RTD) and Giulia Serra (ENER) for their general support to this CETO activity.

Thanks also to JRC colleagues Andreas Schmitz and Ana Vazquez Diaz (CETO deputy project leaders, JRC.C.6) for coordination, support, review and comments.

Authors

Nigel Taylor, JRC.C.2

Aliki Georgakaki, JRC.C.7 Energy Research, Innovation and Competitiveness Team

Simon Letout, JRC.C.7 Energy Research, Innovation and Competitiveness Team

Anna Kuokkanen, JRC.C.7 Energy Research, Innovation and Competitiveness Team

Aikaterini Mountraki, JRC.C.7 Energy Research, Innovation and Competitiveness Team

Ela Ince, JRC.C.7 Energy Research, Innovation and Competitiveness Team

Drilona Shtjefni, JRC.C.7 Energy Research, Innovation and Competitiveness Team

Geraldine JoannyJRC.I3 Technology Innovation Monitoring (TIM) team

Olivier Eulaerts JRC.I3 Technology Innovation Monitoring (TIM) team

Marcelina Grabowska, JRC.I3 Technology Innovation Monitoring (TIM) team

.

Executive Summary

This report on concentrated solar power and heat is one of an annual series of reports from the Clean Energy Technology Observatory (CETO). It address technology maturity status, development and trends; value chain analysis and global market and EU positioning. The scope covers:

a) concentrating solar power (CSP) plants that convert solar energy to electricity, and

b) concentrating solar heat (or cool) for district heating and for industrial processes (SHIP).

Up to now, concentrating solar technologies have developed to a commercial scale but have played only a small role in decarbonising the energy system. Nonetheless considerable potential exists in globally and in the EU. The two major designs used today are parabolic trough power plants and central receiver systems. CSP can be combined with other power generation technologies, either for solar-assisted power generation or in hybrid configurations, also with photovoltaics systems.

Concentrating solar thermal heat for processes primarily addresses thermal energy supply in the range 100–400 ºC for industry and for district heating applications, often as part of an integrated solution with other heat sources [5, 6]. The DNI requirement is much less stringent than for power production. Some applications are emerging for higher temperatures, from 600 °C to over 1000 °C, using central receiver technology.

Global CSP market growth remains modest and on current trends may not reach levels foreseen by the IEA roadmaps. Similarly, in the EU, plans to add 6 GW by 2030 are moving forward slowly for now. The development of the market relies on the design of effective auctions which can potentially reward the flexibility that the technology provides.

As a technology, over the last 10 years CSP has made big steps forward in terms of costs reduction and in established a track record as a reliable option (benefiting from the good performance of the Spanish fleet and that of some recent international projects). However to become more competitive, further standardisation in design and manufacturing can be key to attracting the levels of investment needed to bring deployment rates back on track. R&D has a major role to play in this – as shown by the PV sector, a mass-production processes can accommodate major innovations and cost cutting. Digitisation in all phases needs also be fully embraced.

EU companies working in CSP face still and growing competition, in particular from China. In the international market access to favourable project financing may be equally important to technical prowess. Measures to support EU companies in this regard may be needed.

There is a large EU market for industrial process heat in the range 150 to 400 ºC, a part of which can be addressed by concentrated solar heat systems. Although data specific to concentrated solar heat systems is not readily available (reporting is typically for solar thermal, both concentrating and non-concentrating), there has been significant cost reductions over the last decade and modest market growth. EU companies are in a good positon as technology suppliers. However challenges include: availability of space at the potential industrial locations, need for integrated system concepts customised to user load profiles and access to financing appropriate to industry needs.

In principle, concentrated solar thermal is also an option for supplying district heat systems and decreasing costs are making the technology more attractive for this.

1 Introduction

1.1 Scope and context

This report on concentrated solar power and heat is one of an annual series of reports from the Clean Energy Technology Observatory (CETO). It address technology maturity status, development and trends; value chain analysis and global market and EU positioning. It builds on previous Commission studies in this field [1]. The scope covers:

a) concentrating solar power (CSP[1]) plants that convert solar energy to electricity, and

b) concentrating solar heat (or cool) for district heating and for industrial processes (SHIP).

Thermal energy storage is often an integral part of CSP and SHIP systems and is covered here. The potential use of concentrated solar energy to drive thermochemical fuel synthesis is addressed in the CETO direct solar fuels report [2].

Up to now concentrating solar technologies have developed to a commercial scale but have played only a small role in decarbonising the energy system. Nonetheless considerable potential exists in globally and in the EU. CSP plants for electricity require high levels of steady, direct normal insolation (DNI > 1900 kWh/m2/year). This limits the range of potential locations and in Europe only southernmost areas offer suitable conditions. The two major designs used today are parabolic trough power plants and central receiver or power tower systems [3]. CSP systems comprise the following main elements: solar field (reflectors and receivers), a heat transfer and storage system, and thermal-to-electric power conversion unit. CSP can be combined with other power generation technologies, either for solar-assisted power generation or in hybrid configurations [4]. Concentrating solar thermal heat for processes primarily addresses thermal energy supply in the range 100–400ºC for industry and for district heating applications, often as part of an integrated solution with other heat sources [5, 6, 7, 8]. The DNI requirement is much less stringent than for power production. Some applications are emerging for higher temperatures, from 600ºC to over 1000°C, using central receiver technology. So although the processes are similar to CSP, the scale of the plants and the operating conditions are different. For this reason the two applications are treated separately in several sections of this report.

1.2 Methodology and Data Sources

The structure of report follows the CETO template, with three main sections, each of which foresees a series of specific topics or indicators:

a) Technology maturity status, development and trends

- technology readiness level
- installed capacity & energy production
- technology costs
- public and private RD&I funding
- patenting trends
- scientific publication trends
- assessment of R&I project developments

b) Value chain analysis: this section aims to provide an analysis of the technology value chain with regard to:

- Turnover;
- Gross Value Added;
- Environmental and socio-economic sustainability;
- EU companies and roles;

1 CSP signifies concentrated or concentrating solar power (CSP). The term solar thermal electricity (STE) is also used, but in principle includes non-concentrating systems e.g. solar chimneys or updraft tower concept.

- Employment;
- Energy intensity and labour productivity;
- EU industrial production.

c) Global markets and EU positioning

This section is intended to provide analysis, evolution and perspectives for the technology in the global market and the EU positioning, The relevant indicators are:

- Global market growth (in the last 5/10 years depending on data availability) and relevant short-to-medium term projections;
- EU market share vs third countries share, including EU market leaders and global market leaders;
- EU trade (imports, exports) and trade balance;
- Resource efficiency and dependence (in relation EU competiveness).

The report uses the following information sources

- Existing studies and reviews published by the European Commission
- Information from EU-funded research projects
- EU trade data, trade association reports, market research provider reports and others as appropriate
- JRC own review and data compilation

Details of specific sources are given in the corresponding sections.

2 Technology State of the art and future developments and trends

2.1 Technology readiness level

2.1.1 Solar Thermal Electricity

CSP/STE systems comprise the following main elements: solar field, receiver or absorber, and heat transfer system, thermal storage system, power conversion unit (heat to electricity) and balance of plant. Table 1 sets out the technology characteristics of current commercial STE systems. Parabolic trough designs are the most widely deployed up to now. Designs using dish receivers to power Stirling motors have also been proposed, but so far these have not been commercialised.

Several recent projects have opted for central receiver designs (also known as or solar towers), which allow a higher maximum temperature and hence increased efficiency for power generation and thermal heat storage. Since the solar field comprises many individual heliostats, it can be more easily adapted to uneven terrain. On the other hand, tower designs can be more sensitive to site climatic conditions due to attenuation of the light between the mirrors and the receiver.

Table 1. Main characteristics of commercial trough (PT) and central receiver (CR) plants.

Item	**Parabolic Trough / Fresnel Linear Reflector Designs**	**Central Receiver Designs (Solar Tower)**
Receiver	Line absorbers with high absorptivity (>95%) and low emissivity (<10%);	Metallic point receivers
Heat Transfer Fluid	Thermal oil at max. 395 °C	Molten salt or steam; max. working fluid temperatures of 570 oC
Thermal energy storage	Two-tank molten salt	
Power cycle	Rankine with superheated steam (ORC for smaller facilities)	Rankine with superheated steam
Capacity factor[2] (2050 DNI location)	27%, or greater with TES	26%, or greater with TES
Land area required	2.4 – 3.2 hectares/MW (direct area, including TES)	
Water consumption	3.5 m^3/MWh (with wet cooling[3]) [9]	
CO2 footprint	22 gCO2/kWh	

Source: JRC compilation

Hybrid PV-CSP plant design are also increasingly being considered [4]. PV systems can provide power to the ancillary systems (circulation pumps, control systems etc.), help ensure stable power output and allow the CSP part to maximise thermal heat storage for evening or night time generation. More advanced concepts (yet to be commercialised) involve recuperating heat from the PV modules in the CSP heat transfer system.

There are a wide range of options for improving the performance and cost effectiveness of CSP plants. Ultimately, higher working fluid temperatures and heat storage density are key. CSP is uniquely placed to

[2] Since the nominal power output of the generator in a CSP plant is fixed, the capacity factor can be increased by increasing the size of the solar field and adding a thermal storage system to allow generation after sundown; values up to 60% are proposed.

[3] Dry cooling designs can reportedly reduce the water consumption by 90%, but with a 10% cost penalty on the electricity generated due to the higher plant costs and reduced cycle efficiency.

provide high input temperatures in the solar receiver, but use of molten salt-based systems seems limited by factors such as corrosion problems with high temperature ternary salts. Hence the interest in various air, supercritical CO2 or liquid metal concepts, coupled with high temperature and economic heat storage methods.

The SET-Plan implementation working group (IWG) developed a comprehensive implementation plan "the Initiative for Global Leadership in Concentrated Solar Power" (2017). In addition to setting out detailed targets for R&D and demonstration activities, the plan stressed the need for at least three first–of-a-kind (FOAK) commercial-scale plants in Europe. The IWG, supported by the Horizon STE project, is preparing an update of this plan (draft March 2022) but this is not yet publicly available.

In parallel the Clean Energy Transition Partnership (CETP brings together national and regional R&I programmes in European Member States and Associated Countries) has developed a series of Strategic Research and Innovation Agendas (SRIAs), including concentrated solar technology. The overall CETP report (November 2020) [10] identified the following targets for CSP

- reduce electricity cost (LCOE) to become more competitive with other renewables (i.e., wind and PV) or develop hybrid solutions in combination with other technologies.
- LCOE reduction of CSP technology to 0,09 EUR/kWh in Southern Europe locations (around 2050 kWh/m2/year), without any additional constraint by 2025, targeting 0,08 EUR/kWh by 2030, providing competitive dispatchable solar power.
- Feasibility of novel material approaches via validation in lab or demonstration in relevant environment (liquid, solid, phase change materials or TCS media).
- Cheaper thermal energy storage achieving, by 2030, at least 10% of heat consumed in industrial processes in Europe delivered through concentrated solar technologies.
- Thermal energy cost ≤ 0.03 EUR/kWh for T<400ºC, small scale applications, and ≤ 0.02 EUR/kWh for T>600ºC, large scale applications.
- Demonstration of H_2 solar thermal production viability (target cost of 3 €/kg H2 by 2030).

The associated R&D needs are:

i) Central Receiver and Line-Focusing power plants with lower LCOE

- Advanced heat transfer fluids for higher working temperatures.
- Receivers for average solar fluxes > 1MW/m^2 and T >600ºC, with efficiency > 85%.
- Self-calibrating and cheaper heliostats, below 90 EUR/m2 (installed).
- Components with lower maintenance cost and longer life time (see CC challenge 5, circularity).
- High precision heliostat field and automated control for long focal distance and/or high temperature applications up to 1200°C.
- Innovative plant configurations achieving better use of solar energy resource
- Cheaper line-focusing collector designs.

ii) Reliable and cost-effective medium and high-temperature thermal storage systems.

- Thermal storage systems and materials for T < 550°C with improved cost effectiveness.
- Suitable thermal storage systems and materials for T > 600ºC and T > 750ºC, with investment cost < 15 EUR/kWh.
- Suitable and cost-effective PCM thermal storage systems for 200–300ºC.
- Cost-effective and highly autonomous medium- and high temperature systems for industrial solar heat applications.
- Autonomous and smart solar fields, providing solutions to satisfy 24h operation.
- Collector designs with investment cost <400 EUR/m^2 for small line-focus solar fields.
- More reliable and cost-effective receiver tubes (even non-evacuated).

- Cost-effective polygeneration solar systems, including hybridization by integrating power generation from the produced industrial heat or from waste heat (see CC challenge 5, circularity).

iii) Turbo-machinery developed for specific conditions of solar thermal power plants.

- Specific steam turbine developed for CSP applications (< 200MW).
- Supercritical CO2 turbomachinery.

2.1.2 Concentrated Solar for Industrial Processes

CSHIP typically use parabolic trough or linear Fresnel technology, aiming to provide process heat in the range 100 to 400oC. Systems are generally at the MW level of size (1 MW is approximately 1500 m^2 aperture).

The R&I needs for CHSIP are also addressed by the CETP, under the challenge "Towards 100% renewable industrial heating" [10]. This was based on detailed input from the sector on "Cost-effective and highly autonomous medium- and high temperature systems for industrial solar heat applications". The targets are:

- Application of concentrated solar to industrial processes/synergies of the solar thermal industry, with existing industrial processes achieving a 10% of heat consumed in industrial processes in Europe delivered through concentrated solar technologies, by 2030.
- Thermal energy cost ≤ 0.03 EUR/kWh (thermal) for temperatures lower than 400ºC, in small scale applications.
- Thermal energy cost ≤ 0.02 EUR/kWh (thermal) for temperatures higher than 600ºC, in large scale applications.

The specific R&I challenges are:

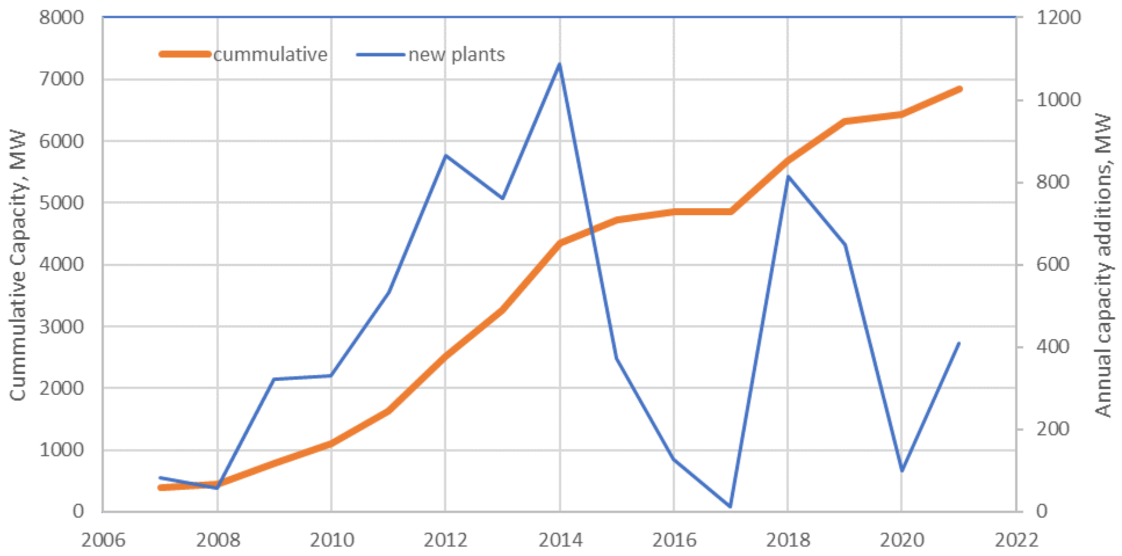
- Autonomous and smart solar fields, e.g. fail detection software, active & predictive management of the solar plant.
- Suitable high temperature (600-1000°C) receivers adapted to industrial processes
- Specific investment cost lower than 400 EUR/m^2 of solar collector surface for small line-focus solar fields
- Materials for increased robustness and durability
- More reliable and cost-effective receiver tubes (even non-evacuated)
- Low melting point heat transfer fluids to reduce operating costs
- Solutions to satisfy 24h operation
- Development of software tools for predictive design and test a solar plant in an industrial environment
- Materials and functional materials for increased robustness, efficiency and durability
- Hybridization by integrating power generation from the produced industrial heat or from waste heat

2.2 Installed Energy Capacity, Generation/Production and Outlook

The worldwide capacity of CSP power plants is approximately 6.5 GW (end 2021), with a further 1.4 GW under construction [11]. As shown in Figure 1, the sector has had modest growth over the last 15 years, but with significant variations in the annual new installations. At the end of 2021 there were 83 operational plants in 11 countries. Spain has the largest fleet, followed by USA and China (**Figure 2**).

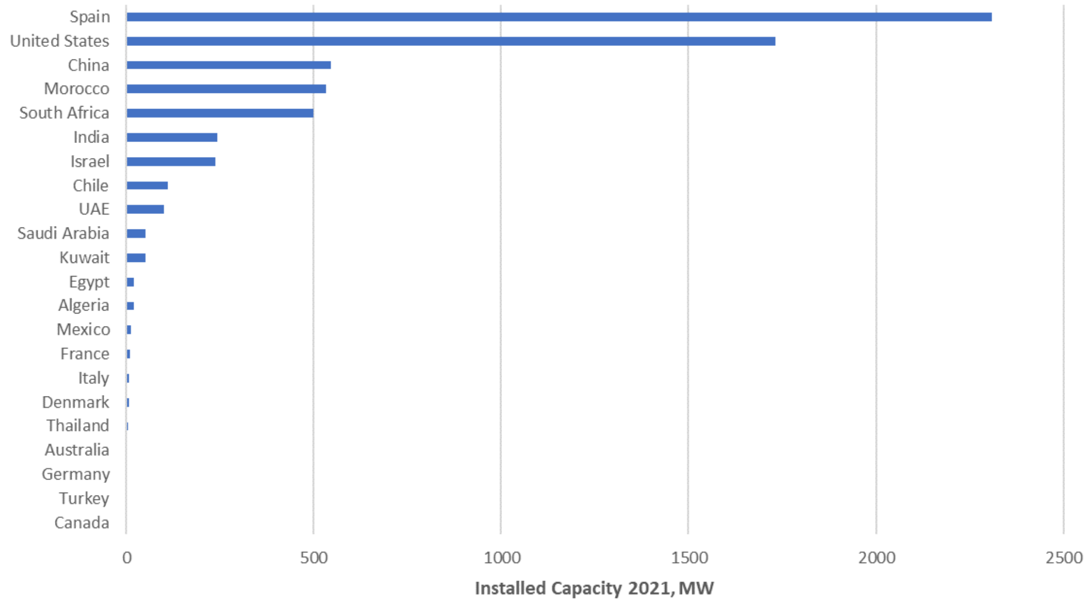
The next two years should see completion of a set of major projects in the UAE (Noor Energy 1 / DEWA IV: 100MW tower, three 200MW trough and a CSP-PV hybrid project). In South Africa, the Redstone plant is due to become operational in 2023, while Botswana is planning 200 MW (2 CSP plants). The Chinese provinces of Gansu, Qinghai and Jilin has pipeline of 11 projects totalling 1.1 GW scheduled for completion by 2024. Also the province of Xinjiang has announced a 1.3 GW of CSP.

Figure 1. Development of global CSP capacity



Source: CSPGuru/SolarPACES data base and JRC elaboration

Figure 2 Breakdown of CSP plants by country



Source: CSPGuru/SolarPACES data base and JRC elaboration

In the medium to long term, the IEA envisages a modest role for CSP, with installed capacity rising to 60 GW by 2030 and 267 GW by 2040 under its sustainable development scenario. The more recent (2021) Net Zero by 2050 scenario is more ambitious with 204 TWh (approximately 80 GW) from CSP in 2030, implying an average annual capacity growth of 31% 2020 to 2030. As this corresponds to ~6.7 GW of new capacity every year, CSP deployment is not currently aligned with the Net Zero Scenario [12].

The main CSP markets are expected to be in the Middle East and Asia-Pacific regions, particularly in China and India. For Europe, the IEA SDS scenario foresees only modest capacity increases to 2050 when installed capacity would amount to 14 GW, providing about 1% (45 TWh) of its electricity [13]. The IRENA ReMAP global analysis [14] is more ambitious, with a 2050 scenario including 633 GW of CSP (contributing 3.7% of electricity generation).

The EU's current CSP capacity is 2.4 GW. Almost all this is in Spain, where 45 plants of 50 MW size were installed in the period 2009-2013. The National Energy and Climate Plans (NECPs) for 2030 indicate the addition another 6.2 GW. The total installed capacities would then be Spain, 7.3 GW, Italy 0.88 GW, Greece, 0.1 GW, Cyprus, 0.05 GW, Portugal, 0.3 GW). Spain's planned renewables auction in October 2022 includes 220 MW earmarked for solar thermal projects with six hours of storage. The plants may be combined with biomass, bioliquids and photovoltaic capacity. To help further develop the European market and the CSP industrial sector, the Horizon STE Project (funded under H2020) is supporting an Initiative for Global Leadership in Solar Thermal Electricity and acts as competence centre of the SET-Plan STE Implementation Working Group. It is analysing the situation in several European countries, such as Spain, Italy, Germany, Turkey, France, the Netherlands, Luxembourg and Portugal, etc., with companies involved in CSP and/or as potential off-takers. The overall assessment report is expected to be released in autumn 2002.

For CSHIP, market data is not so readily available. It is a sub-sector of the solar thermal heat, which is typically divided into three application areas: buildings, industrial processes (SHIP), and district heating. From a top-down perspective in 2019 Eurostat data shows that the EU's heat energy consumption was 43,992 ktoe (514 TWh) of which 14,725 ktoe (171 TWh) were for industry. The solar thermal sector only provided a small fraction of this 17 ktoe (0.2 TWh). The contribution of concentrated solar to this is however not known.

At the global level, IRENA is now collecting data for large scale solar thermal plants, including CHSIP [15]. Analysing the same data, Krueger et al [16] identify more than 900 commercial solar heat projects with more than 50 m2 collector area, in 21 countries. A proportion of these use concentrated solar heat. Their data show a growth for CSHIP in 2020 of 14 632 m2 aperture (almost all parabolic trough). The 2 largest new plants were 3 MWth (Turkey) and 3.9 MWth (China).

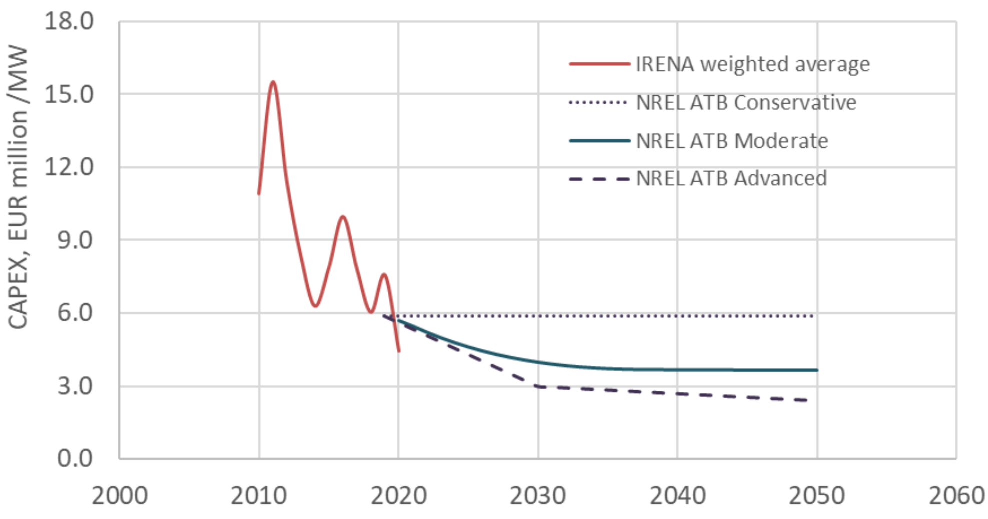
Looking to future scenarios, Solar Heat Europe's roadmap [17] foresees that SHIP and DH applications will grow to 280 GWth and 140 GWth respectively by 2030.

2.3 Technology Cost – Present and Potential Future Trends

2.3.1 Concentrating Solar Power (Solar Thermal Electricity)

Figure 3 shows the trend in CAPEX (CAPital Expenditure) for large CSP plants, both historic (based on IRENA data [18, 19]) and projections from the US NREL Annual Technology Baseline 2022 [20], which provides 3 technology scenarios: conservative with no change in CAPEX, O&M, or capacity factor; moderate, with innovations in the power block, receiver, thermal storage, and solar field; and advanced, with higher temperature systems, and modularity in the solar field. NB These scenarios refer to solar resource class 7 with 2281 kWh/m2/y.. The last decade has seen a substantial reduction (by about 70%) and is currently about EUR 5 million/MW for a large solar tower plant with at least 8 hours thermal storage. This can translate into an LCoE of less than EUR 100 /MWh, depending on solar resource level and plant specifics.

Figure 3. Historic and future CAPEX trends for CSP plants. The IRENA data is a weighted average of different plant types.



Source: JRC elaboration based on IRENA [19] and NREL ATB [20] data.

The technology has significant scope for improvement in all areas: the solar field, the power block, high-temperature higher efficiency power cycles and thermal storage [21]. Both the EU SET Plan and US research programmes see the potential to further reduce this to a level of 3 EUR million/MW. However, with very modest global market growth, it remains a challenge to develop volume production needed to drive down costs, as has happened for wind and solar PV.

IRENA's LCEO data for 2019 (there is only very limited data for 2020) gives an average of 186 EUR/MWh, but a large spread with 5th and 95th percentiles of 95 and 304 EUR/MWh respectively. Recent auctions suggest that this average can be halved for plants currently in construction in favourable locations. It should be noted that LCOE may not reflect the market value of dispatchable CSP electricity.

2.3.2 Concentrating Solar for Heating and Cooling

Cost and LCoH data specific to CSHIP systems is scarce. Nonetheless a collaboration between the Solar Payback Project (DE) and IRENA has created a database of SHIP plant information [16, 21] but breakdown by technology is not available at the moment. Nonetheless it is reported that the CAPEX for solar district heating in Denmark fell from USD 573/kW in 2010 to USD 409/kW in 2019, and with a corresponding reduction in LCOH from USD 66 /MWh to USD 45/MWh.

In the same period the CAPEX of new European SHIP systems fell from USD 1670/kW to USD 541/kW. Kruger et al [16] report the average LCoH values for the period as follows:

- European project, T < 150oC, LCOH of USD 87 /kWh (average plant 400 kW, yield 564 kWh/m2/y.
- Global projects, 150 < T < 400oC, LCoH of USD 97/kWh (average size 334 kW, yield 654 kWh/m2/y)

2.4 Public R&I funding

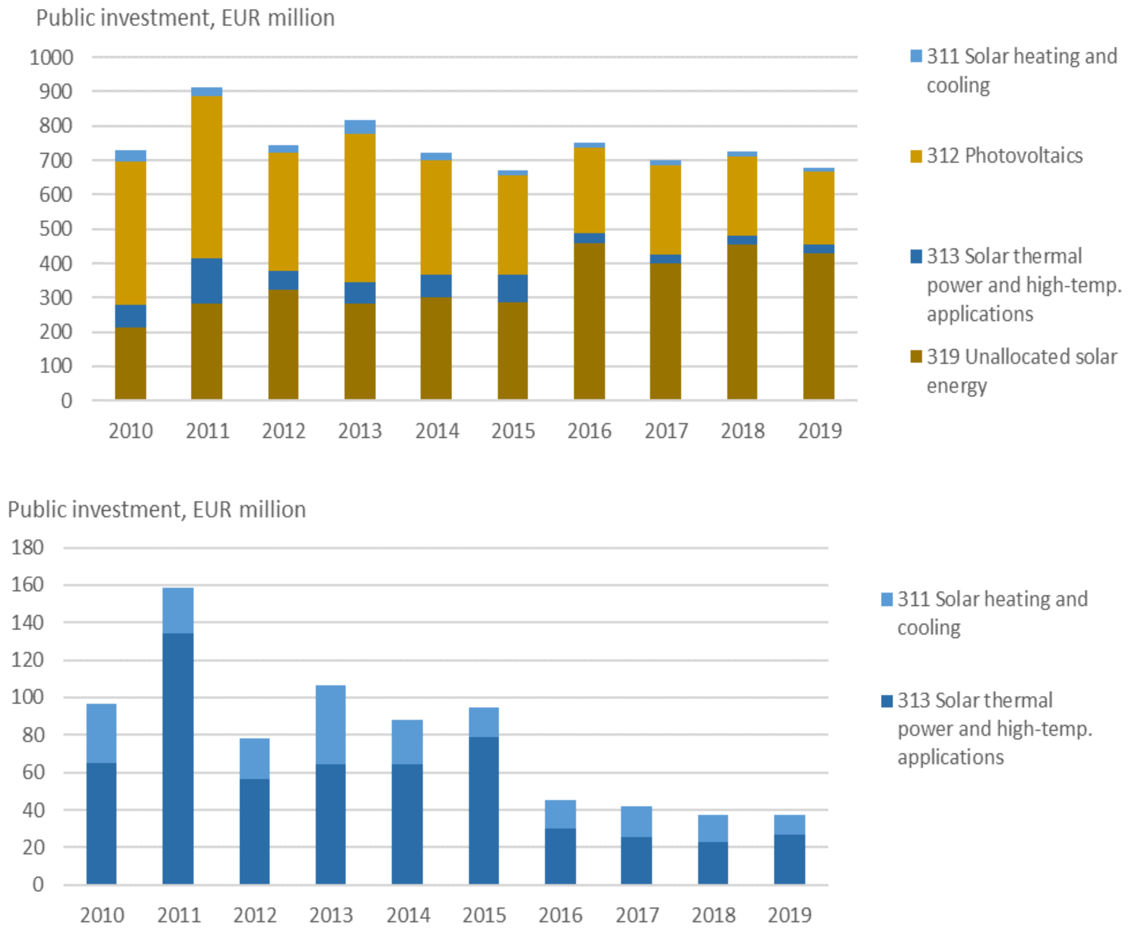
2.4.1 IEA Global Public RD&D data

The IEA collects annual data on public R&D investments for clean energy technologies from its members [22]. This data is used here to assess the situation for CSP. The relevant reporting fields are:

- 3.1 Solar energy
- 311 Solar heating and cooling
- 3.1.2 Photovoltaics
- 313 Solar thermal power and high-temp. applications
- 319 Unallocated solar energy

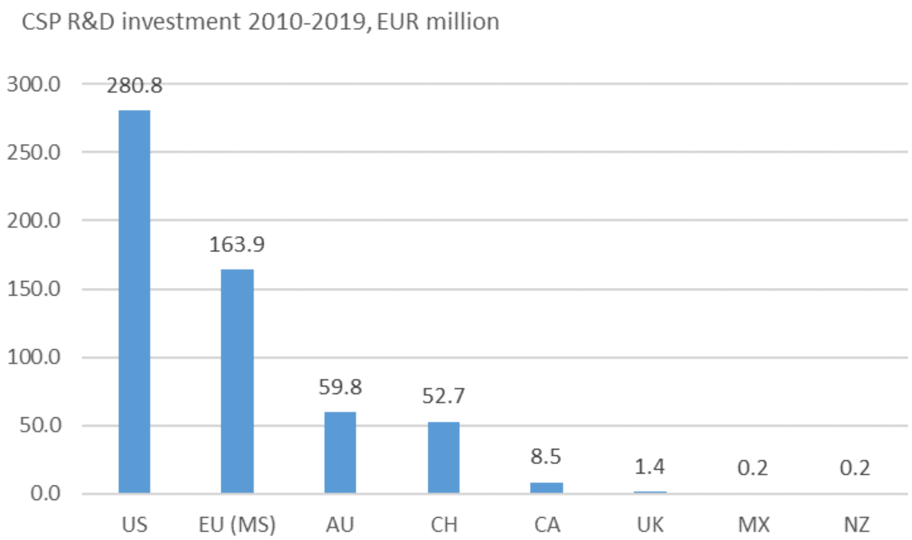
However not all countries provide disaggregated data and some data is missing for specific countries and years (e.g. Italy and Spain have not reported on this aspect recently). Notwithstanding these caveats, the available data has been examined. Figure 4a shows that for solar energy as a whole, the RD&D budgets were stable at current values from 2010 to 2019, so a decrease in real terms. In terms of the breakdown, fewer countries are reporting in detail and the "unallocated" field accounted for over 50% of the total in 2019. Since the share of CSP (3.1.3 solar thermal power and high temperature applications) is small, Figure 4b shows the data in detail and confirm a steady decrease in pubic RDD funding. Turning to the country and regional breakdown, Figure 5 shows the US as largest funder, followed by the EU (to the extent available) and other major countries. The US is largest funder, followed by the EU, then Australia and China. Within the EU, Germany and France are the largest funders according to this dataset, as shown in Figure 6.

Figure 4. Data reported to the IEA for public RD&D funding for solar energy over the period 2010 to 2019 for a) all four sub-fields and b) just the solar heating and cooling and CSP. NB the annual totals were the current values as reported.



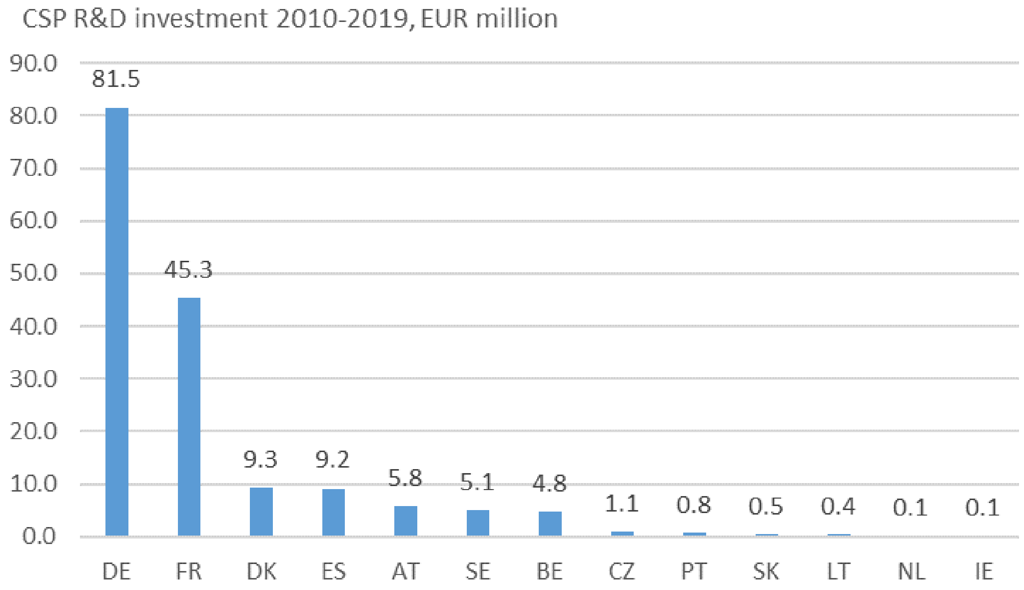
Source: JRC based on IEA [22]

Figure 5. Public RD&D funding by the EU and major economies for solar thermal power and high temperature applications over the period 2010 to 2019. NB the totals are current values, as reported.



Source: JRC based on IEA [22]

Figure 6. Public RD&D funding reported to IEA by EU countries (without Italy) for solar thermal power and high temperature applications over the period 2010 to 2019 NB the totals are current values, as reported.



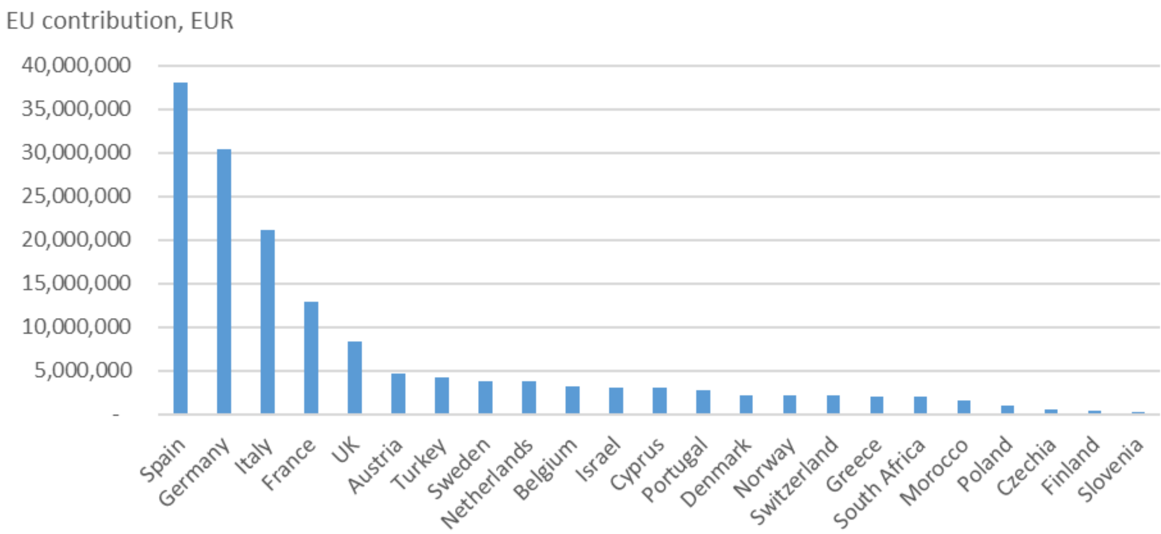
Source: JRC based on IEA [22]

2.4.2 EU Horizon Funding

Under Horizon 2020 (2014-2020) the EU has supported 56 CSP and CSH-related projects with approximately EUR 186 m contribution. The total budget for these projects is in excess of EUR 200m. CSP and coordination projects accounted for 81% of the grants, with the remainder for CSH. Under Horizon Europe four projects have been funded so far, for just over EUR 9 million.

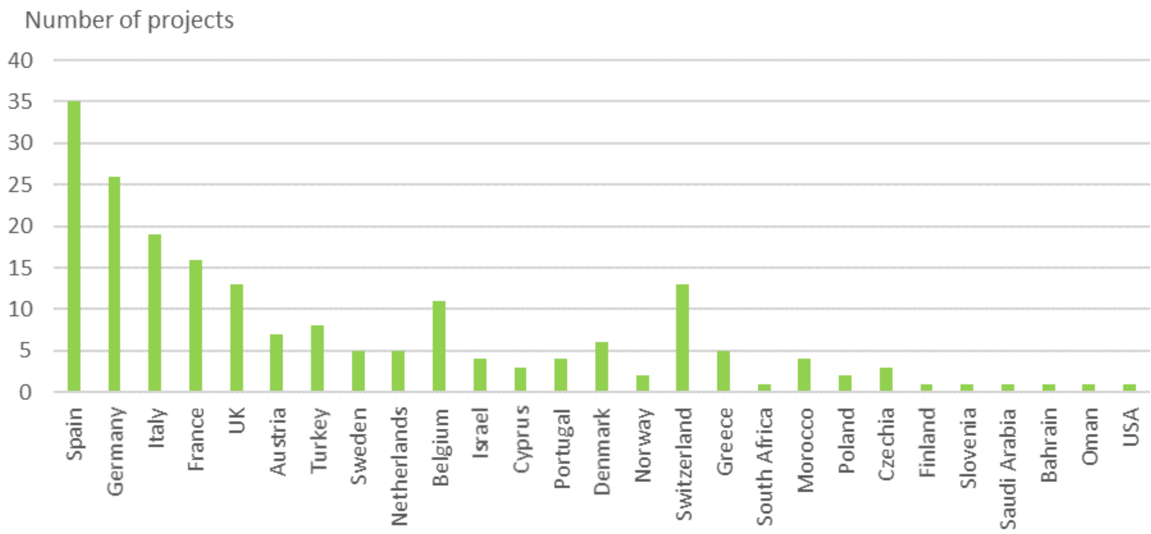
For CSP, **Figure 7** shows the total EU contribution per country. Spain, Germany, Italy and France are the main beneficiaries. Figure 8 shows the number of projects per country, and indicates a similar ranking.

Figure 7. H2020 funding for CSP projects, 2014-2020



Source: JRC TIM analysis of Cordis data

Figure 8. Number of H2020 CSP projects per country, H2020, 2014-2020.

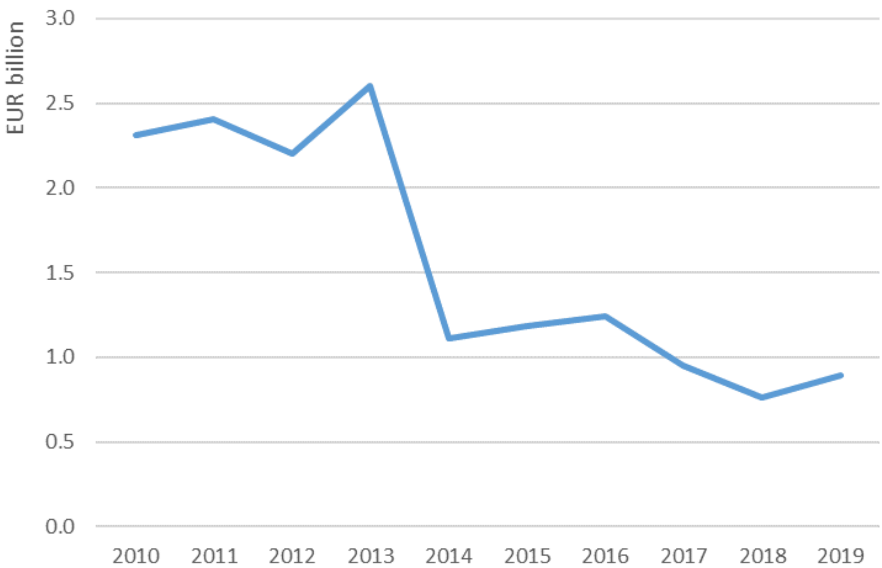


Source: JRC TIM analysis of Cordis data

2.5 Private R&D funding

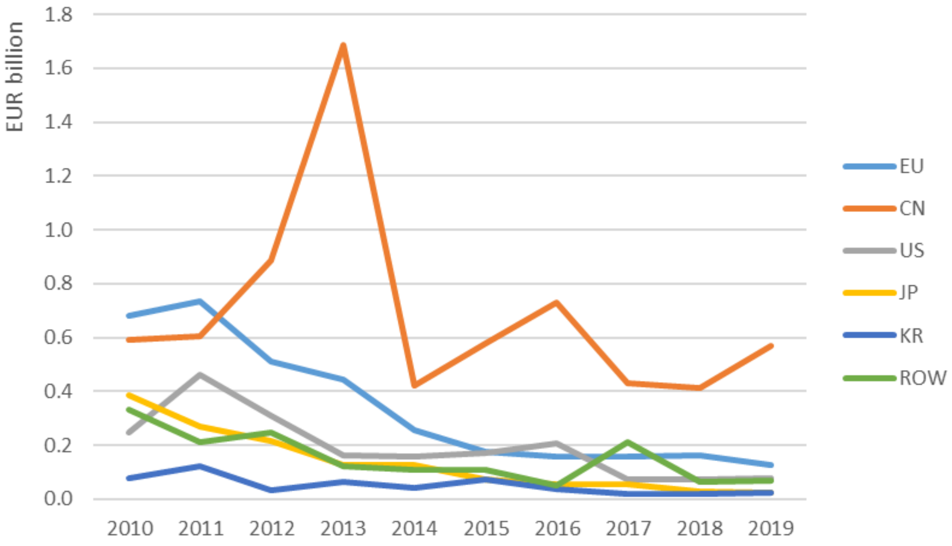
In the absence of technology specific data, estimates of private R&I rely the use of patenting data as a proxy [23, 24] and should be interpreted with caution. As evident from **Figure 9**, the data indicate a marked decline in investments over the last decade. **Figure 10** shows the trends at country/regional level. The decline is apparent for all the major economies including the EU. For China the overall decrease is less pronounced, although the data shows considerable fluctuations. **Table 2** and **Table 3** show the top organisations for R&D investments globally and for the EU respectively.

Figure 9. Overall trend in annual R&D investments by private companies, using patenting data as proxy.



Source: JRC analysis

Figure 10. Trends in annual R&D investments for the EU and major economies, using patenting data as proxy.



Source: JRC analysis

Table 2. Top organisations globally for R&D investments 2015-2019, using patenting data as proxy.

Organisation	**Country**
Ningbo High Tech Zone Shidai Energy Technology Co Ltd	CN
Binzhou Armour Force Solar Technology Co., Ltd.	CN
Solarcity Corp	US
Sunpower Corporation	US
Zhejiang Supcon Solar Energy Technology Co Ltd	CN
Huaneng Clean Energy Research Institute	CN
China State Construction Co Ltd	CN
Guangdong Fivestar Solar Energy Co Ltd	CN
Zhejiang Jiadele Solar Energy Co Ltd	CN
Nantong Jinyang Solar Technology Co Ltd	CN
Nextracker Inc	US
Wuhu Sunrise New Building Materials Technology Co., Ltd.	CN
Ningbo Hi Tech Zone Shidai Energy Technology Co Ltd	CN
Absolicon Solar Collector Ab	EU
Zhejiang Hongle Solar Thermal Tech Co Ltd	CN
Chengdu Aonengpu Technology Co., Ltd.	CN

Organisation	Country
Alion Energy Inc	US
Kabushiki Kaisha Toyoda Jidoshokki Seisakusho	JP
Synhelion Sa	CH
Robert Bosch Gmbh	EU

Source JRC analysis

Table 3. Top EU organisations for R&D investments 2015-2019, using patenting data as proxy

Organisation	Country
Absolicon Solar Collector Ab	SE
Robert Bosch Gmbh	DE
Viessmann Werke Gmbh Co Kg	DE
Cockerill Maintenance Ingenierie Sa	BE
Azelio Ab	SE
Eni Spa	IT
Solarisfloat Lda	PT
Magaldi Power Spa	IT
Abengoa Solar New Technologies Sa	ES
A Raymond Et Cie	FR
Jenaer Glaswerk Schott Gen	DE
Cordivari Srl	IT
Kraftanlagen Munchen Gmbh	DE
Heliac Aps	DK
Soltec Innovations Sl	ES
Meccanotecnica Umbra Spa	IT
Ripasso Energy Ab	SE
Nexans	FR
Sabic Global Technologies Bv	NL
Esdec Bv	NL

Source: JRC analysis

2.6 Venture Capital Investments

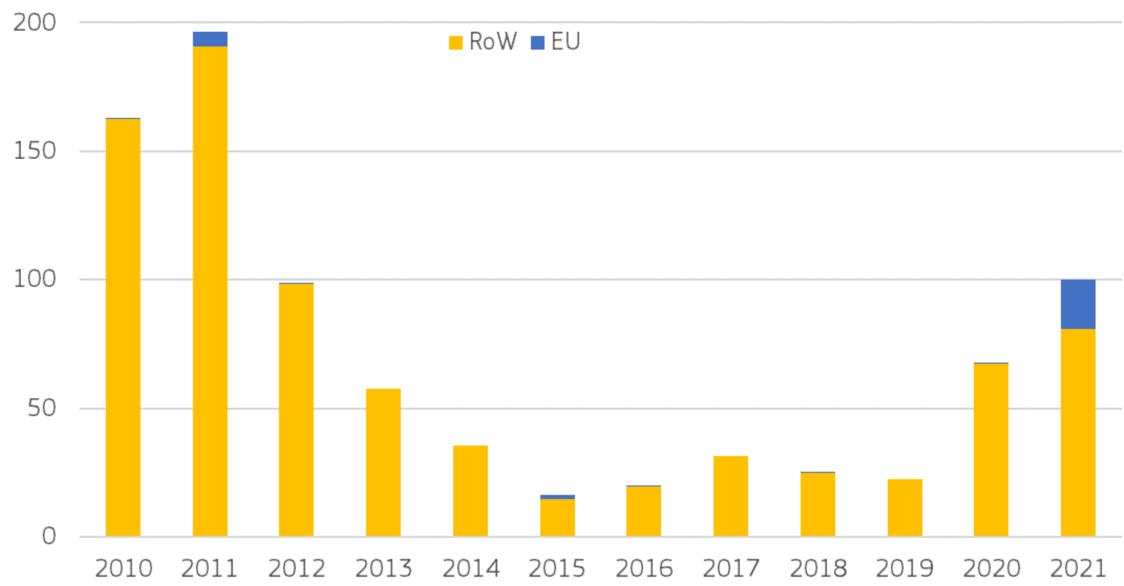
There is no data specifically on private annual R&D investment for CSP at EU or global scale. An analysis has been made of venture capital (VC) investments over the considered period, using the JRC's CINDECS methodology [25] using the Pitchbook data service. An initial search for the period 2010 to 2021 identified 77 VCs[4] and 57 deals above EUR 1 m.

Figure 11 shows the annual total of VC investments from 2010 to 2021, split between the EU and the RoW. Overall the investments dropped from a peak of almost EUR 200 m in 2021 to approximately in EUR 10 m by the middle of the decade. These investments were dominated by the US company Brightsource Energy that received EUR 369 m, but ceased trading in 2017 when its technology was sold to a Chinese company. Recently there has been an increase in investments, which reached EUR 100 m in 2021.

The investments in EU VC companies is only a small fraction of the global total and has been sporadic, with deals only in 2011, 2015 and 2021. The most recent of these involve Heliac, a Danish company developing a concentrating solar system supplying hot water to district heating systems (so a process application rather than one for solar thermal electricity. Figure 12 shows the country breakdown for the same period. The US dominates, in particular for the 2010 to 2015 with the Brightsource Energy investment mentioned above. Brightsource also tops the list of companies, as shown in Figure 13. The 2nd company is US-based Heliogen and has recently raised investments for a very high temperature (> 700oC) solar tower concept and targeting process heat applications.

Overall, it appears that VC investments are not playing a major role in technology development, which largely remains in the hands of the established component suppliers and engineering companies.

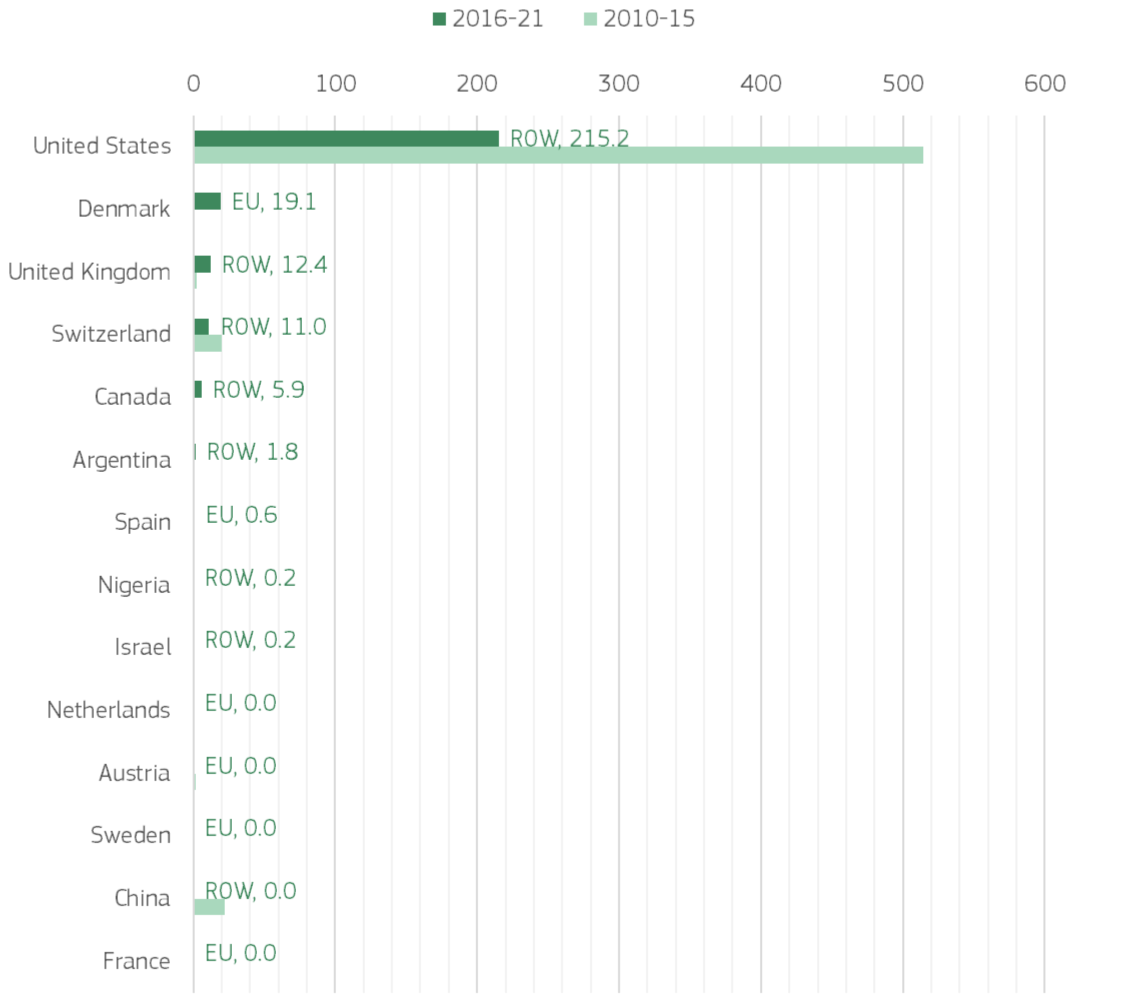
Figure 11. Total VC investments (EUR million) by region for concentrating solar power and heat**.**



Source: JRC based on Pitchbook

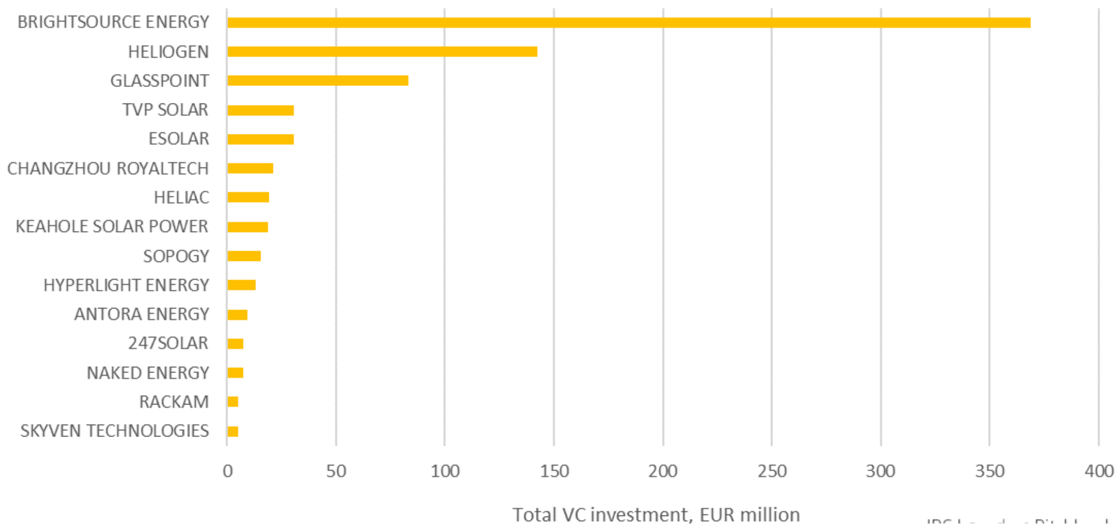
[4] VC companies include pre-venture companies and venture capital companies. Pre-venture companies are companies that have received angel or seed funding, or are less than 2 years old and have not received funding. Venture Capital companies are companies that have, at some point, been part of the portfolio of a venture capital firm. Investments reflect investments in all active companies over that period irrespectively of their current status (defunct, publicly held, privately held with no VC backing, merged or acquired, no longer actively tracked in the data source…). Early stages investments include: Grants, Angel & Seed (i.e. Pre-Seed, Accelerator/Incubator, Angel and Seed) and Early stage VC (Series A and B). Later stages investments include: Late Stage VC (and undisclosed series), Small M&A and Growth Private Equity. Small M&A refers to the acquisition by an operating company of a non-control stake in a pre-venture or VC company. Later stages investments do not include: buyout private equity and public investments.

Figure 12. Concentrating solar power and heat – top countries for total VC investments (EUR million)



Source: JRC based on Pitchbook

Figure 13. Concentrating solar power and heat – top companies for VC investments 2010 to 2021



Source: JRC based on Pitchbook

Active innovators are distributed among several major economic players. The US (1st) relies on a strong base of venture capital companies, while all identified innovators in Japan (2nd) are corporations. Together, they host 42 % of active companies and are followed by a group of 8 countries hosting even shares of the following 40 %. Overall, Europe accounts for 32 % of identified companies (essentially in Germany, Italy and France). Its share of active venture capital companies is however lower than in the rest of the world, and in the US in particular.

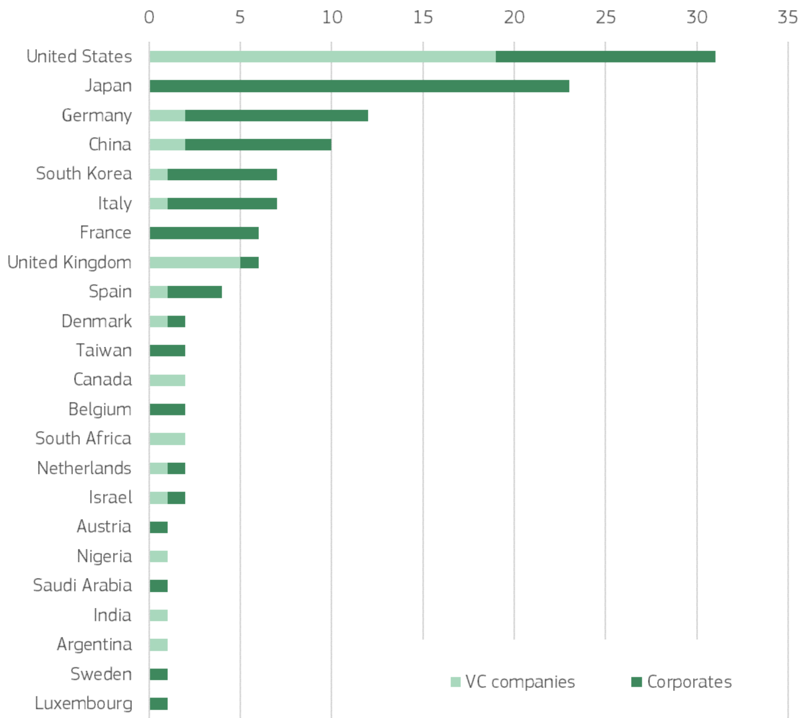
Global venture capital investment realised since 2016 are lower (- 53 %) than those of the previous 2010-15 period, essentially due to collapsing later stages investments in the US. Following a long period of low activity, higher levels of investments seem to confirm a renewed interest from investors but are still far from competing with largest deals seen in the early 2010s (such as in the US company BRIGHTSOURCE ENERGY) and remain concentrated in a few companies.

Global early stage investments are limited, essentially consist of grants and do not show a discernible trend. They have however increased over the 2016-21 period (+21 %, amounting to € 90 million), mainly supported by investments in the US based company HELIOGEN in 2020.

Via Danish firm HELIAC, the EU attracted 7 % of early stages investments (in the form of a grant in 2021). This highlights a gap with the rest of the world (mostly the US and UK) where a few early ventures leveraged angel, seed and early VC money in combination with or in place of grants.

The recent increase of global later stages investments (which account for € 176 million over the current period) is only due to a few larger later stage deals in 2020 and 21. Despite lower investment levels (-70 % as compared to previous period), the US leads the race, accounting for 77 % of later stages investments over the 2016-21. The sole US based company HELIOGEN attracted 59 % of all later stages investments, with new investors such as Arcelor Mittal's Corporate Venture Capital. The EU only accounts for 8% of later stage investments over the period (essentially in Danish company HELIAC).

Figure 14. Number of innovating companies 2016-2020 by country.



Source: JRC compilation of sources

2.7 Patenting trends

The analysis followed the established JRC methodology [26] and considered the Patstat (European Patent Office) data for the period to 2019[5] The CPC codes relevant to CSP[6] are:

- Y02E 10/40 - Solar thermal energy
- Y02E 10/44 - Heat exchange systems
- Y02E 10/46 - Conversion of thermal power into mechanical power
- Y02E 10/47 - Mountings or tracking

The filings are classified as follows:

- Patent families (or inventions) measure the inventive activity. Patent families include all documents relevant to a distinct invention (e.g. applications to multiple authorities), thus preventing multiple counting. A fraction of the family is allocated to each applicant and relevant technology.
- High-value inventions (or high-value patent families) refer to patent families that include patent applications filed in more than one patent office.
- Granted patent families represent the share of granted applications in one family. The share is then associated to the fractional counts in the family.

Globally, inventions per year fell from a peak of 1490 in 2012 to 1089 in 2019[7]. Looking at the most recent data (2017 – 2019) in **Figure 15**, China is dominant in terms of overall numbers. However for high value inventions the picture changes and the EU is leader, although its output has been decreasing since 2012 (**Figure 16**). Also of note is that in 2019 China moved into 2nd place for high value patents, passing the USA. **Figure 17** shows the listing of top individual countries for high value patents over 2017 to 2019. Germany, France, Spain and Italy take places 3 to 6 respectively, behind the USA and China.

Concerning the technical scope of the inventions, the CPC codes offer only a limited breakdown. As shown in **Table 4**, mountings or tracking is the largest category, followed by heat exchange systems and thermal to mechanical power conversion. For over one third no details are given.

Table 5 shows the top organisations for high value inventions over 2017 to 2019, and includes five EU organisations. Absolicon (SE) is overall leader. It produces solar concentrators based on parallel trough technology, mainly for industrial applications in sectors such as food and beverage, brewery, textile, pulp and paper, chemicals, district heating, desalination, pharmaceuticals, tea, dairy and mining.

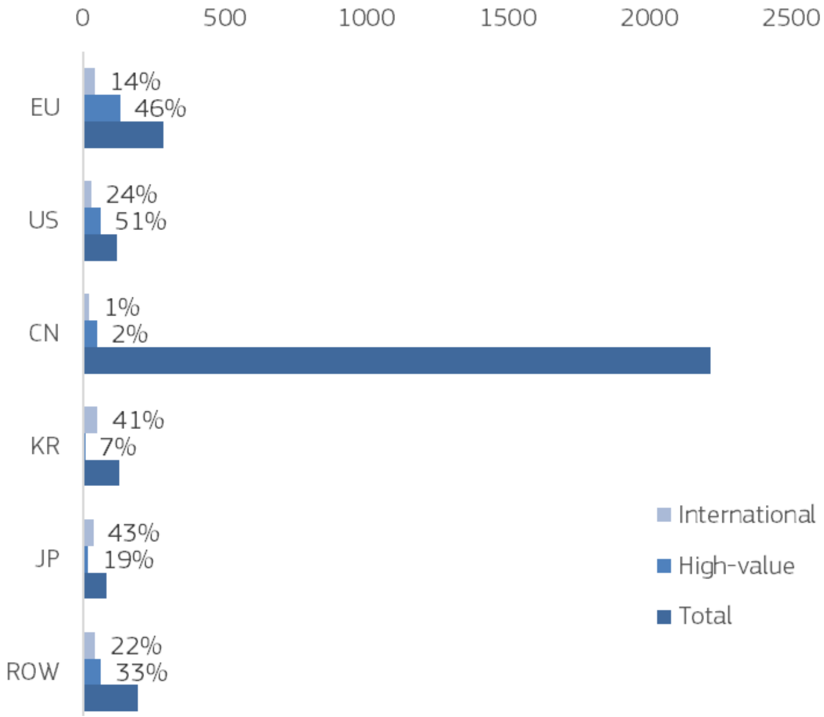
Table 4. Breakdown global CSP patents by CPC sub-technology code

Sub-Technology Area	2017	2018	2019	Total
Thermal to Mechanical Power Conversion	19	10	6	35
Heat exchange systems	29	14	13	56
Mountings or tracking	53	41	34	128
Not specified	38	43	31	112
Grand Total	139	108	85	332

Source JRC analysis

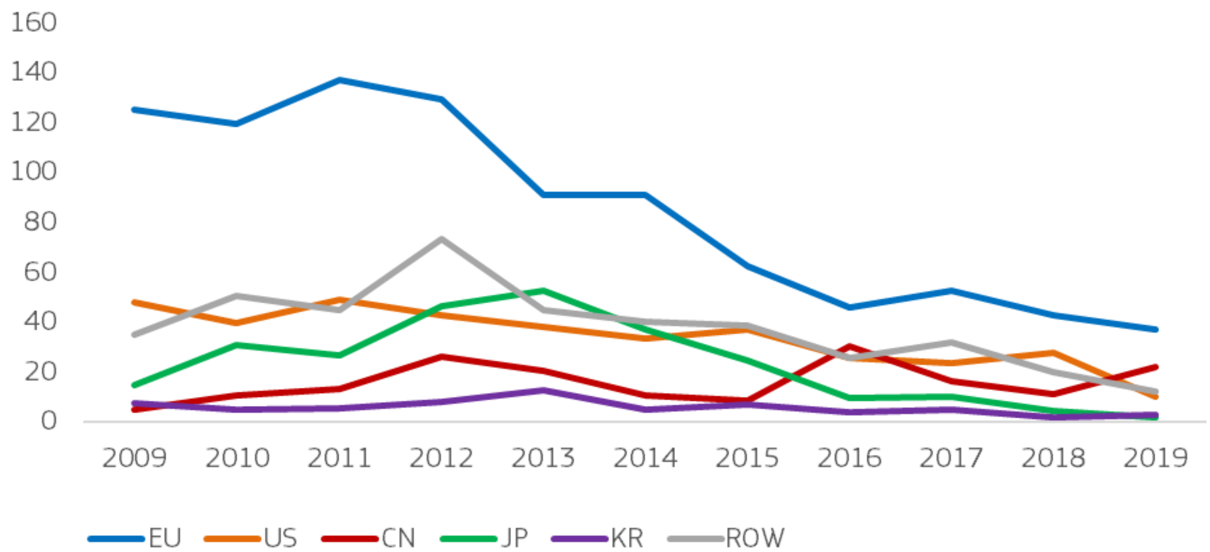
[5] JRC update: May 2022 – for details on the processing methodology see [23, 24, 26]).
[6] Previously CSP had specific CPC categories for tower, trough and Fresnel designs, but these have been discontinued.
[7] Since the analysis for the CPR 2020 SWD, the Chinese patents have been re-categorised, leading to a substantially lower total count (50% less).

Figure 15. Number of inventions and international and high value shares for 2017-2019.



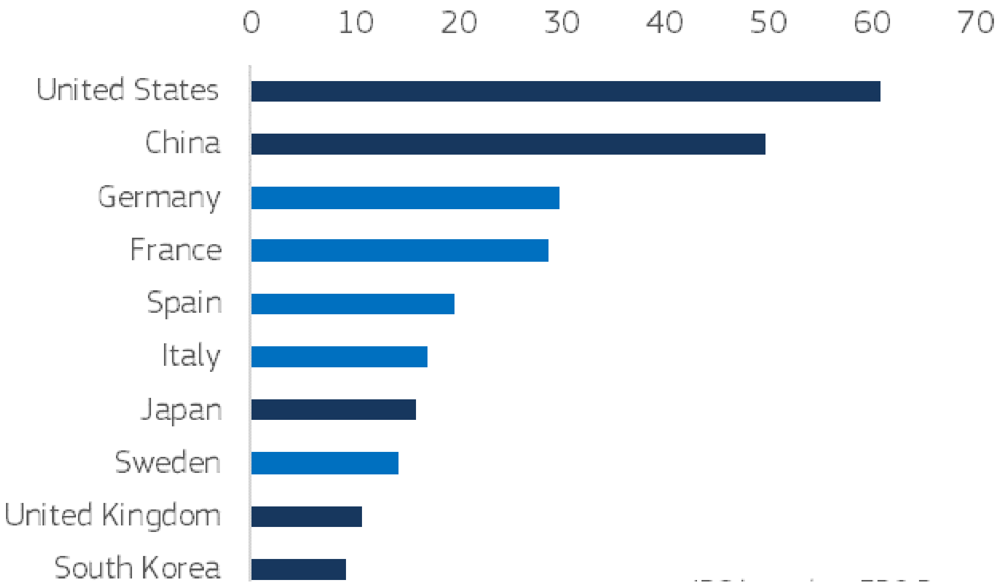
Source: JRC based on EPO Patstat

Figure 16. High value inventions for CSP from 2009 to 2019.



Source: JRC based on EPO Patstat

Figure 17. Top 10 countries for high value inventions 2017-2019



Source: JRC based on EPO Patstat

Table 5. Top 10 entities for high-value inventions 2017 -2019

Entity	Inventions 2017-2019
Absolicon Solar Collector Ab (SE)	5
Nextracker Inc (US)	5
Vestel Elektronik Sanayi Ve Ticaret As (TR)	4
Ojjo Inc (US)	4
Soltec Innovations Sl (ES)	3
Ripasso Energy Ab (SE)	3
Azelio Ab (SE)	3
National Technology Engineering Solutions Of Sandia Llc (US)	3
Magaldi Power Spa (IT)	3
Glasspoint Solar Inc (US)	3

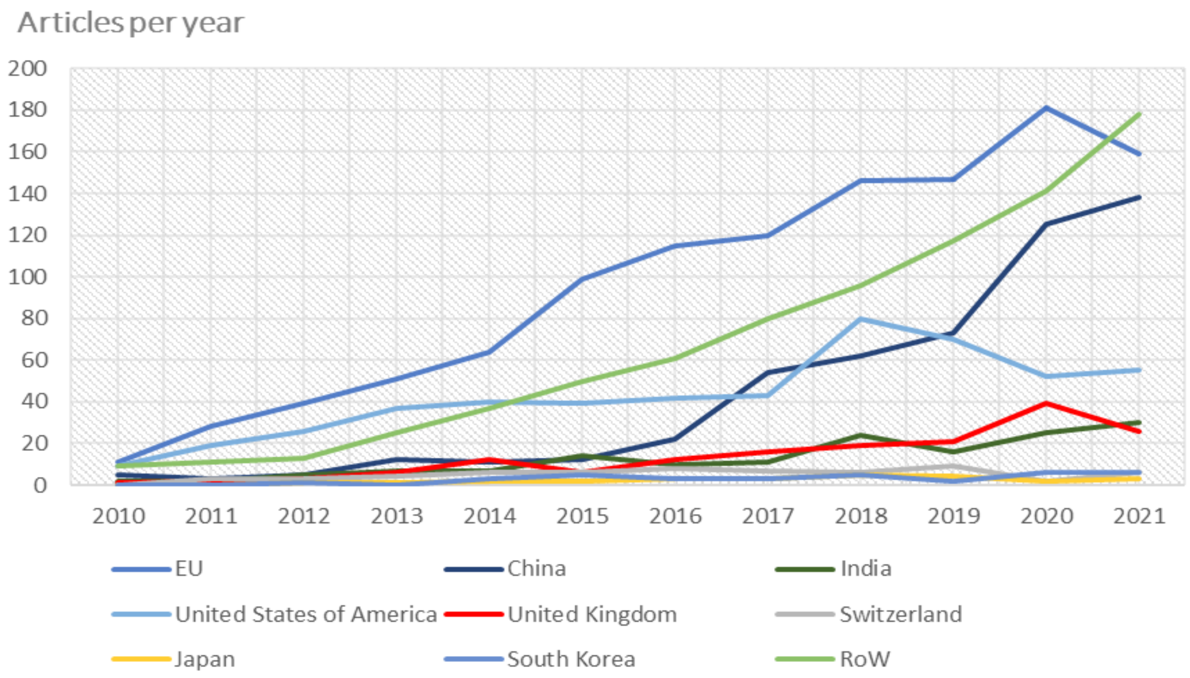
Source: JRC analysis

2.8 Level of Scientific Publications

The JRC's Technology Innovation Monitor system (TIM) was used to analyse the scientific articles published over the period 2010 to 2022. The search string "topic:("concentrated solar power" OR "solar thermal electricity" OR ("CSP" AND "solar")) AND class:article" retrieved 2,765 articles.

Figure 18 shows the time trend for the EU and leading countries and regions. The EU and USA have traditionally been a leader in this field, but in the last five years China and other countries (RoW) have emerged as significant contributors.

Figure 18. Trend in scientific publications on CSP and CSH for the leadings countries and regions



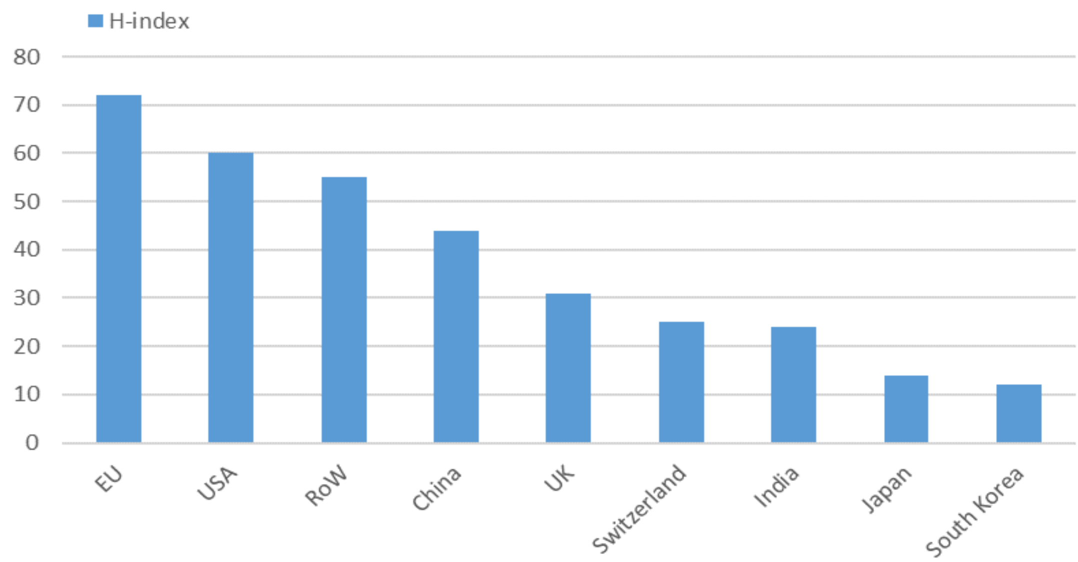
Source: JRC analysis of TIM data

For impact analysis, TIM provides three parameters:

- Highly cited papers (top 10% cited normalised per year and field)
- Field Weighed citation impact (FWCI) is calculated as the average number of citations the article receive normalised per year and per field.
- h-index of a country: the largest number h such that at least h articles in that country for that topic were cited at least h times each.

Figure 19 ranks the h-index values for the major country and country groupings based on the whole data set (2010-2022). The EU has the highest score, followed by USA, RoW and China. Table 6 shows the ranking of EU countries, which Spain leads in terms of both number of articles and h-index. In terms of % highly cited articles and the FWCI parameter, Austria and the Netherlands are highest, although their output in this field is much lower.

Figure 19. h-value scores for scientific publications on concentrating solar power for the leadings countries and regions



Source: JRC TIM analysis

Table 6. Leading EU countries for CSP scientific articles

Country/region	Total articles	% highly cited	FWCI	H-index
EU	1165	18%	1.41	72
Spain	434	22%	1.47	53
Germany	256	16%	1.57	44
Italy	225	23%	1.59	39
France	159	16%	1.20	30
Portugal	58	3%	0.85	15
Austria	29	28%	1.64	15
Sweden	28	18%	1.37	13
Denmark	24	42%	2.45	13
Greece	23	13%	1.12	10
Belgium	18	11%	1.41	12
Netherlands	17	24%	2.53	11
Finland	17	0%	0.97	9
Cyprus	12	8%	0.84	7

Source: JRC TIM analysis

2.9 Impact and Trends of EU-supported Research and Innovation

2.9.1 EU R&D

2.9.1.1 Horizon 2020 and Horizon Europe

Under H2020 the EU supported 56 projects in several different calls and topics. Annex 1 provides a listing of the projects and most relevant details. The overall breakdown in terms of technical area and funding instruments is shown in **Table 7**. Almost all the projects are completed, with 7 still running. It is noted that the SET-Plan implementation working group (IWG) has been a detailed evaluation of technology progress for the update of the implementation plan (draft March 2022) but this is not yet publicly available.

Table 7. Breakdown of concentrated solar projects in Horizon 2002

Sector and Funding Instruments	**EC Grant [EUR]**	**Number of Projects**
Thermal Energy Storage	19,868,089	9
IA	13,557,625	1
MSCA	1,266,311	6
RIA	4,994,153	1
SME	50,000	1
Solar Thermal Electricity	107,988,071	30
CSA	999,656	1
ERC	4,424,020	2
IA	52,939,054	7
MSCA	754,150	3
RIA	45,975,206	9
SME	2,895,985	8
Process Heat	24,649,248	8
IA	13,815,765	2
RIA	6,865,224	2
SME	3,968,259	4
H&C buildings	4,049,384	2
RIA	3,999,384	1
SME	50,000	1
General/Coordination	19,623,005	5

Sector and Funding Instruments	**EC Grant [EUR]**	**Number of Projects**
CSA	10,520,374	4
RIA	9,102,631	1
Desalination	10,045,215	2
IA	9,995,215	1
SME	50,000	1
Grand Total	186,223,011	56

Source: JRC elaboration of Cordis data

A further source of EU support to installations of innovative renewable energy technology and carbon capture and storage is via funds available from ETS allowances. Under the previous NER300 financing instrument (managed jointly by the European Commission, the European Investment Bank and the EU Member States) only one CSP project has been funded (although several applications were approved but then failed to find matching investments). The MINOS CSP project is to install and operate a 50 MW plant in Crete. It is in progress and expected to become operational in 2024, after delays related to the COVID pandemic. The main technology provider is the Chinese company COSIN Solar (formerly Supcon).

Under the Innovation Fund (successor to NER-300), the DECARBOMALT project is being funded to build a solar thermal heating plant, heat pumps and a storage facility to provide renewable heat to a malt production process in Croatia. The overall relevant costs are EUR 7.5 million with a grant contribution of approximately EUR 5 million. Details of the solar thermal technology are not available at time of writing.

Also to note, the Plataforma Solar De Almería (PSA), which in the past was financed by DLR, then CIEMAT and the Spanish Government and now is transferred to the EU.

2.9.2 Other European and International Activities

2.9.2.1 CSP ERA-NET

ERA-NET is an EU funding instrument designed to support public-public partnerships on R&I. Over the period 2014-2018 the SOLAR-ERA.NET network funded both PV and CSP, with five CSP projects. This represented a total financing of approximately EUR 6.7 million. Since 2019 CSP has its own dedicated CSP ERA-NET. The first call lead to six projects being funded (total funding EUR 9.3 million, total costs EUR 13.2 million) – see **Table 8**. A further call was launched in October 2021, with 5 full proposals received. Details of the funded projects should be available mid-2022.

2.9.2.2 EERA JP-CSP

The European Energy Research Association launched a CSP Joint Programme in 2011. The objective is to integrate and coordinate the scientific collaboration among the leading European research institutions in CSP in order to contribute to the achievement of the SET-Plan targets. EERA-CSP provides information on the R&D projects in which its members are involved. It has been proactive in developing CSP-related input to the Clean Energy Technology Partnership [10], in particular the R&D objectives discussed in section 2.2 above.

Table 8. Projects funded under the CSP ERANET 1st call (2020/21).

Title	Scope
European Parabolic Trough with Molten Salt (EuroPaTMoS)	European expertise and testing infrastructure for parabolic trough (PTC) with molten salt (MS), to accelerate transfer of technology from R&D to commercial deployment
Advanced thermocline concepts for thermal energy storage for CSP (NEWCLINE)	cost efficient thermal storage system able to reduce capital costs up to 40%
INNOvative SOLar micro-TES with high-POWER density (InnoSolPower)	demonstrate a novel concept of an efficient, low-cost, low temperature, high energy density micro-thermal energy storage (μTES) for CSP
High performance parabolic trough collector and innovative silicone fluid for CSP power plants.(Si-CO)	Techno-economically demonstrate a new optimized and large-scale parabolic trough collector (Si-PTC) design that operates using HELISOL®XLP at 430ºC, a silicone based heat transfer fluid (Si-HTF).
Thermal Energy Storage for On-demand Solar Trigeneration (TES4Trig)	unifying the strategies for CSP into a single innovative CCHP system driven by solar parabolic trough collectors (PTCs), based on the integration of the Organic Rankine Cycle (ORC) and Ejector Cooling Cycle (ECC) with a cost-effective TES system.
Techno-economical evaluation of different thermal energy storage concepts for CSP plants (CSPplus)	develop a new tool capable of fully identify, develop, and compare new storage concepts in an easy manner, providing a reliable and cost-effective solution based on the specific conditions of each possible scenario

Source: JRC elaboration of CSP ERANET data

2.9.2.3 Member State National Programmes

The proposed update to the SET-Plan Implementation Plan for CSP notes the support to CSP in the following EU Member state programmes

- German Energy Research Framework Programme
- Federal Ministry for Economic Affairs and Energy (Germany)
- Helmholtz Program on Renewables (Germany)
- Italian Electric System Research program (2022-2024)
- Support from CDTI to technological development and industrial innovation (Spain)
- Support/grants from MICINN to research activities (Spain)
- Greek R&D Framework Programme (2021-2027)
- Grants from Research Promotion Foundation (RESTART) and other structural funds (Cyprus)
- Support/grants from National and Regional funding Portugal2030 / Alentejo2030 to R&D activities (Portugal)
- Italian Electric System Research Program (2022-2024)

2.9.2.4 IEA Technology Collaboration Programme

- The IEA oversees a technology collaboration programme for Solar Power and Chemical Energy Systems called SolarPACES. It reports to the Working Party on Renewable Energy Technologies (REWP). Currently SolarPACES has 19 members: Australia, Austria, Brazil, Chile, China, European Commission, France, Germany, Greece, Israel, Italy, Mexico, Morocco, Republic of Korea, South

Africa, Spain, Switzerland, UAE and USA. European organisations play a very prominent role, providing the chair and five Operating Agents.

- Also the IEA Solar Heating & Cooling Technology Collaboration Programme promotes the use of all aspects of solar thermal energy, including concentrating soiar heat and cooling.

2.9.2.5 US Sunshot Programme

The US Department of Energy Sunshot programme includes 2030 targets for CSP that recognise two distinct roles for CSP plants in the electricity market:

- $0.10 /kWh for peaker plants with no more than six hours of energy storage
- $0.05 /kWh for baseload plants with a minimum of 12 hours of energy storage

Gen3 CSP is the DoE's program for an innovative CSP system with thermal energy storage capable of providing heat at greater than 700 °C. A Brayton cycle is considered the likely successor to the current steam Rankine cycle due to its potential for high efficiency. Initially three heat transfer pathways were investigated: solid: sand-like particles, new molten salts and supercritical CO2. Based on the results, the DOE has decided to focus on the solid particle solution. Deciding factors included: fewer components needed, less complex to operate, fewer high-cost materials to transfer the thermal energy, and a capability to be used for temperatures greater than 800 °C. It has awarded Sandia national lab a grant to develop a multi-megawatt-thermal CSP test facility with a falling-particle receiver system, 6 hours of thermal storage, and using sCO2 or air as working fluid at more than 700°C

The DOE Solar Energy Technology Office also runs a Solar Desalination Prize (2020) to accelerate the development of low-cost desalination systems that use solar-thermal power to produce clean water from salt water.

2.9.2.6 China

In 2009 the Ministries of Science and Technology (MOST), of Finance and of Education, the State-owned Assets Supervision and Administration Commission of the State Council, the All China Federation of Trade Unions and China Development Bank established the Chinese National Solar Thermal Energy Alliance as a non-profit membership organisation. Its aim is to lead R&D innovation and promote the solar thermal development and application under the guidance of MOST. This has led to strong growth in R&D activities, and Chinese organisations are now leaders in terms of number of scientific publications and of patents.

In parallel, China has developed a series of commercial scale demonstration projects. A capacity of 1.35 GW was included in the 1st round, for a FiT of 1.15 RMB/kWh (approximately 0.17 EUR/kWh). Nine plants totalling 550 MW were completed by the 2021 deadline. A second round of development projects (11 plants, 100 MW each) are now in progress, to be completed by end 2024. Also production capabilities for key equipment have been developed and these are proving themselves competitive internationally. The Chinese company COSIN Solar (formerly Supcon) is the equipment supplier to the Minos CSP plant in Crete, a project supported by NER-300.

2.9.2.7 Other countries

Other non-European countries with significant research publications in 2019 are India (17), Australia (15), South Africa (9), Morocco (7), United Arab Emirates (7), Chile (6), Pakistan (6), Brazil (5) and Malaysia (5).

Morocco stands out for its demonstration plants. The IRSEN Green Energy Park at Ben Guerir hosted the pilot plant for the H2020 ORC-Plus project. The Ouarzazate complex includes a 400 kW demo of an innovative US solar tower technology (called 24/7), which uses a hot air cycle (T_{max} over 900oC), thermal storage and a Brayton turbine.

3 Value chain Analysis

3.1 Turnover

In the absence of publicly available, market-based data, the JRC estimates the current global market for CSP at approximately EUR 6 billion (assuming 500 MW annual installations and an existing park of 6 GW that incurs fixed and variable OPerational Expenditure - OPEX – costs).

3.2 Gross value added

No data available at time of writing.

3.3 Environmental and Socio-economic Sustainability

The following Table 9 summarises the data available on various aspects of sustainability, following the CETO model.

Table 9. CETO summary table for environmental and socio-economic sustainability

Parameter/Indicator	**Input**
Environmental Parameters/Indicators:	
LCA standards, PEFCR or best practice, LCI databases	No sector-specific guidelines or databases, but LCA typically performed to ISO 14040 and ISO 14044 standards
GHG emissions	Most studies arrive at values well below 40 gCO2eqv/kWh and with an energy payback time of less than 1 year [27, 28]. The H2020 PreFlexMS project [29] estimated 24.3 gCO2eqv/kWh for a 100 MW central tower receiver with 8 hours storage in a location with 2,900 $W/m^2/a$. The emission associated with the construction and operation phases are similar. Recycling of materials at end of life was credited with some negative emissions.
Energy balance	Studies give an energy payback time of less than 1 year [27]
Ecosystem and biodiversity impact	No studies have been located so far regarding methodologies for assessing impact of CSP on biodiversity or on the natural environment. For central receiver plants, some US environmental groups raised concerns about the potential impact of concentrated light beams on wildlife
Water use	3.5 m3/MWh (in operation, with wet cooling) Dry cooling designs can reportedly reduce the water consumption by 90%, but with a 10% cost penalty on the electricity generated due to the higher plant costs and reduced cycle efficiency
Air quality	For operation, no known issues
Land use	CSP: 2.4 – 3.2 hectares/MW (direct area, including TES)
Soil health	Potentially relevant to the area covered by the solar
Hazardous materials	Not directly in installed systems but checks needed for the component supply chain e.g. REACH materials
Economic Parameters/Indicators:	

Parameter/Indicator	Input
LCC standards or best practices	Not known
Cost of energy	See section 2.3
Critical raw materials	CSP plants do not use (or do not significantly use) materials from the EU's critical raw materials list. The technology does use of silver for mirrors in the solar field.
Resource efficiency and recycling	The H2020 PreFlexMS project [29] notes that recycling of materials at end of life was credited with some negative emissions.
Industry viability and expansion potential	Yes, see markets section
Trade impacts	Yes, see markets section
Market demand	Yes, see markets section
Technology lock-in/innovation lock-out	No dominant technology or technology provider
Tech-specific permitting requirements	No information
Sustainability certification schemes	No information
Social Parameters/Indicators:	
S-LCA standard or best practice	No information
Health	No technology specific issues
Public acceptance	Yes, instances of planning permission issues: environmental concerns, also regarding high intensity solar beams (glare, danger to birds)
Education opportunities and needs	No specific information
Employment and conditions	IRENA reports that the CSP provides 34,000 jobs, of which approximately 5000 in Europe [30]. More detailed breakdown is not available.
Contribution to GDP	No information
Rural development impact	Can provide local jobs in rural areas
Industrial transition impact	Yes
Affordable energy access (SDG7)	Yes, CSP can contribute

Parameter/Indicator	Input
Safety and (cyber)security	No technology-specific information available at this point in time
Energy security	CSP and CSHIP can contribute by replacing fossil imports
Food security	No technology specific information available
Responsible material sourcing	No technology-specific requirements for EU REGULATION (EU) 2017/821

Source: JRC compilation

3.4 Role of EU Companies

Leading CSP technology companies include Abengoa (Spain), BrightSource Energy (US), Aalborg CSP (Denmark), Cosin Solar (China), TSK Flagsol (Germany), Cobra Energia (Spain), Torresol Energy (Spain), Acciona Energy (Spain), Siemens (Germany). Ener-T International (Israel), Flabeg FE (Germany), Ingeteam Power Technology (Spain), Rioglass (Belgium), Sener (Spain). The European trade association ESTELA lists 49 organisations with activities are spread over 9 EU countries. There is a very strong Spanish presence.

The last five years have seen the emergence of Chinese suppliers, engineering companies and finance houses as major players in the market. Nonetheless European companies continue to play an important role in the latest international developments, both for overall plant engineering as well as for specialised solar field components (Rioglass, Flabeg, TSK Flagsol). Siemens is a major supplier of the steam turbine power block.

3.5 Employment in value chain

IRENA reports that the CSP provided 79 000 jobs globally in 2021, of which approximately 59 000 in China and 5 200 in the EU [30]. The EU value is more or less unchanged from 2019.

It is noted that the solar heat and cool sector as a whole provided 769 000 jobs (of which 19 000 in the EU), but the fraction in concentrated solar heat is not reported (and likely to be small).

A breakdown in terms of jobs per value chain segment is not available. Also there no EUR'ObservRE socio-economic data for this sector.

3.6 Energy intensity /labour productivity

No data has been found on energy intensity (units of energy per unit of GDP/sector turnover) or productivity data.

3.7 EU production Data (Annual production values)

There is no Prodcom code that specifically addresses CSP/CSHIP plants. This probably reflects small size of the market and the fact that it involves a mix of technologies and components: reflectors, solar absorbers/ receivers, heat transfer & storage equipment, steam boilers and the steam turbine & generator sets[8].

[8] ProdCom item 841919 "Instantaneous or storage water heaters, non-electric (excl. instantaneous gas water heaters and boilers or water heaters for central heating)" refers to solar thermal heating for use in buildings.

4 EU position and Global competitiveness

4.1 Global & EU market leaders

EU companies have traditionally been leaders in all aspects of CSP technology and project development. A recent trend is the emergence of Chinese organisations as international project developers (e.g. Shanghai Electric) and technology providers (e.g. COSIN Solar, formerly Supcon Solar).

A stakeholder consultation with the ESTELA in May 2022 provided a series of relevant observations, which are summarised as follows:

- Development of the EU market for CSP relies on the design of effective auctions which can potentially reward the flexibility that the technology provides.
- Need for appropriate financial schemes for the construction of CSP plants.
- Underline the potential to supply low, medium and high temperature industrial heat, and in long term perspective, contribute to production of the new fuels.
- A main challenge is the different energy policy in each Member State, leading to uneven development and deployment of the technology across EU.
- Another challenge is national market protection in Middle East and Asia, notably China. Latest CST auctions announced in the regions favoured national companies and impeded EU industry from competing. It is essential that the funding conditions available to European developers be comparable to those already available to developers outside Europe.

The Horizon STE Project is supporting an Initiative for Global Leadership in Solar Thermal Electricity is expected to release its analysis of industry and markets in in several European countries in autumn 2022.

4.2 Trade

No detailed data on trade for CSP equipment and services has been located up to now. However, in terms of the global annual market it is likely that trade represents a significant share (>50%) since most commercial projects are developed in countries other than those of the main technology suppliers (EU, China).

In its input paper to the Strategic Research and Innovation Agenda of the Clean Energy Transition Partnership for Horizon Europe, the EU CSP industry foresees a conservative 50% share in the future developments up to 2030. Given the IEA estimate of 60 GW worldwide installed to that year, this could mean a business market of around EUR 100 billion.

4.3 Resources efficiency and dependence in relation to EU competitiveness

The EU industry associated with CSP and CSHIP is relatively small and not known to use any imported materials subject to restrictions in terms of supply and availability.

5 Conclusions

Global CSP market growth remains modest and on current trends may not reach levels foreseen by the current IEA roadmaps. Similarly in the EU, plans to add 6 GW by 2030 are moving forward slowly for now. As also noted by industry stakeholders, the development of the EU market relies on the design of effective auctions which can potentially reward the flexibility that the technology provides.

As a technology, over the last 10 years CSP has made big steps forward in terms of costs reduction and established a track record as a reliable option, benefiting from the good performance of the Spanish fleet and that of some recent international projects. The current geo-political situation may favour CSP both as a baseload or evening peak power generator.

However to become more competitive, further standardisation in design and manufacturing can be key to attracting the levels of investment needed to bring deployment rates back on track. R&D has a major role to play in this – as shown by the PV sector, a mass-production processes can accommodate major innovations and cost cutting. Digitisation in all production phases needs also to be fully embraced.

EU companies working in CSP face still and growing competition, in particular from China. In the international market access to favourable project financing may be equally important to technical prowess. Measures to support EU companies in this regard may be needed.

Concerning advanced design (temperatures above 700 °C), the EU continues to pursue several options at R&D level, while the USA is now focussing on air-particle systems. The EU may need to consider a structured approach to getting to a first-of-a-kind (FOAK) plant based on one design concept.

There is a large EU market for industrial process heat in the range 150 – 400 °C, a part of which can be addressed by concentrated solar heat systems. Although data specific to concentrated solar heat systems is not readily available (reporting is typically for solar thermal, both concentrating and non-concentrating), there has been significant cost reductions over the last decade and modest market growth. EU companies are in a good positon as technology suppliers. However challenges include: availability of space at the potential industrial locations, need for integrated system concepts customised to user load profiles and access to financing appropriate to industry needs.

In principle, concentrated solar thermal is also an option for supplying district heat systems. Decreasing costs are making the technology also more attractive for this application.

References

1. Taylor, N., Solar Thermal Electricity Technology Development Report 2020, EUR 30501 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-27268-7, doi:10.2760/76672, JRC123158.

2. Taylor, N. et al., Clean energy Technology Observatory: Direct Solar Fuels in the European Union - 2022 Status Report on Technology Development, Trends, Value Chains and Markets, EUR, European Commission, 2022, ISBN 978-92-79-XXXXX-X, doi:10.2760/XXXXX), JRCXXXXXX.

3. DLR, Solar thermal power plants; Heat, electricity and fuels from concentrated solar power, 2021

4. Xing Ju, Chao Xu*, Yangqing Hu, Xue Han, Gaosheng Wei, Xiaoze Du, A review on the development of photovoltaic/concentrated solar power (PVCSP) hybrid systems, Solar Energy Materials & Solar Cells 161 (2017) 305–327

5. Matthias Rehfeldt & Tobias Fleiter & Felipe Toro, A bottom-up estimation of the heating and cooling demand in European industry, Energy Efficiency (2018) 11:1057–1082

6. Ravi Kumar, Krishna Chaitanya, Sendhil Kumar Natarajan, Solar thermal energy technologies and its applications for process heating and power generation - A review, Journal of Cleaner Production 282 (2021) 125296

7. C.A. Schoeneberger, C.A. McMillan, P. Kurup, S. Akar, R. Margolis, E. Masanet Solar for industrial process heat: A review of technologies, analysis, approaches, and potential applications in the United States, Energy 206 (2020) 118083

8. Colin McMillan, William Xi, Jingyi Zhang , Eric Masanet, Parthiv Kurup , Carrie Schoeneberger, Steven Meyers, Robert Margolis, Evaluating the economic parity of solar for industrial process heat, Solar Energy Advances 1 (2021) 100011

9. Sathaye, J., O. Lucon, A. Rahman, J. Christensen, F. Denton, J. Fujino, G. Heath, S. Kadner, M. Mirza, H. Rudnick, A. Schlaepfer, A. Shmakin, 2011: Renewable Energy in the Context of Sustainable Development. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press

10. Clean Energy Transition Partnership, SET Plan Stakeholder Groups Dialogues Summary Paper, Overview of Relevant RDI Challenges identified in the SET Plan Stakeholder Groups Dialogues in preparation of the CETP Strategic Research and Innovation Agenda, Final Version, November 2020

11. Johan Lilliestam, Richard Thonig, Chuncheng Zang, & Alina Gilmanova (2021). CSP.guru (Version 2021-07-01) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.5094290

12. IEA, Net Zero by 2050 A Roadmap for the Global Energy Sector, revised version July 2021

13. International Energy Agency, World Energy Outlook 2016

14. IRENA (2018), Global Energy Transformation: A Roadmap to 2050, IRENA, Abu Dhabi

15. IRENA (2021), Renewable Power Generation Costs in 2020, International Renewable Energy Agency, Abu Dhabi., ISBN 978-92-9260-348-9

16. Krueger at al, Status in solar Heat from concentrating Solar Systems, Proc. SolarPaCES 2021

17. Solar Heat Europe Roadmap 2021

18. IRENA, Tracking Energy Innovation Impacts Framework, 2022 (funded under H2020 grant agreement no. 899899).

19. IRENA (2022), Renewable Power Generation Costs in 2021, International Renewable Energy Agency, Abu Dhabi., ISBN 978-92-9260-452-3

20. NREL Annual Technology Baseline (ATB)

21. J. Lilliestam, Fengli Du, A. Gilmanova, M. Mehos, Zhifeng Wang, R. Thonig, Scaling Up CSP: How Long Will It Take?, Proc. SolarPACES 2021

22. IEA (2021), Energy Technology RD&D Budgets: Overview, IEA, Paris https://www.iea.org/reports/energy-technology-rdd-budgets-overview

23. A. Fiorini, A. Georgakaki, F. Pasimeni, E. Tzimas, “Monitoring R&D in Low-Carbon Energy Technologies”, EUR 28446 EN (2017), doi: 10.2760/434051,

24. Pasimeni, F., Fiorini, A., and Georgakaki, A. (2019). Assessing private R&D spending in Europe for climate change mitigation technologies via patent data. World Patent Information, 59, 101927. https://doi.org/10.1016/j.wpi.2019.101927

25. Kuokkanen, A., Georgakaki, A., Mountraki, A., Letout, S., Telsnig, T., Kapetaki, Z., Quaranta, E., Czako, V. and Pasimeni, F., European Climate Neutral Industry Competitiveness Scoreboard (CINDECS) - Annual Report 2021, EUR 31183 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-55804-0, doi:10.2760/5869, JRC129336..

26. Pasimeni, F. (2019). SQL query to increase data accuracy and completeness in PATSTAT. World Patent Information, 57, 1-7. https://doi.org/10.1016/j.wpi.2019.02.001

27. C. Lamnatou, D. Chemisana, Concentrating solar systems: Life Cycle Assessment (LCA) and environmental issues, Renewable and Sustainable Energy Reviews, Volume 78, October 2017, Pages 916-932

28. Nathanael Koa, Manuel Lorenza, Rafael Horna, Hannes Kriega, Michael Baumanna, Sustainability Assessment of Concentrated Solar Power (CSP) Tower Plants – Integrating LCA, LCC and LCWE in one Framework Procedia, CIRP 69 (2018) 395 – 400

29. Gasa G, Lopez-Roman A, Prieto C, Cabeza LF. Life Cycle Assessment (LCA) of a Concentrating Solar Power (CSP) Plant in Tower Configuration with and without Thermal Energy Storage (TES). Sustainability. 2021; 13(7):3672. https://doi.org/10.3390/su13073672

30. IRENA and ILO (2022), Renewable energy and jobs: Annual review 2022, International Renewable Energy Agency, Abu Dhabi and International Labour Organization, Geneva.

List of abbreviations and definitions

CAPEX	Capital Expenditure
CN	China
CPC	common patent
CSP	Concentrated (concentrating) Solar [thermal] Power
CSH	Concentrated (concentrating) Solar [thermal] Heat
CSHIP	Concentrated Solar Heat for Industrial Processes
CR(S)	central receiver (system), aka solar tower system
EPC	engineering, procurement and construction
ETS	Emission Trading System
EU	European Union
FiT	feed-in tariff
FOAK	First–of-a-Kind
GW	Giga Watt
HTF	heat transfer fluid
IA	Innovation Action
IEA	International Energy Agency
IRENA	International Renewables Energy Agency
ISCC	integrated solar combined cycle
IP	Implementation Plan
JP	Japan
LCoE	levelised cost of electricity
MENA	Middle East and North Africa
MSCA	Marie Skłodowska-Curie Action
OPEX	Operational Expenditure
PPA	power purchase agreement
PV	photovoltaic
RES	Renewable Energy Source
RIA	Research and Innovation Action
SET	Strategic Energy Technology
STE	solar thermal electricity
TES	thermal energy storage
TRL	Technology Readiness Level
US	United States

List of figures

List of tables

Annexes

Annex 1 Listing of H2020 and Horizon Europe Projects for CSP and CSH

Acronym	Title	CSP sub-category	Type	EC Grant	Start	End
DESOLINATION	DEmonstration of concentrated SOLar power coupled wIth advaNced desAlinaTion system in the gulf regION.	Desalination	IA	9,995,215	01/06/2021	31/05/2025
SWCSP - Solar Water	Creating sustainable fresh water from desalinating seawater using Concentrating Solar Power (CSP)	Desalination	SME	50,000	01/02/2019	31/05/2019
CSP ERANET	Joint programming actions to foster innovative CSP solutions	General/ Coordination	CSA	4,563,051	01/06/2019	31/05/2024
CST4ALL	Support To The Activities Of The Concentrated Solar Thermal Technology Area Of The Set Plan	General/ Coordination	CSA	599,529	01/10/2022	30/09/2025
CySTEM	Cyprus Solar Thermal Energy Chair for the Eastern Mediterranean	General/ Coordination	CSA	2,500,000	01/07/2015	30/06/2020
MUSTEC	Market uptake of Solar Thermal Electricity through Cooperation	General/ Coordination	CSA	2,396,526	01/10/2017	30/09/2020
NESTER	Networking for Excellence in Solar Thermal Energy Research	General/ Coordination	CSA	1,060,798	01/01/2016	31/12/2018
SFERA-III	Solar Facilities for the European Research Area - Third Phase	General/ Coordination	RIA	9,102,631	01/01/2019	31/12/2022
Innova MicroSolar	Innovative Micro Solar Heat and Power System for Domestic and Small Business Residential Buildings	H&C buildings	RIA	3,999,384	01/09/2016	31/08/2020
LIGHTHOUSE	LIGHTHOUSE: concentrated thermal solar power directly connected to the heating and cooling systems of buildings at the local	H&C buildings	SME	0,000	01/08/2016	31/01/2017

Acronym	Title	CSP sub-category	Type	EC Grant	Start	End
	level.					
helioSTEAM	A novel concentrated solar steam system for industrial applications with a high degree of pre-manufacturing at extremely low prices.	Process Heat	SME	50,000	01/07/2015	31/12/2015
HELIOtube	Inflatable solar collectors for a low cost CSP Plant with irreducibly small carbon footprint	Process Heat	SME	1,843,052	01/11/2015	31/10/2017
HyCool	Industrial Cooling through Hybrid system based on Solar Heat	Process Heat	IA	5,818,972	01/05/2018	30/04/2021
INSHIP	Integrating National Research Agendas on Solar Heat for Industrial Processes	Process Heat	RIA	2,498,661	01/01/2017	31/12/2020
Re-Deploy	Re-deployable solar boilers based on concentrating solar collecotors for ESCO type sale of thermal energy to industrial processes.	Process Heat	SME	2,025,207	01/02/2016	31/01/2019
SHIP2FAIR	Solar Heat for Industrial Process towards Food and Agro Industries Commitment in Renewables	Process Heat	IA	7,996,793	01/04/2018	31/03/2022
SOLPART	High Temperature Solar-Heated Reactors for Industrial Production of Reactive Particulates	Process Heat	RIA	4,366,563	01/01/2016	31/12/2019
TurboSol	TurboSol: Turbo-Solar Thermal Power for Industrial Drying Processes	Process Heat	SME	50,000	01/03/2018	30/06/2018
ABraytCSPfuture	Air-Brayton cycle concentrated solar power future plants via redox oxides-based structured thermochemical heat exchangers/thermal boosters	STE	RIA	2,995,458	01/11/2022	31/10/2026

Acronym	Title	CSP sub-category	Type	EC Grant	Start	End
AUTO-RST	Flexible automated manufacturing of RST Facets: High Performance Solar Reflectors for CSP industry	STE	SME	1,577,233	01/10/2019	30/09/2021
CAPTure	Competitive SolAr Power Towers – CAPTure	STE	RIA	6,104,033	01/05/2015	30/04/2020
CDRONE	Towards un-subsidised solar power – Cleandrone, the inspection and cleaning solution	STE	SME	50,000	01/06/2016	30/11/2016
CRITICAL	When Flows Turn Turbulent in the Supercritical Fluid Region	STE	ERC	1,924,020	01/09/2021	31/08/2025
DIMONTEMP	Distributed Monitoring of HTF Temperature at Solar Thermal Power Plants	STE	SME	50,000	01/02/2016	31/07/2016
EREMOZ	Effect of rare-earth doping elements on the mechanical and oxidation resistance performance of silicon carbide coated carbon fibre / zirconium carbide composites for high temperature applications	STE	MSCA	195,455	01/04/2018	17/04/2020
FOCALSTREAM	Breakthrough high performance cost competitive solar concentration system for combined heat and power generation	STE	SME	1,018,752	01/05/2016	30/04/2019
FRIENDS2	Framework of Innovation for Engineering of New Durable Solar Surfaces	STE	MSCA	346,500	01/01/2015	31/12/2018
GRIDSOL	Smart Renewable Hubs for Flexible Generation: Solar Grid Stability	STE	RIA	3,421,448	01/10/2016	30/11/2019
HELITE	High precision and performance heliostat for variable geometry fields of Thermosolar Plants	STE	SME	50,000	01/03/2016	31/08/2016
HORIZON-STE	Implementation of the Initiative for Global Leadership in Solar	STE	CSA	999,656	01/04/2019	31/03/2022

Acronym	Title	CSP sub-category	Type	EC Grant	Start	End
	Thermal Electricity					
IN-POWER	Advanced Materials technologies to QUADRUPLE the Concentrated Solar Thermal current POWER GENERATION	STE	IA	4,998,928	01/01/2017	31/12/2020
MinWaterCSP	MinWaterCSP - Minimized water consumption in CSP plants	STE	RIA	5,861,372	01/01/2016	31/12/2018
MOSAIC	MOdular high concentration SolAr Configuration	STE	RIA	5,077,734	01/12/2016	30/11/2020
MSLOOP 2.0	Molten Salt Loop 2.0: key element for the new solar thermal energy plants.	STE	IA	2,243,085	01/11/2016	31/07/2019
NEXT-CSP	High Temparature concentrated solar thermal power plan with particle receiver and direct thermal storage	STE	RIA	4,947,420	01/10/2016	31/12/2020
NEXTOWER	Advanced materials solutions for next generation high efficiency concentrated solar power (CSP) tower systems	STE	IA	4,981,304	01/01/2017	31/12/2020
OCONTSOLAR	Optimal Control of Thermal Solar Energy Systems	STE	ERC	2,500,000	01/09/2018	31/08/2023
ORC-PLUS	Organic Rankine Cycle - Prototype Link to Unit Storage	STE	IA	6,249,316	01/05/2015	30/04/2019
PEGASUS	Renewable Power Generation by Solar Particle Receiver Driven Sulphur Storage Cycle	STE	RIA	4,695,365	01/11/2016	31/10/2020
POLYPHEM	Small-Scale Solar Thermal Combined Cycle	STE	RIA	4,975,961	01/04/2018	31/03/2022
PreFlexMS	Predictable Flexible Molten Salts Solar Power Plant	STE	IA	14,362,194	01/06/2015	31/05/2018

Acronym	Title	CSP sub-category	Type	EC Grant	Start	End
RAISELIFE	Raising the Lifetime of Functional Materials for Concentrated Solar Power Technology	STE	IA	9,291,723	01/04/2016	31/03/2020
SCARABEUS	Supercritical CARbon dioxide/Alternative fluids Blends for Efficiency Upgrade of Solar power plants	STE	RIA	4,950,266	01/04/2019	31/03/2023
Small-scale CSP	Numerical and experimental analysis of a novel thermal energy storage for a small-scale concentrated solar power plant	STE	MSCA	212,195	01/06/2018	31/05/2020
SOLWARIS	Solving Water Issues for CSP Plants	STE	IA	10,812,504	01/05/2018	30/04/2022
TANKRETE	A breakthrough concrete mega tank for thermal fluids storage over 500ºC in thermal solar energy generation	STE	SME	50,000	01/05/2019	31/10/2019
TENCENT	The next generation of Hybrid Concentrating Solar Power Plants	STE	SME	50,000	01/08/2015	31/10/2015
TOPCSP	Towards Competitive, Reliable, Safe and Sustainable Concentrated Solar Power (CSP) Plants	STE	MSCA	2,576,261	01/10/2022	30/09/2026
TRANSREGEN	Portable thermal fluid regeneration system for Solar Thermal Plants	STE	SME	50,000	01/03/2015	31/08/2015
WASCOP	Water Saving for Solar Concentrated Power	STE	RIA	5,941,608	01/01/2016	31/12/2019
GLASUNTES	Innovative high temperature thermal energy storage concept for CSP plants exceeding 50% efficiency	TES	MSCA	259,558	01/05/2016	30/04/2019
HIFLEX	HIgh storage density solar power plant for FLEXible energy systems	TES	IA	13,557,625	01/09/2019	31/08/2023
HP-MOSES	Solar assisted high temperature heat pumps	TES	SME	50,000	01/05/2017	31/10/2017

Acronym	Title	CSP sub-category	Type	EC Grant	Start	End
	for molten salt energy storage applications.					
NPMSSES	Nanoparticle Enhanced Molten Salts for Solar Energy Storage	TES	MSCA	195,455	01/03/2017	28/02/2019
SESPer	Solar Energy Storage PERovskites	TES	MSCA	195,455	13/11/2017	12/11/2020
SOCRATCES	SOlar Calcium-looping integRAtion for Thermo-Chemical Energy Storage	TES	RIA	4,994,153	01/01/2018	31/12/2020
Solar-Store	Solar Powered Thermochemical Heat Storage System	TES	MSCA	195,455	01/07/2017	30/06/2019
SUNSON	Concentrated Solar energy storage at Ultra-high temperatures aNd Solid-state cONversion	TES	RIA	2,999,938	01/12/2022	31/05/2026
THERMES	A new generation high temperature phase change microemulsion for latent thermal energy storage in dual loop solar field	TES	MSCA	224,934	17/09/2019	16/09/2021
THERMOSTALL	High Performance Seasonal Solar Energy Latent Heat Thermal Storage Using Low Grade, Low Melting Temperature Metallic Alloys	TES	MSCA	195,455	01/11/2016	31/10/2018

Source: JRC compilation

).

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.