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CONCENTRATED SOLAR POWER AND SOLAR HEATING AND COOLING IN THE EUROPEAN UNION

STATUS REPORT ON TECHNOLOGY DEVELOPMENT, TRENDS, VALUE CHAINS & MARTKETS

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Contact information

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

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

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Contents

Abstract

This Clean Energy Technology Observatory report analyses the current status, development, and trends of solar thermal energy, including both concentrated solar power (CSP) and solar heat for buildings, district heating, and industrial processes. While CSP has developed to a commercial scale, up to now it has played a small role in decarbonizing the energy system, and the global market growth remains modest. The EU's progress in adding CSP capacity to the existing fleet of plants has also been slow. Targeted auctions may be needed to reward the technology's supply flexibility. Further standardization in design and manufacturing, R&D investment, and digitization are essential for CSP to become more cost-competitive and attract the needed investment to increase deployment rates. EU companies face strong competition from China, and access to project financing may be equally important to technical prowess. Solar thermal technologies for heating and cooling have a low overall market penetration and require an integrated solution, and there is a need for cost reduction to maintain competitiveness. The EU remains a technology leader in system integration, digitization, and thermal storage.

Foreword on the Clean Energy Technology Observatory

The European Commission set up the Clean Energy Technology Observatory (CETO) in 2022 to help address the complexity and multi-faced character of the transition to a climate-neutral society in Europe. The EU's ambitious energy and climate policies create a necessity to tackle the related challenges in a comprehensive manner, recognizing the important role for advanced technologies and innovation in the process.

CETO is a joint initiative of the European Commission Joint Research Centre (JRC), who run the observatory, and Directorate Generals Research and Innovation (R&I) and Energy (ENER) on the policy side. Its overall objectives are to:

- monitor the EU research and innovation activities on clean energy technologies needed for the delivery of the European Green Deal
- assess the competitiveness of the EU clean energy sector and its positioning in the global energy market
- build on existing Commission studies, relevant information & knowledge in Commission services and agencies, and the Low Carbon Energy Observatory (2015-2020)
- publish reports on the Strategic Energy Technology Plan (SET-Plan) SETIS online platform

CETO provides a repository of techno- and socio-economic data on the most relevant technologies and their integration in the energy system. It targets in particular the status and outlook for innovative solutions as well as the sustainable market uptake of both mature and inventive technologies. The project serves as primary source of data for the Commission's annual progress reports on competitiveness of clean energy technologies. It also supports the implementation of and development of EU research and innovation policy.

The observatory produces a series of annual reports addressing the following themes:

- Clean Energy Technology Status, Value Chains and Market: covering advanced biofuels, batteries, bioenergy, carbon capture utilisation and storage, concentrated solar power and heat, geothermal heat and power, heat pumps, hydropower & pumped hydropower storage, novel electricity and heat storage technologies, ocean energy, photovoltaics, renewable fuels of non-biological origin (other), renewable hydrogen, solar fuels (direct) and wind (offshore and onshore).
- Clean Energy Technology System Integration: building-related technologies, digital infrastructure for smart energy system, industrial and district heat & cold management, standalone systems, transmission and distribution technologies, smart cities and innovative energy carriers and supply for transport.
- Foresight Analysis for Future Clean Energy Technologies using Weak Signal Analysis
- Clean Energy Outlooks: Analysis and Critical Review
- System Modelling for Clean Energy Technology Scenarios
- Overall Strategic Analysis of Clean Energy Technology Sector

More details are available on the CETO web pages

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Authors

Taylor, N., JRC.C.2

Georgakaki, A., JRC.C.7

Letout, S., JRC.C.7

Kuokkanen, A., JRC.C.7

Mountraki, A. , JRC.C.7

Ince, E. , JRC.C.7

Shtjefni, D, JRC.C.7

Tattini J. , JRC.C.6

Diaz Rincon A. , JRC.C.6

Executive Summary

This report address technology maturity status, development and trends; value chain analysis and global market and EU positioning for solar thermal energy technologies and is part of the annual series of reports from the Clean Energy Technology Observatory (CETO). It covers concentrated solar for both power (CSP) generation and solar heat (or cool) for buildings, district heating and industrial processes (SHIP).

Up to now, concentrated solar technologies have developed to a commercial scale but have played only a small role in decarbonising the energy system. The two major designs used today are parabolic trough power plants and central receiver systems, both with several thermal storage sufficient to deliver power for several hours at the rated capacity. CSP can also be hybridised with other power generation technologies, in particular with photovoltaics systems. Global CSP market growth remains modest and for now it is not on track to reach in 2030 the capacity levels recommended by the IEA to be in line with the Net Zero by 2050 target. The EU has made little progress on plans to add to the existing capacity of 2.33 GW. The development of the market relies on the design of effective auctions that can potentially reward the supply flexibility that the technology provides. Spain's renewed commitment to add 2.4 GW of CSP capacity by 2030 can boost the sector.

CSP technology has achieved significant cost reductions over the last ten years and established a track record as a reliable electricity supply 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 would 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 to be fully embraced. EU companies manufacture all the components needed for CSP plants, but now face strong competition, in particular from China. In the international market, access to favourable project financing may be equally important to technical prowess.

A range of solar thermal technologies address the heating and cooling sector, where the EU's decarbonisation progress is much slower than for electricity (22.9% RES for heating in 2021 compared to 37.5% for electricity). Commercial options (including storage) are available for buildings, district heating networks and for industrial processes, although overall market penetration remains low (0.1%). The 2022 EU Solar Energy Strategy considers that solar thermal energy demand should triple by 2030.

Solar thermal heat for industrial 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. The need for high direct normal irradiance is much less stringent than for power production. Some applications of concentrated solar thermal are emerging for higher temperatures, from 600 °C to over 1000 °C, using central receiver technology.. The EU remains a technology leader and major areas of focus include system integration, digitisation and thermal storage, although research funding for all solar technologies has decreased in real terms over the last decade. The levelised cost of heat can be competitive with other conventional sources, particular in areas with good solar resource. This may be offset by the fact that solar thermal heating and cooling is often not standalone and needs to be part of an integrated solution. EU companies are in a good positon as technology suppliers. Traditionally they have supplied 90% of the EU demand, but COMEXT trade data for 2021-2022 indicate significantly increased imports, in particular from China. Further efforts on cost reduction may be needed to maintain competitiveness.

Solar heating is used in district heating and cooling systems in 264 cities and towns in Europe (approximately 5% of all such systems)). There is also a large EU market for industrial process heat in the range 150 – 400 °C. EU companies are in a good position as technology suppliers for concentrated systems. 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.

Table 1. CETO SWOT analysis for the competitiveness of CSP.

Strengths	**Weaknesses**
– Dispatchable power based on large scale thermal storage – Good operational record in the EU – Strong EU industrial expertise and world–leading R&D – No/little use of critical raw materials and high circularity potential (high level of recycling of components)	– High CAPEX – Limited capacity factor (full load hours) – lack of standardised designs – Limited sites in the EU, restricting scalability
Opportunities	**Threats**
– EU and global policy targets to decarbonise electricity generation – Growing demand for renewable electricity and for high-temperature industrial processes including thermochemical fuel synthesis – Cost reduction with modular design and manufacturing and digitisation – Next-generation designs with higher temperatures and higher efficiencies – Can support desalination	– Competition from low-cost PV plus large-scale storage – International competition for manufacturing, plant development and for R&I

Source: JRC, 2023

Table 2. CETO SWOT analysis for the competitiveness of solar thermal heating and cooling.

Strengths	**Weaknesses**
– Well established, mature technology – Strong EU manufacturing base – Covered by EU Ecodesign and Energy Label requirements for space and water heating – No use of CRMs and good circularity potential (high recycling rates)	– Cost competitiveness strongly dependent on price of fossil fuels – Often not a standalone solution and requires integration with other heat or cool sources to meet demand at certain times
Opportunities	**Threat**
– EU policy targets to decarbonise the heating (and cooling) sector – Potential to supply the high temperatures required by many industrial processes	– Competition from a lower-cost PV + heat pump systems – Low cost imported solar heating and cooling systems

Source: JRC, 2023

1 Introduction

1.1 Scope and context

This report on solar thermal energy 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. For 2023 the scope[1] covers:

a) Concentrated solar power (CSP[2]) plants that convert solar energy to electricity, included storage options to allow dispatch during evenings and at night time.

b) Concentrated and non-concentrated solar thermal heating and cooling (SHC) for buildings, district networks and for industrial processes; also in this case thermal storage is integral to the system.

This report builds on previous Commission studies in this field [1, 2, 3] as well as the recent EurObserv'ER barometer on solar thermal [4].

For the power sector, CSP technologies have developed to a commercial scale but play only a minor role. Nonetheless, there is considerable potential, both globally and in the EU. CSP plants for electricity require high levels of steady, direct normal insolation (DNI > 1900 kWh/m^2/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 (also called power tower) plants [5]. 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 [6]. The use of concentrated solar energy to drive thermochemical fuel synthesis is addressed in the CETO solar fuels report [7].

Solar thermal technologies are important for decarbonising the heating and cooling sector, which accounts for 50% of global energy consumption and contributes to 40% of CO2 emissions. The market for low and medium temperature heat worldwide is estimated at 12,222 TWh, of which 58% is for buildings and about 42% for industrial processes (chemical, food & beverages, machinery, mining, textiles, word processing), with 2,700 TWh for low temperature and 2,400 TWh for medium temperature applications [8]. The Fit for 55 policy package requires an increase of RES share in H&C by 0.8% per year to 2026 and 1.1% after that, while for District Heating and Cooling (DHC), the required annual increase would be 2.1%. A range of non-concentrated solar heating and cooling technologies are commercially available in the main application areas: domestic hot water systems, solar district heat, solar heat for industrial processes, solar air conditioning and cooling and hybrid solar thermal and photovoltaics. Concentrated 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 in order to ensure continuity of supply [9, 10, 11]. The direct normal insolation 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.

Solar thermal technologies (concentrated and non-concentrated) are considered a strategic net-zero technology[3] in the proposed Net Zero Industry Act [12].

[1] *In 2022 CETO produced a report on concentrated solar power and heat. It has been decided to extend this to all solar thermal technologies from 2024 on. This year's report is transitional, with limited information on non-concentrated solar thermal included.*

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

[3] *This categorisation reflects three criteria: 1) technology readiness level; 2) contribution to decarbonisation and competitiveness; and 3) security of supply risks (in terms of strategic imports dependencies).*

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

c) Global markets and EU positioning

This section looks at the technology's perspectives 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).

Details of specific sources are given in the corresponding sections and are summarised in Annex 1.

2 Technology status and development trends

2.1 Technology readiness level

2.1.1 Concentrated Solar Power - 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 3*** 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 3. 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 °C
Thermal energy storage	Two-tank molten salt	
Power cycle	Rankine with superheated steam (ORC for smaller facilities)	Rankine with superheated steam
Capacity factor[4] (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[5]) [13]	
CO2 footprint	22 gCO2/kWh [14] Europe: 99.8 gCO2/kWh, China 129.7 gCO2/kWh [15] (25 year life)	

Source: JRC, 2023

Hybrid PV-CSP plant design are also increasingly being considered. PV systems can provide power to the ancillary systems (circulation pumps, control systems etc.), help ensure stable power output and allow the CSP

[4] Since the nominal power output of the generator in a CSP plant is fixed by the rated power of the turbine and generator, 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.

[5] 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.

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 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.

In 2023 the SET-Plan implementation working group (IWG) revised its planning document "the Initiative for Global Leadership in Concentrated Solar Power" [16]. The strategic targets are:

- Cost reduction of electricity provided during periods with low wind, PV or hydropower infeed, to values below 15 c€/kWh in Southern Europe locations by 2025, targeting below 10 c€/kWh by 2030, considering 2050 kWh/m^2/year as reference conditions and no constraints regarding the size/type of the plant and Power Purchase Agreements (PPA) with a duration of at least 25 years. Also, the general framework conditions outlined in the previous section should apply.
- Development of the next generation of CSP/STE technology (NEXTGEN) to achieve at least 3 points of increase in the overall power plant efficiency from the reference value 39.4 percent16 to 42.4 percent by 2025.
- At least one First of a Kind (FOAK) integrated in the energy system by 2025, demonstrating either the cost reduction or the efficiency increase.
- Thermal energy cost for industrial process heat applications below 3 c€/kWh by 2030 for the same Southern Europe locations as the target 1, with process temperatures higher than 200°C and 25 years' lifetime.
- Demonstration of 24/7 economically viable solar thermal baseload production of green hydrogen and other solar fuels by 2030.

Table 4 R&I activities in the 2023 CST Implementation Plan [16].

Areas of activity	Defined R&I activities of current IP
1. Line-focus solar power plants technology	Activity 1.1: Component development, process innovation and cost optimization for molten salts systems Activity 1.2: Solar collector fields with silicone oil as HTF
2. Central Receiver power plants technology	Activity 2.1: Improvement and optimization of current central receiver molten-salt technology Activity 2.2: Innovative concepts, materials and components for central receiver molten-salt technology Activity 2.3: Solar tower with particle receiver technology
3. Reliable and cost-effective heat transfer medium and high-temp. thermal storage systems	Activity 3.1: Single molten salt thermocline Activity 3.2: Next generation of Thermal Energy Storage technologies
4. Turbo-machinery developed for specific conditions of solar thermal power plants	Activity 4.1: Development of expansion turbine technologies for advanced CSP power blocks Activity 4.2: Development of turbo-machinery for supercritical CO2 cycles
5. Medium-and high temp. systems for industrial solar heat applications	Activity 5.1: Medium temperature systems for industrial solar heat applications

	Activity 5.2: High temperature solar treatment of minerals and metals
6. Thermochemical production of solar fuels and hydrogen	Activity 6.1: Liquid synthetic fuels from solar redox cycles Activity 6.2: Solar fuels from carbon neutral feedstock Activity 6.3: Solar particle receivers/reactors for solar fuels production
7. Cross-cutting issues	Activity 7.1: Digitalization of CSP plants for a more efficient monitoring, operation and maintenance Activity 7.2: Innovative coatings for CSP mirrors Activity 7.3: Reliable CSP, PV and other renewables integration Activity 7.4: Promoting the utilization of CSP with thermal storage to facilitate variable RE penetration in the electrical system

Source: CST Implementation Plan [16]

2.1.2 Solar Heating and Cooling

Solar thermal technologies offer a range of established solutions for all the heating and cooling application areas as shown in Table 5. The EU Renewable Energy Heating and Cooling Technology Innovation Platform (RHC-ETIP) has dedicated technology plan for solar thermal and in 2022 issued a strategic research and innovation agenda [17] (see Box 1): The importance of system integration is addressed in the ETIP SNET 2022 white paper "Coupling of Heating/Cooling and Electricity Sectors in a Renewable Energy-Driven Europe" [18]. The Clean Energy Technology Partnership has also assessed the R&I needs for SHIP under the challenge "Towards 100% renewable industrial heating" [19].

Table 5 Overview of solar thermal technologies and application areas.

Application	Temperature Range, °C	Solar thermal technology	TRL
Building water heating and cooling (domestic hot water)	40-60	Non-concentrated (flat plate collectors, vacuum tube (glazed) collectors	9
Space heating and air conditioning		Non-concentrated (flat plate collectors, vacuum tube (glazed) collectors	9
District heating (& cooling)	40-100	Non-concentrated (flat plate collectors, vacuum tube (glazed) collectors Concentrated designs with line or point receivers	9
Heat for industrial processes (low temperature)	Below 150	Non-concentrated (flat plate collectors, vacuum tube (glazed) collectors	9
Heat for industrial processes (medium temperature)	150 to 400	Parabolic trough or linear Fresnel technology with linear receivers; systems are generally at the MW level of size (1 MW is approximately 1500 m^2 aperture).	9
Heat for very high temperature processes	>400	Concentrated systems with solar towers	8

Source: JRC, 2023

Box 1 The EU Renewable Energy Heating and Cooling Technology Innovation Platform's strategic research and innovation agenda for solar thermal, 2022 [17]

A.1 - Development of system components for solar district heating (SDH) and solar heat for industrial process (SHIP) including thermal storage (mid-high temperature/pressurised)

A.2 - Demonstration projects for high temperature SHIP projects (<400°C)

A.3 - Improved hybrid collectors, such as PVT

A.4 - Developing prefabricated multifunctional solar façade systems

A.5 - Developing 'Solar-Active-Houses' with high solar fraction

B.1 Integration of large solar thermal systems and storages process including thermal energy storage

B.2 Integrated solutions for SHIP below 400˚C

B.3 Digitalisation

C.1 Environmental legislation, and land availability for SDH

C.2 – Developing new Business Models for Solar Thermal

C.3 – Solar thermal resource mapping

- C.3.1 Method development for advanced Solar thermal resource mapping and alignment with local energy demand

- C3.2. – Data integration to existing European data platforms

- C.3.2 – Promotion and dissemination strategies of solar thermal resources

C.4 Statistical data collection

- C.4.1 – Harmonized cost data collection for the main solar thermal applications

- C.4.2 – Harmonized statistical data collection

2.2 Installed Capacity and Production

2.2.1 Concentrated Solar Power

The worldwide capacity of CSP plants is approximately 6.4 GW (as of end 2022) [20]. As shown in Figure 1a, the market grew slowly over the last 12 years, with significant variations in the annual new installations. At the end of 2022 there were 83 operational plants in 11 countries. Spain has the largest fleet, followed by USA and China (Figure 2).

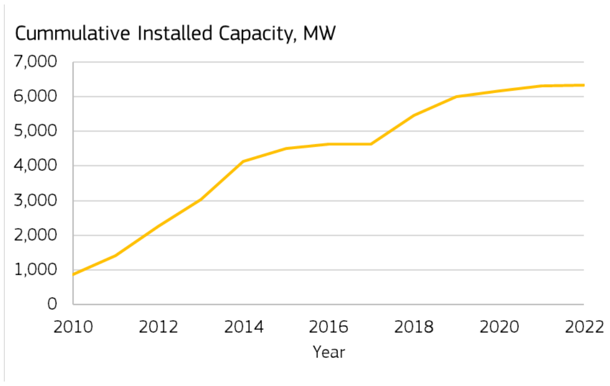
The CSP-guru listing [20]. shows almost 1.3 GW as under construction. These include a set of major projects in the United Arab Emirates (Noor Energy 1 / DEWA IV: 100 MW tower, three 200 MW trough and a CSP-PV hybrid project); the 100 MW Redstone plant in South Africa, and 510 MW in China. There are also a number of planned developments. Botswana is studying the development 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 (some of these are included in the above-mentioned plants in construction. Also, the province of Xinjiang has announced development of 1.3 GW of CSP.

In the medium to long term, POLES-JRC model projects a modest role for CSP in its CETO Global 2°C Scenario (see Annex 3), with global installed capacity more than doubling from current levels to more than 14 GW in 2030 and then more than doubling again to 31 GW in 2050. Mirroring CSP global capacity expansion, electricity generation from CSP reaches 23 TWh in 2030 and 43 TWh in 2050 under POLE-JRC's CETO Global 2°C Scenario. While in the next two decades power generation from CSP grows at a faster pace than overall electricity generation, in the 2040-2050 decade CSP deployment and generation slows down reducing thus its share overall electricity generation. . The IEA's 2021 Net Zero by 2050 scenario is somehow more optimistic, projecting 204 TWh (73 GW) from CSP in 2030, and 1386 TWh (426 GW) by 2050 [21]. The IEA NZE scenario foresees an annual capacity growth of 31% from 2020 to 2030, or ~6.7 GW of new capacity every year. However, CSP current deployment rate is far from this. The IRENA World Energy Transition Outlook goes as far as envisaging approximately 3000 TWh by 2050 [22]. The main CSP markets are expected to be in the Middle East and Asia-Pacific regions, particularly China and India.

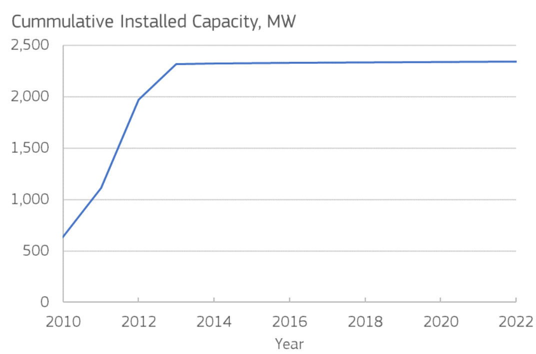
The EU has a current CSP installed capacity of 2.33 GW [4]. Almost all of this is located in Spain, where 45 plants of 50 MW were installed in the period 2009-2013 (**Figure 1**b). **Figure 3** shows the evolution of electricity generation in the EU over the past decade based on Eurostat data. The 2019 National Energy and Climate Plans (NECPs) for 2030 indicate the addition another 6.2 GW, again almost entirely in Spain. However little progress has been made on this so far. Plans are moving ahead for a hybridised PV-CSP plant in southern Spain. This would combine 110 MW CSP unit with 6 hours storage capacity and a 40 MWp PV system to maximise the grid connection capacity. Spain's renewables auction in October 2022 included 220 MW earmarked for solar thermal projects with six hours of storage, but no bids below the pre-determined maximum allowed price were received. In June 2023 Spain's revised draft of the National Integrated Energy and Climate Plan nonetheless targets 4.8 GW of CSP by 2030 i.e., 2.4 GW of additional CSP capacity to be deployed.

The POTEnCIA CETO Climate Neutrality Scenario projects almost no CSP capacity growth from current levels. CSP deployment in the POTEnCIA model is limited by its high CAPEX and by growing competition from solar PV and wind - charecterised by lower Levelised Cost of Electricity (LCOE) - and from battery storage. The targets of CSP capacity expansion defined in the 2019 NECPs are not achieved in this scenario, as investments in CSP are not yet occurring and recent auctions have not received any bid. However, once existing CSP plants reach end of lifetime, the model refurbishes them, thus maintaining the existing installed capacity. The CSP uptake projected under the POTEnCIA CETO Climate Neutrality Scenario should be regarded as a minimum level, which could be higher reflecting the targets in the 2023 NECPs, provided that policy measures are put in palce to reward plants' flexibility as a means to supports the secure operation of the power sector. The recent EurObserv'ER barometer [4] is mildly more optimistic, projecting 3 GW by 2030.

Figure 1 Installed and operational CSP capacity 2005 to 2022: global (left) and EU (right).



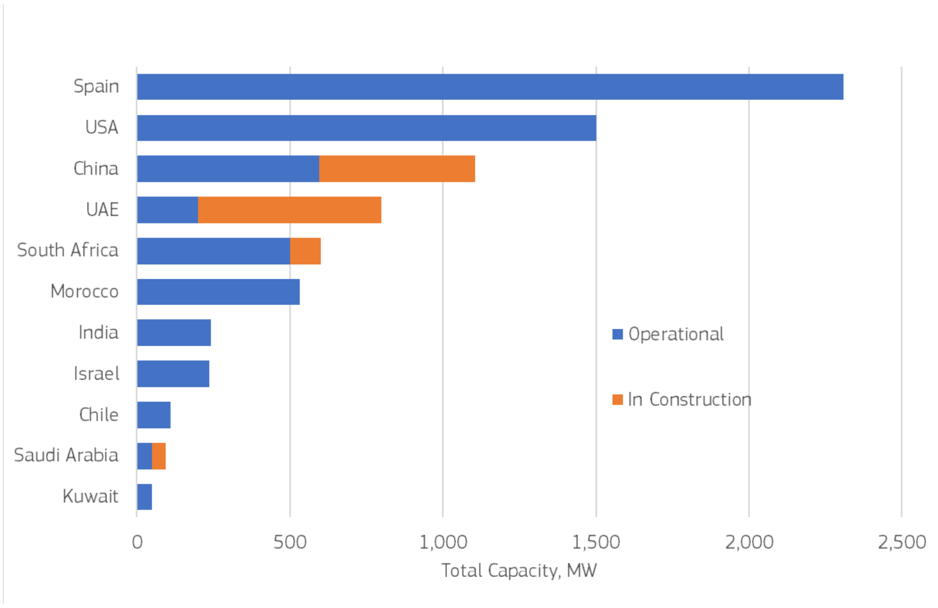
a) global



b) EU

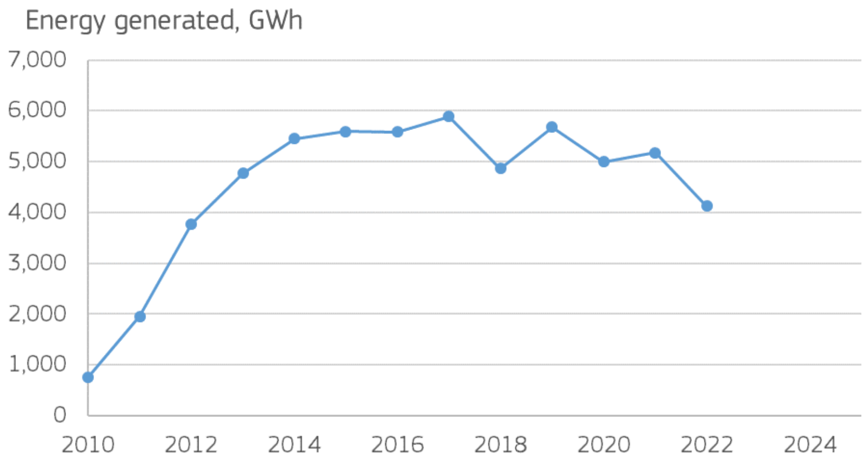
Source: CSPGuru/SolarPACES data base and JRC elaboration

Figure 2 Breakdown of CSP plants by country with a cumulative capacity installed of 50 MW or more.



Source: JRC elaboration of CSPGuru data

Figure 3 Electricity output of EU CSP plants.



Source: JRC elaboration of Eurostat data: NRG_BAL_PEH

2.2.2 Solar Heating and Cooling

The global overall solar thermal collector capacity was 542 GWth by the end of 2022, corresponding to 774 million m^2 of collector area[6] and an annual solar thermal energy yield of 442 TWh [23]. Although growth in 2022 was only 4%, the capacity has more than doubled over the last decade, up from 230 GWth in 2010 (***Figure 4***). China, Turkey, US, Germany and Brazil are the top countries in terms of installed capacity.

For the EU, Eurobserv'ER reports that the installed capacity grew by 1.661 GWth (11%) in 2022 to reach 37.86 GWth in 2022 [4]. Several EU markets saw strong growth (Italy, France, Greece and Poland). Solar thermal is installed on approximately 10 million buildings, representing 3.9% of the total stock of 259 million units [24]. Eurostat data only partially captures the extent of SHC deployment. In the EU derived heat statistics for 2021 (nrg_bal_pch), solar thermal contributes 0.687 TWh (0.1%) to a total of 651 TWh. Although overall market share

[6] *This corresponds to approximately 0.4% of the global rooftop area (200,000 km2).*

for water heater and space heating/cooling is low, in several Mediterranean regions solar water heating is extensively used for buildings.

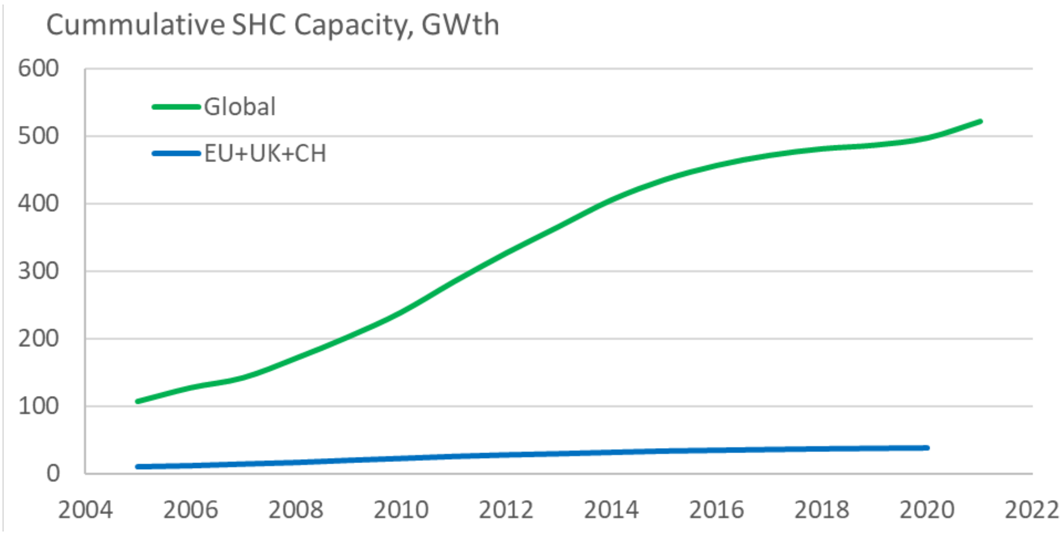
Large scale systems are used in district heating (DH) systems in 264 cities and towns in Europe (approximately 5% of DH systems)[7]. Denmark alone has 150 DH systems that use solar thermal as one of their heat sources, and this is facilitated by access to seasonal thermal storage in the same systems.

Concerning solar heat for industrial processes (SHIP), this is most used in the food and beverage sector. The sector grew by at least 30 MWth in 2022 to 856 MWth, with 1.22 million m^2 now in operation. The SHIP-Plants info site[8] lists 296 projects globally and for 2022 claims the additional of 86 systems with 43,588 m^2. [9]

The final category considered here is for photovoltaic thermal systems[10], with a cumulative installed capacity at the end of 2022 of 789 MWth (1.5 million m^2) and 276 MWp electric [23]. The majority is deployed in Europe. The market fell in 2022 and is strongly dependent on support schemes.

Looking at future scenarios for solar thermal in the EU, the REPowerEU communication reinforced the need to accelerate the diversification of energy supply for heating and cooling. The 2022 EU Solar Energy Strategy notes that energy demand covered by solar heat and geothermal should at least triple to reach the EU 2030 targets, implying an increase to approximately 114 GWth (81 TWh[11]). Solar Heat Europe's roadmap [25] is much more ambitious, foreseeing potential for 560 GWth installed by 2030 (with 140 GWth for buildings, 280 GWth for SHIP and 140 GWth for DH applications) and 40 million buildings with solar thermal systems[12]. On the other hand, in the 2019 NECPs, only 10 Member States analysed the potential role of solar thermal, with a total contribution of 60-70 TWh by 2030 [2626]. It remains to be seen if these ambuitions are raised in the current revision of the NECPs. The POTEnCIA CETO Climate Neutrality Scenario projects that solar thermal increases thermal production by around 60% in 2030 compared to 2020 (I.e. 46 TWh) and generates 82 TWh of heat in 2050.

Figure 4. Development of SHC capacity worldwide and in Europe (EU+IK+CH)



Source: JRC analysis of data from IEA SHC Market Report 2022 and Solar Heat Europe Market Report 2021

[7] *5000 DH in Europe, as cited in the IEA SHC Task 68 presentation to the Webinar "The Rise of Solar district Heating", 28 March 2023, Euroheat and Power and Solar Heat Europe.*

[8] *https://energieatlas.aee-intec.at/index.php/view/map?repository=ship&project=ship_edit*

[9] *There is less data on concentrated solar heat industrial processes (CSHIP), but Solar Concentra database of projects in Spain lists 22 projects, with 2.3 MWth and 4 395 m2 collectors - see https://www.ressspi.com/biz/listaProyectos.*

[10] *These are hybrid systems, using panels that combine photovoltaics cells and solar thermal heat collection.*

[11] The solar energy yield factor is 714 GWh/GW, based on Solar Heat Europe data. For global data mentioned at the beginning of the section the factor is 815 GWh/GW, reflecting a higher overall solar resource.

[12] *No breakdown is available between solar water heating and space heating for buildings*

2.3 Technology Costs

2.3.1 Concentrated Solar Power (Solar Thermal Electricity)

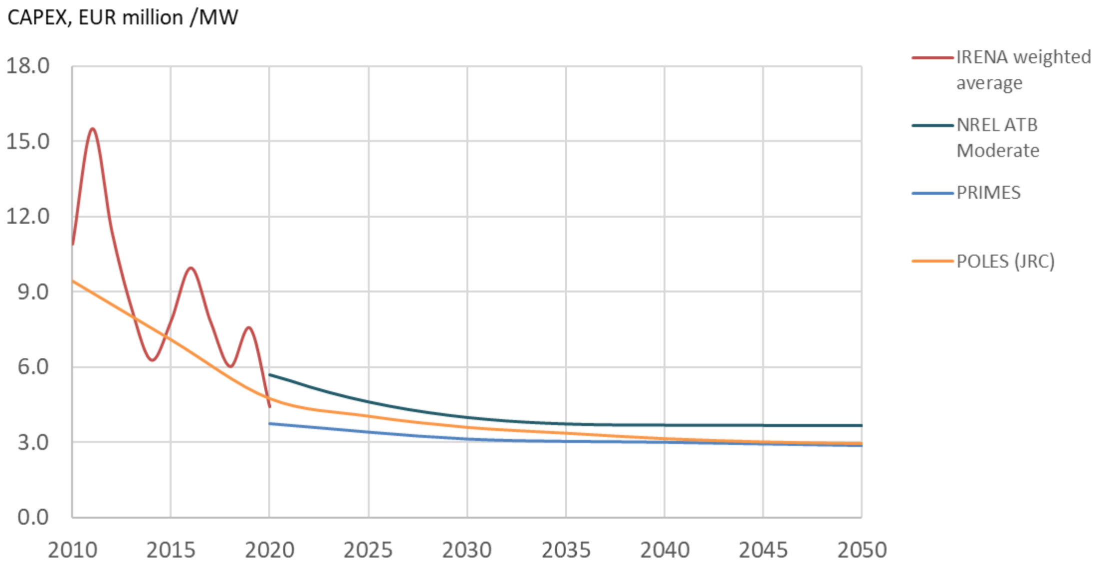
Figure 5 shows the evolution in CAPEX for large CSP plants. The historic trend to 2020 uses IRENA data [27]. The last decade has seen a substantial reduction (about 70%) and is currently about EUR 5 million/MW for a sizeable solar tower plant with at least 8 hours of thermal storage. This can translate into an LCoE of less than EUR 100 €/MWh, depending on solar resource level and plant specifics.

The projections to 2050 are from the POLES-JRC CETO Global 2°C Scenario performed in CETO Task B2 on energy system modelling (see Annex 3), from PRIMES and from the US NREL Annual Technology Baseline 2022 [28] (moderate scenario, with innovations in the power block, receiver, thermal storage, and solar field and refer to solar resource class 7 with 2281 kWh/ m^2/y).

The technology has significant scope for cost reductions in all areas: the solar field, the power block, high-temperature higher efficiency power cycles and thermal storage [30]. Both the EU SET Plan and US research programmes see the potential to further come down to a level of 3 EUR million/MW. However, with very modest global market growth, it remains a challenge to develop the volume production needed to drive down costs, as has happened for wind and solar PV.

IRENA's has LCoE data[13] up to 2019 gives an average of 186 EUR/MWh, but a large spread. It also reports auction data for 2020 and 2021, with significantly reduced values of 85 and 68 EUR/MWh respectively[14]. It should be noted that the LCOE metric does not necessarily reflect the market value of CSP plants to cover load peaks when PV and wind are not available.

Figure 5. Historic and future CAPEX trends for CSP plants. The IRENA data is a weighted average of different plant types.



Source: JRC elaboration based on POLES-JRC, IRENA [27] and NREL ATB [28] data.

2.3.2 Solar Heating and Cooling

CAPEX data for solar hot water systems is not available so far. Cost calculations are also complicated since for buildings need a back-up system is needed depends on the type of facility (open loop for DHW, closed loop for DHW or heating, etc.). ISolar Heat Europe [24] report the following ranges for LCOH (reflecting technology scale and location):

[13] *https://www.irena.org/Data/View-data-by-topic/Costs/Global-LCOE-and-Auction-values*

[14] *Converted from USD/MWh with a 1 USD = 1.1 EUR*

– Solar district heating: 20 to 45 EUR/MWh

– SHIP: 40 to 70 EUR/MWh

– Solar for DHW 20 to 110 EUR/MWh

For large systems, 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 [29] report the average LCoH values for the period as follows:

– European project, T < 150°C, LCoH of USD 87 /kWh (average plant 400 kW, yield 564 kWh/ m^2/y.

– Global projects, 150 < T < 400°C, LCoH of USD 97/kWh (average size 334 kW, yield 654 kWh/ m^2/y)

2.4 Public RD&I Funding and Investments

2.4.1 IEA Global Public RD&D data

Data on public R&I investments relies that collected annually by the IEA from its members [31]. The relevant reporting fields are:

– 3.1 Solar energy

– 311 Solar heating and cooling

– 3.1.2 Photovoltaics

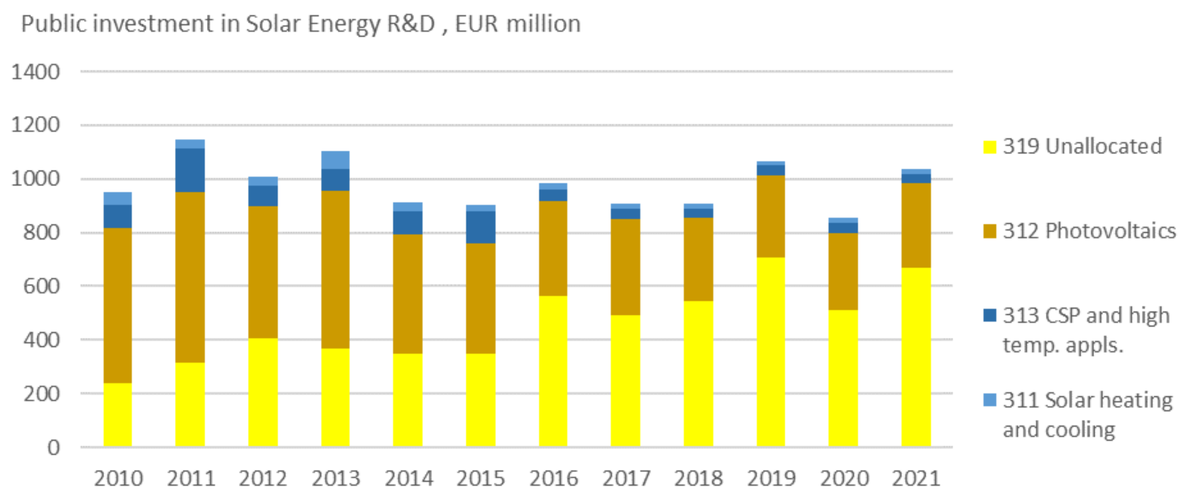
– 313 Solar thermal power and high-temp. applications

– 319 Unallocated solar energy

Figure 6 shows that for solar energy as a whole, the RD&D budgets were approximately stable at current values from 2010 to 2021, so a decrease in real terms. In recent years over 50% of the declared budgets are reported as “unallocated”, so without disaggregation to the various technology areas (e.g such those reported by USA, the EU framework programme and Korea). For those countries that do report disaggregated values, the trend appears to be for decreasing R&D funding (Figure 7).

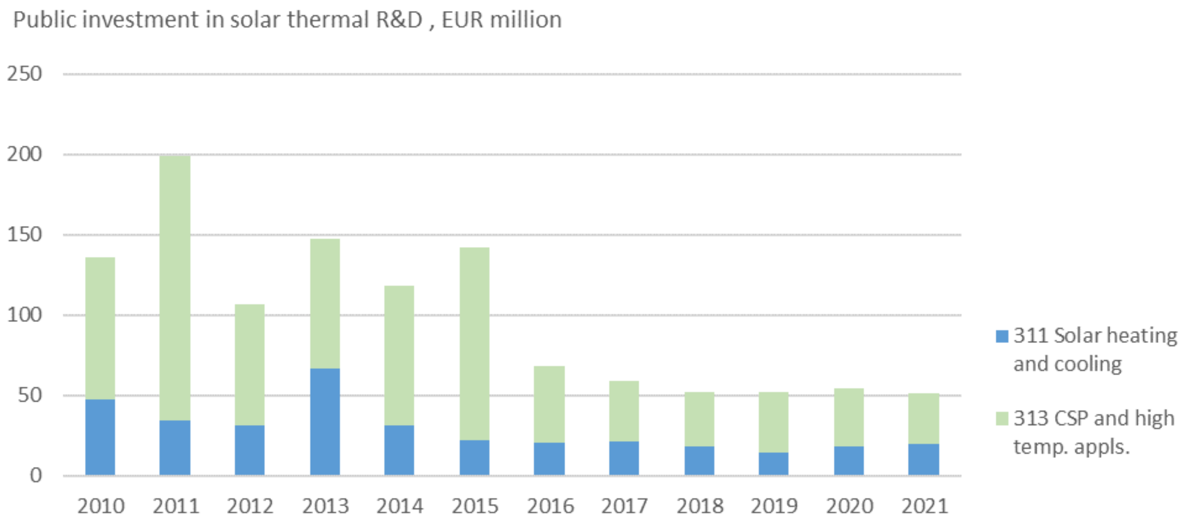
For the EU member states, Table 6 shows the reported values for 2021. Here the proportion of unallocated funding is 24%. Several countries know to have active research in this area (e.g. Italy, Greece and Portugal) did not report. The overall time trend for the two solar thermal categories is shown in Figure 8, indicating a reduction in funding over the last decade for both CSP and solar thermal heating and cooling.

Figure 6 Global data (current values) reported to the IEA for public RD&D funding for solar energy



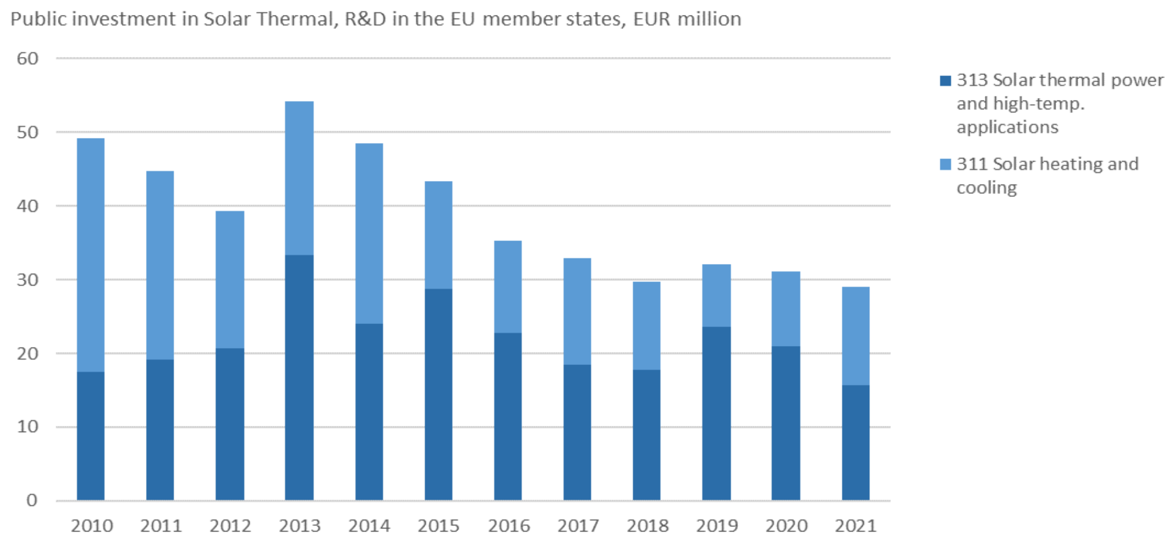
Source: *JRC based on IEA [31]*

Figure 7 Available disaggregated public RD&D funding (current values) for solar thermal as reported to IEA NB the totals are current values. NB Data for the USA and the EU framework programme is not included.



Source: *JRC based on IEA [31]*

Figure 8 Public RD&D funding (current values) reported to IEA by EU countries for solar thermal R&I (EU framework programme funding not included).



Source: *JRC based on IEA [31]*

Table 6 Breakdown of the public RD&D funding reported to IEA by EU countries for solar energy for 2021.

	3.1 Solar Energy	**3.1.1 SH&C**	**3.1.2 PV**	**3.1.3 CSP&H**	**3.1.9 Unallocated**
AT	5.0	0.9	3.0	0.2	1.0
BE	0.4	0.3	0.1	0.0	0.0
CZ	1.1	0.3	0.4	0.1	0.3
DE	109.6	6.6	93.2	9.7	0.0
DK	3.3	1.7	1.6	0.0	0.0
EE	0.3	0.0	0.3	0.0	0.0
EL					

ES	42.0				42.0
FI	4.6				4.6
FR	78.8	1.2	62.9	5.7	9.0
HU	6.8	0.0	6.8	0.0	0.0
IE	0.7	0.0	0.6		0.1
IT					
LT	1.2		1.1		0.1
LU					
NL	22.3	2.0	20.2		0.1
PL	9.2				9.2
PT					
SE	11.9	0.2	6.0		5.6
SK	0.3	0.1	0.0		0.2
MS Total	**297.4**	**13.5**	**196.2**	**15.6**	**72.1**
EU FP	**118.5**				**118.5**

Source: JRC based on IEA [31]

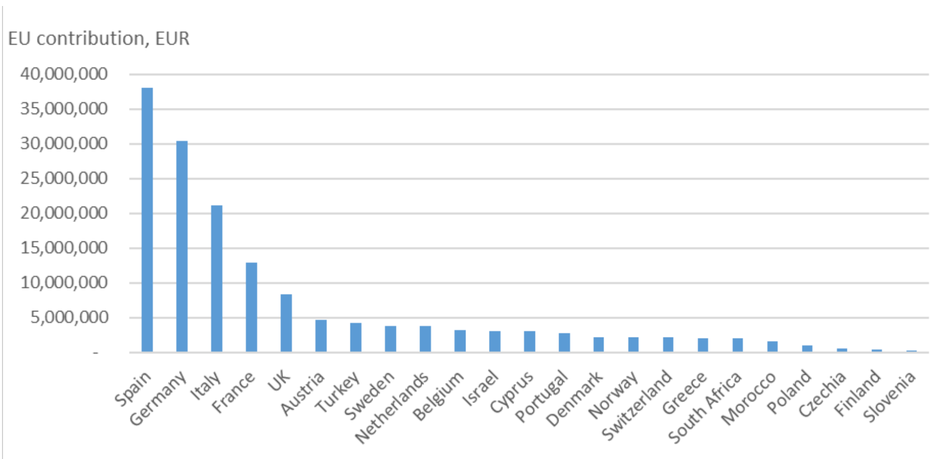
2.4.2 EU Horizon Funding

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 9** shows the total EU contribution per country. Spain, Germany, Italy and France are the main beneficiaries. Funding has continued in Horizon Europe (2021-2027) for solar thermal, with at least 13 projects approved up to August 2023, and representing a budget of just over EUR 30 million (see Annex 4).

2.5 Private RD&I funding

As shown in **Figure 10**, four countries host together 61% of innovating companies active over the 2017-2022 period. The US (1st) relies on a strong base of both start-ups and corporate innovators, while all identified innovators in Japan (2nd), Germany (3rd) and most of those based in China (4th) are corporations. Overall, Europe accounts for 31% of innovators active over the 2017-2022 period (essentially in Germany, Italy and France). The EU however hosts a much lower share of start-ups than the US does.

Figure 9. H2020 funding for CSP projects, 2014-2020

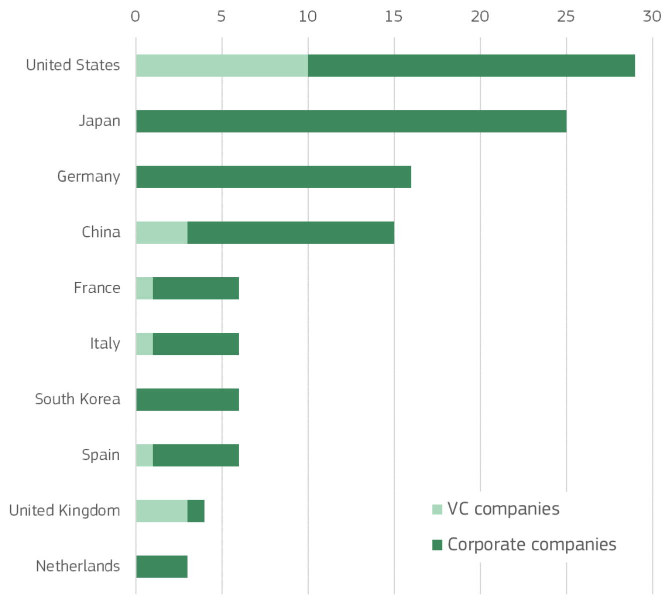


Source: JRC TIM analysis of CORDIS data

2.5.1 Overall private R&I investments based on patents

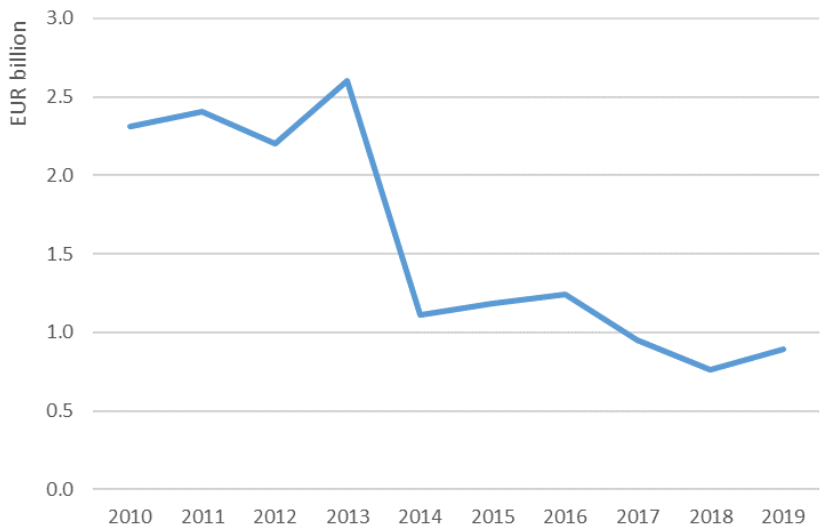
Estimates of private R&I for CSP have been made using patenting data as a proxy [32, 33][15]. **Figure 11** indicates a marked decline in such investments over the last decade. **Figure 12** shows the trends at country/regional level. China is leader since 2012. The EU is in second place, investments show a steady decline in the same period. **Table 7** show the top organisations for R&D investments globally.

Figure 10 Number of innovating companies active over the period 2017-2022, by country (Top 10)



Source: JRC compilation of sources. Active VC companies include start-ups that have been founded or have raised venture capital over the considered period. Active corporate companies include subsidiaries of top corporate R&I investors with relevant high-value patents over the considered period.

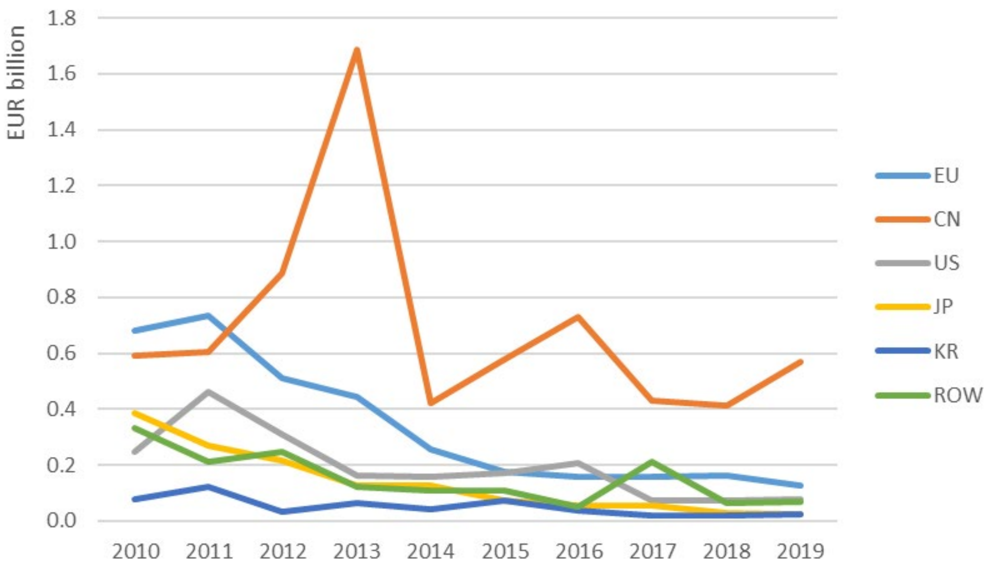
Figure 11. Overall trend in annual R&D investments by private companies, using patenting data as proxy.



Source: JRC, 2023

[15] *Up to now no similar analysis has been made for solar thermal heating and cooling.*

Figure 12. Trends in annual R&D investments for the EU and major economies, using patenting data as proxy.



Source: *JRC, 2023*

Table 7. Top organisations globally for R&D investments 2015-2019, using patenting data as proxy.

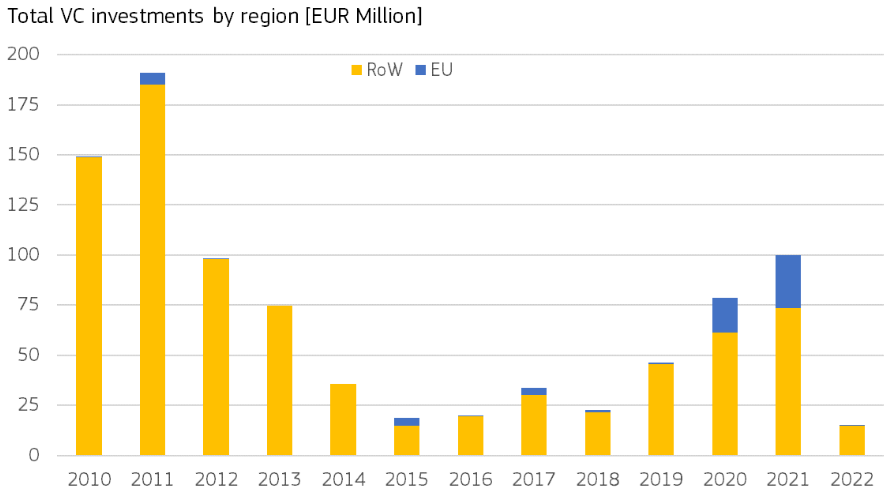
Organisation	Country
SOLARCITY CORP	US
SUNPOWER CORPORATION	US
NINGBO HIGH TECH ZONE SHIDAI ENERGY TECHNOLOGY CO LTD	CN
OJJO INC	US
BINZHOU ARMOUR FORCE SOLAR TECHNOLOGY CO., LTD.	CN
ZHEJIANG SUPCON SOLAR ENERGY TECHNOLOGY CO LTD	CN
NEXTRACKER INC	US
HUANENG CLEAN ENERGY RESEARCH INSTITUTE	CN
GREE ELECTRIC APPLIANCES INC OF ZHUHAI	CN
GUANGDONG FIVESTAR SOLAR ENERGY CO LTD	CN
ALION ENERGY INC	US
CHENGDU AONENGPU TECHNOLOGY CO., LTD.	CN
ZHEJIANG JIADELE SOLAR ENERGY CO LTD	CN
ZHEJIANG HONGLE SOLAR THERMAL TECH CO LTD	CN
CHENGDU ANGDIJIA TECHNOLOGY CO LTD	CN
SHANDONG LINUO RITTER NEW ENERGY CO LTD	KR
JIANGSU SUNNIC SOLAR ENERGY INDUSTRIAL CO LTD	CN
NANTONG JINYANG SOLAR TECHNOLOGY CO LTD	CN
XIAN THERMAL POWER RESEARCH INSTITUTE CO LTD	CN
NINGBO HI TECH ZONE SHIDAI ENERGY TECHNOLOGY CO LTD	CN

Source JRC, 2023

2.5.2 Venture capital investments

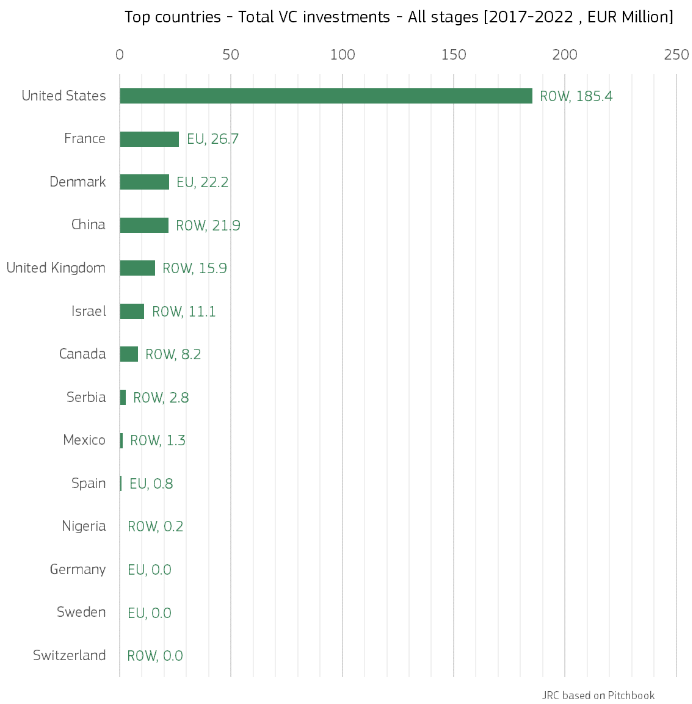
An analysis has been performed for concentrated solar thermal power and heat applications following the JRC methodology [34]. Available data suggests that global VC investments have dropped in 2022 and the rebound seen in the EU and in the US between 2019 and 2021 has not been maintained. In the EU, France and Denmark attracted the most significant investment (in companies such as Newheat and Heliac). In 2022, global VC investment remain driven by later-stage deals in US (such as 247Solar, HyperBorean) and UK-based companies (Naked Energy). It also includes a large seed round in the company Odqa RE technologies founded in 2017 in the UK and developing a state-of-the-art solar receiver.

Figure 13 Trends in venture capital investments in the EU and the rest of the world 2010 to 2022



Source: *JRC analysis based on Pitchbook data*

Figure 14 Trends in venture capital investments in the EU and the rest of the world 2010 to 2022



Source: *JRC analysis based on Pitchbook data*

2.6 Patenting trends

The analysis looked at CSP only and followed the JRC methodology [35] using Patstat (European Patent Office) data for the period to 2020[16]. The relevant CPC codes 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[17]. 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 – the EU has been leader for almost all the decade 2010-2020, although its output has been decreasing since 2012 (**Figure 16**). However in 2020 China moved into top place also for high value patents. **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 8**, 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.

Figure 17 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 8. Breakdown global CSP patents by CPC sub-technology code

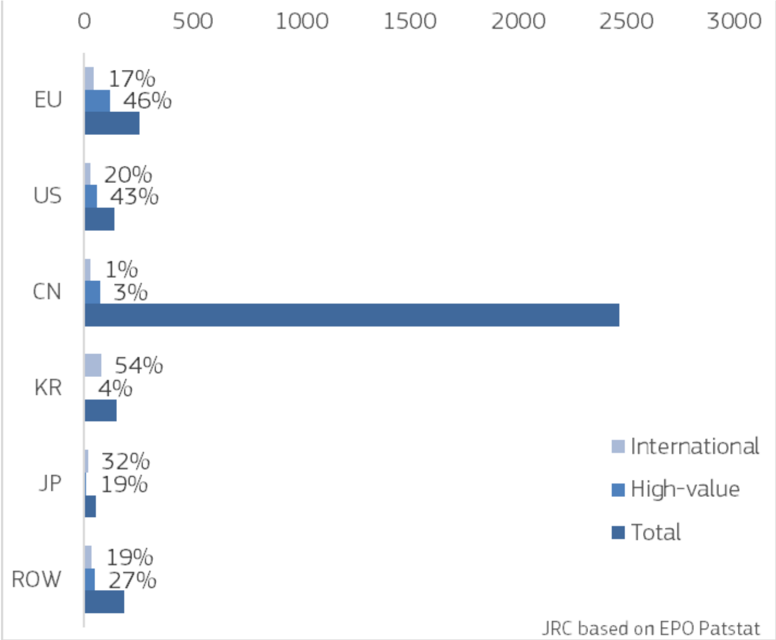
Sub-Technology Area	**2017**	**2018**	**2019**	**Total**
Thermal to Mechanical Power Conversion	19	10	6	35
Heat exchange systems	29	14	13	56
Mountings or tracking	53	41	34	128
Not specified	38	43	31	112
Grand Total	139	108	85	332

Source JRC, 2023

[16] *JRC update: August 2023 – for details on the processing methodology see [23, 24, 26]).*

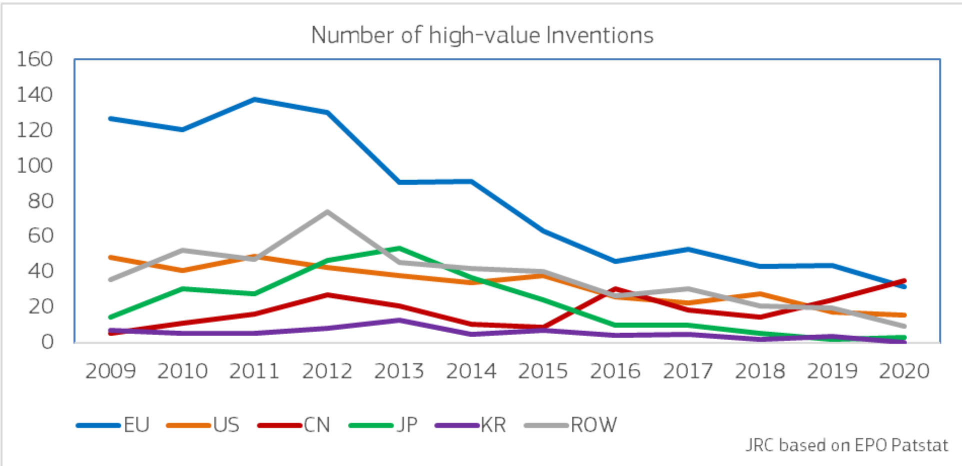
[17] *Since the analysis for the CPR 2020 SWD, the Chinese patents have been re-categorised, leading to a substantially lower total count (50% less).*

Figure 15. Number of inventions and international and high value shares for 2018-2020.



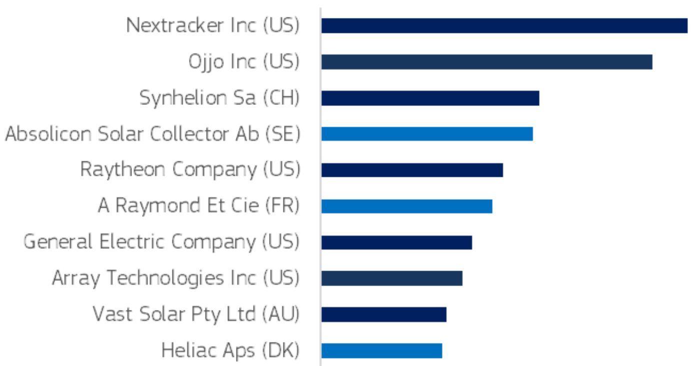
Source: JRC based on EPO Patstat

Figure 16. High value inventions for CSP from 2009 to 2020.



Source: JRC based on EPO Patstat

Figure 17. Top 10 companies worldwide for high value inventions 2018-2020



Source: JRC based on EPO Patstat

2.7 Scientific publication trends

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.

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 9 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 lower.

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.

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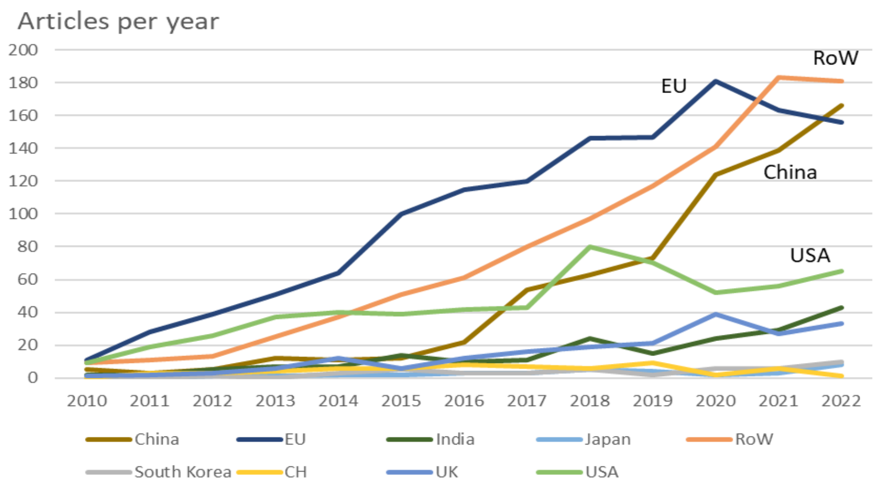
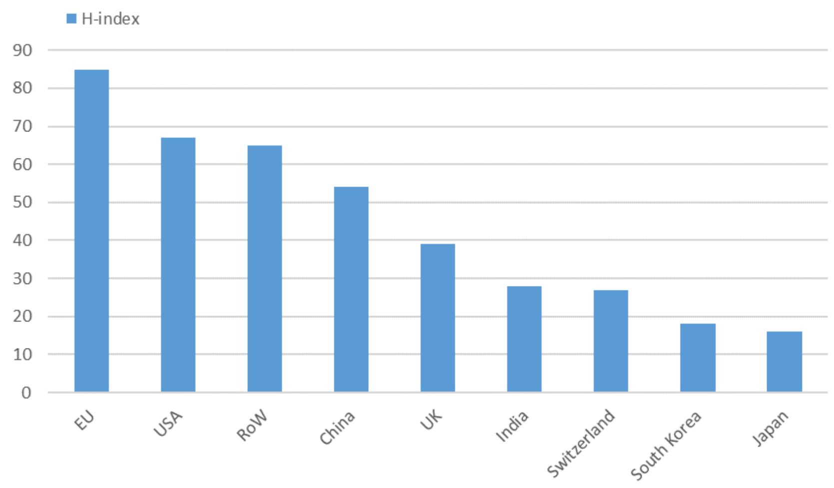
Figure 18. Trend in scientific publications on CSP and CSH for the leadings countries and regions



Source: *JRC analysis of TIM data*

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



Source: JRC TIM analysis, 2023

Table 9. Leading EU countries for CSP scientific articles 2010 to 2022

Country	total articles	non highly cited	highly cited articles	FWCI	H-index
Spain	508	417	91	1.41	60
Germany	291	244	47	1.48	51
Italy	251	202	49	1.48	43
France	174	149	25	1.2	36
Portugal	65	63	2	0.89	20
Sweden	34	27	7	1.44	16
Austria	32	25	7	1.38	17
Denmark	31	20	11	2.04	13
Greece	28	24	4	1.37	13
Belgium	23	18	5	1.82	15
Netherlands	21	17	4	2.47	13
Finland	19	18	1	1.09	12
Poland	14	11	3	1.63	6
Cyprus	13	12	1	0.87	7

Source: JRC TIM analysis, 2023

3 Value Chain Analysis

3.1 Turnover

The global solar heat and cooling sector is estimated to have had a turnover of EUR 17.4 billion in 2021 [23]. For Europe, Solar Heat Europe (EU+UK+CH) report EUR 1.79 billion, about 10% of the global total. No data has been found on a breakdown between the building, district heat and industrial process sectors.

For CSP, in the absence of public market-based data, the JRC estimates the current global market at approximately EUR 6 billion (assuming 500 MW annual installations and an existing park of 6 GW that incurs – operational costs).

3.2 Gross value added

No data is available at time of writing.

3.3 Environmental and socio-economic sustainability

Annex 2 provides summary of the available data and methods regarding environmental, social and economic sustainability according the CETO scheme.

3.4 Role of EU Companies

For solar thermal collectors, globally Chinese manufacturers are leading, but several EU companies are in the top 20. A 2023 report for the Commission [36] notes that the industry struggled in 2022, with manufacturers having difficulties sourcing materials and components as a result of the continued effects of the COVID pandemic on suppliers in Europe and internationally. The 2023 EurObsev'ER barometer [4] notes different situations within Europe: the number of German manufacturers dropped from 38 to 23 from 2015 to 2022[18], and many of these remaining have also diversified or are using separate suppliers for some components. In contrast, Greek manufacturers have seen significant growth in solar collector output and strong exports.

For SHIP, the Solar-Payback site provides mapping of 72 suppliers of turnkey solar process heat systems, with 34 in the EU. Mexican and Chinese companies report the most projects, but EU companies are well represented: G2 Energy (NL), Ritter XL Solar (DE), Soliterm (DE), Sunoptimo (BE), Cona Solar (AT), Solid Solar Energy Systems (AT), Next source (NL).

For CSP the situation for EU companies is unclear, given the very weak domestic market and intense competition. 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

The global solar heat and cooling sector is estimated to have provided 389,000 jobs in 2021 [23]. Solar Heat Europe estimates 18,400 jobs in 2021 for Europe (EU+UK+CH) [24].

For CSP, IRENA [37] reports 79 000 jobs globally in 2021, of which approximately 59 000 in China and 5 200 in the EU (37(a value more or less unchanged from 2019).

3.6 Energy intensity and labour productivity

No data has been identified for these indicators

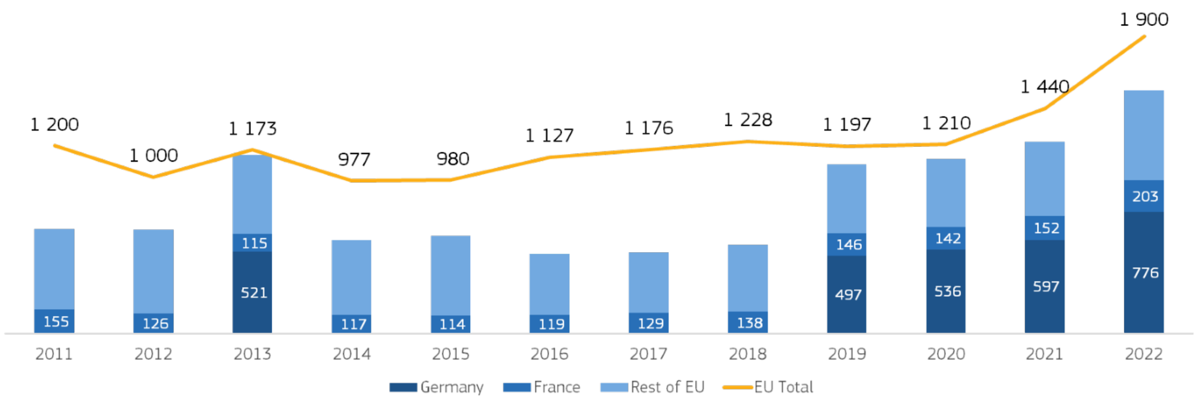
[18] *August 2022, https://solarthermalworld.org/news/strongly-downsized-but-crisis-ridden-solar-collector-industry-in-germany/*

3.7 EU Production Data

The CETO analysis of production uses the Eurostat statistics on the production of manufactured goods, as recorded under Prodcom (PRODuction COMmunautaire) codes. For solar thermal, Prodcom code 27521400 (Non-electric instantaneous or storage water heaters) is used as a proxy to monitor the EU's manufacturing output in the solar thermal industry. This PRODCOM code is the most relevant to solar water heating, yet it also includes gas and other non-electric water heaters; thus, the dataset needs to be treated with caution. **Figure 20** shows that, over the past ten years (2013-2022), the production value has increased by 62% with an annual compound growth of 5% and an average value of EUR 1.2 billion. It was not affected by the pandemic, and, in 2022, it increased by nearly 32%, reaching EUR 1.9 billion. Germany was the top EU producer, holding more than one fifth of the total EU production (ten-year average). The sum of countries' production (boxes) is lower than the 'EU Total' (line) because some Member States keep their production data confidential. However, Eurostat includes the confidential data in the 'EU Total' estimates.

For CSP/T plants, there is no specific code or one suitable to be considered a proxy. This probably reflects the small size of the market and that it comprises a broad mix of components: reflectors, solar absorbers/ receivers, heat transfer & storage equipment, steam boilers and the steam turbine & generator sets.

Figure 20 Annual EU production of non-electric instantaneous or storage water heaters (yellow line) and available data (columns) from the main Member State disclosing data [EUR Million]



Source: *JRC based on PRODCOM data*

4 EU Market 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 and technology providers (e.g. Shanghai Electric, COSIN Solar, formerly Supcon Solar).

For solar thermal heating and cooling, the listing of top companies worldwide by Solrico[19] includes: Greenonetec (Austria), Dimas(Greece), Bosch Thermotechnik (Germany), Papaemmanouel (Greece,), Thermosolar (Slovakia), Viessmann (Germany), Delpaso Solar (Spain), BDR Thermea (Spain), Cosmosolar (Greece) and Hewalex (Poland).

4.2 Trade (Import/export) and trade balance

In 2022, the Harmonised System (HS) classification was revised[20] and included a new code (HS841912) dedicated to solar water heaters, which previously was included under the HS841919[21], a general code for non-electric water heaters – other than gas. However, it is not certain that all traders used the new code on its first year of implementation.

On the other hand, there are no specific codes dedicated to CSP. It is likely that trade represents a significant share (>50%) of the global market since many commercial projects are developed in countries other than those of the main technology suppliers (EU, US and China). Table 10 shows the overall EU import-export data for 2021 and 2022 for both the solar water and other water heater codes. Considering the combined data, EU exports grew by 6% from 2021 to 2022, but imports also grew substantially by 108% to almost EUR 300 million, leading to a slight negative trade balance. This is also seen in the data for the new solar thermal code, which recorded EUR 15 million exports and EUR 42 million imports.

Table 10 Extra-EU exports and imports for 2021 and 2022 for non-gas water heaters.

Products		2021	2022
EU Exports	H841912 (solar thermal)	N/A	15
	H841919 (other water heaters)	281	284
	Total, non-electric, non-gas water heaters	281	299
EU Imports	H841912 (solar thermal)	N/A	42
	H841919 (other water heaters)	143	255
	Total non-electric, non-gas water heaters	143	297

Source: JRC based on COMEXT data

In 2022 according to the HS841912 solar heater code data, China was the major importing partner holding 75% of total extra-EU imports (Figure 21). Germany, Italy, Romania, France and Netherlands were the top EU importers in 2022. The extra-EU exports reached EUR 15 million, with Morocco, United Arab Emirates and Switzerland being the top destinations (Figure 21). France, Austria and Germany were the top EU exporters of solar water heaters (Figure 22), exporting mainly to other Member states.

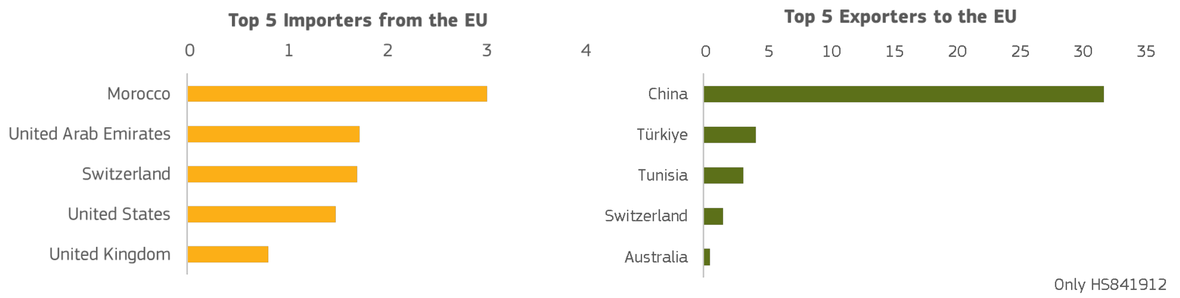
[19] https://www.solrico.com/

[20] World Customs Organization (WCO), HS Nomenclature 2022 Edition https://www.wcoomd.org/en/topics/nomenclature/instrument-and-tools/hs-nomenclature-2022-edition.aspx

[21] HS 841919 - Instantaneous or storage water heaters, non-electric – Other NB Gas water heaters are under HS841911- Instantaneous gas water heaters (excl. boilers or water heaters for central heating)

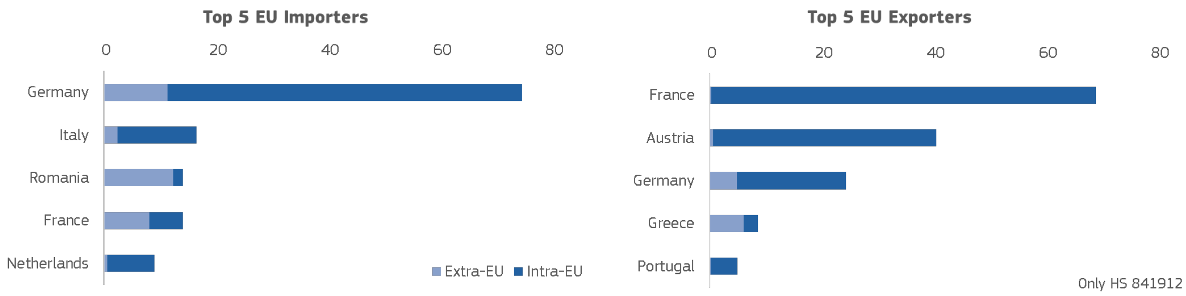
From global COMTRADE data, and again considering only HS841912, China was the top global exporter of solar water heaters while the EU had a strong presence amongst the top 10 global exporters and importers (Figure 23). However, many countries may have not declared their trade data for 2022 in COMTRADE yet[22].

Figure 21: Trade in solar water heaters registered under HS841912, top countries importing (eft) and exporting (right) to the EU 2022 [EUR Million]



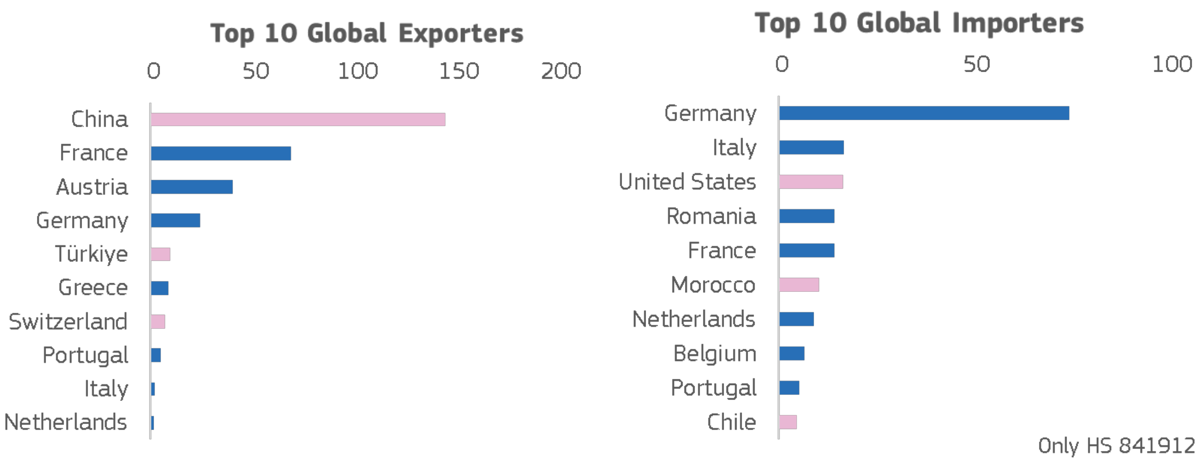
Source: JRC based on COMEXT data

Figure 22: Trade in solar water heaters registered under HS841912: top EU Member States importing (left) and exporting (right) in 2022[EUR Million]



Source: JRC based on COMEXT data

Figure 23: Global trade in solar water heaters registered under HS841912: top countries exporting (left) and importing (right) for 2022 [EUR Million].



Source: JRC based on COMTRADE data

[22] *Latest year data (2022) may be incomplete for comtrade, because it does not provide estimates for the missing values as comext does.*

4.3 Resource efficiency and dependence in relation to EU competitiveness

The EU industry associated with CSP is relatively small and not known to use any imported materials subject to restrictions in terms of supply and availability. In terms of the EU's critical raw material list, its uses copper, potentially also aluminium in structural parts, and rare earths in generators.

For solar thermal systems, main materials in collectors include copper, aluminium and glass. The sector claims a 95% recycling rate (for both weight and volume) for systems [36]. There are considerable opportunities for improving circular economy concepts [39] and reducing environmental impact [40].

5 Conclusions

A broad range of solar thermal technologies (both concentrated and non-concentrated) are available to support the decarbonisation of the energy system.

Although, over the last decade, the concentrated solar power sector has made progress in reducing costs and establishing a reliable track record for electricity generation, global market growth remains modest. The latest generation of CSP plants targets a plant size of 100 MW with molten salts for heat transfer and storage (typically 8 hours). Hybridisation with PV systems is also increasingly a feature. R&D efforts are in progress to develop higher efficiency systems using peak temperatures above 600°C and heat transfer with CO2, liquid sodium or other media. In Europe, no new commercial systems have been built for several years. The EU nonetheless remains a leader in R&D in terms of scientific publications and high value patents, although it was overtaken by China in 2020.

For solar thermal heat and cool, the EU is also a leader in terms of technology, although it represents only approximately 10% of the global market. Increasing gas prices and security of supply concerns have given new impetus to the EU market. Both concentrated and non-concentrated systems offer the potential for supplying industrial process heat and district heat systems. Continued efforts on cost reduction and integrated system concepts are needed.

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List of abbreviations and definitions

CAPEX Capital Expenditure

CPC common patent

CSP Concentrated (concentrated) Solar [thermal] Power

CSH Concentrated (concentrated) Solar [thermal] Heat

CSHIP Concentrated Solar Heat for Industrial Processes

CR(S) central receiver (system), aka solar tower system

DH District heating

DHC District heating and cooling

DNI Direct normal irradinace

EPC engineering, procurement and construction

ETS Emission Trading System

EU European Union

FiT feed-in tariff

FOAK First–of-a-Kind

HTF heat transfer fluid

IA Innovation Action

IEA International Energy Agency

IRENA International Renewables Energy Agency

ISCC integrated solar combined cycle

IP Implementation Plan

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

PVT photovoltaic thermal [hybrid device]

RES Renewable Energy Source

RIA Research and Innovation Action

SHIP Solar Heat for Industrial Processes

STE solar thermal electricity

TES thermal energy storage

TRL Technology Readiness Level

RHC ETIP: European Technology and Innovation Platform on Renewable Heating and Cooling

RHC Renewable Heating and Cooling

FP7 Seventh Framework Programme

H2020: Horizon 2020,

HE Horizon Europe

SET Plan: Strategic Energy Technology Plan

IWG: Implementation Working Group

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Annex 1 Summary Table of Data Sources for the CETO Indicators

Theme	Indicator	Main data source
Technology maturity status, development and trends	Technology readiness level	Literature SET-Plan roadmaps ETIP strategic research agendas
	Installed capacity & energy production	CSP-Guro (IEA SolarPaces) Eurobsev'ER Barometer Solar Heat Worldwide (IEA TCP SHC)
	Technology costs	NREL ATB POLES-JRC, POTEnCIA
	Public and private RD&I funding	JRC analysis of VC and patents
	Patenting trends	JRC patent analysis
	Scientific publication trends	JRC TIM
	Assessment of R&I project developments	Not assessed for 2023
Value chain analysis	Turnover	Solar Heat Worldwide (IEA TCP SHC) Solar Heat Europe
	Gross Value Added	No data found
	Environmental and socio-economic sustainability	See annex 2
	EU companies and roles	Eurobsev'ER solrico
	Employment	IEA, IRENA, Solar Heat Worldwide
	Energy intensity and labour productivity	No data found
	EU industrial production	JRC PRODCOM analysis (proxy analysis due to lack of solar thermal code)
global markets and EU positioning	Global market growth and relevant short-to-medium term projections	Eurobsev'ER, Solar Heat Worldwide (IEA TCP SHC), Solar Heat Europe
	EU market share vs third countries share, including EU and global market leaders	See above
	EU trade (imports, exports) and trade balance	JRC COMEXT analysis
	Resource efficiency and dependencies (in relation EU competiveness)	Literature

Annex 2 Sustainability Assessment Framework

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 See examples: C. Lamnatou, D. Chemisana, Concentrated solar systems: Life Cycle Assessment (LCA) and environmental issues, Renewable and Sustainable Energy Reviews, Volume 78, October 2017, Pages 916-932 Milousi, M. et al, Evaluating the Environmental Performance of Solar Energy Systems Through a Combined Life Cycle Assessment and Cost Analysis. Sustainability 2019, 11, 2539.
GHG emissions	CSP: Most studies arrive at values well below 40 gCO2eqv/kW E.g. The H2020 PreFlexMS project 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. NB It is not clear to what extent CO2 release during site preparation are taken into account. SHC: Flat plate collector: 23.8 gCO2eqv/kWh; vacuum tube collector 22.2 gCO2eqv/kWh [xx]
Energy balance	CSP: Studies give an energy payback time of less than 1 year SHC: no data found up to now
Ecosystem and biodiversity impact	CSP: No studies have been located so far regarding methodologies for assessing impact on biodiversity or on the natural environment.
Water use	CSP: 3.5 m3/MWh (in operation, with wet cooling) NB 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 field, but no specific studies identified so far
Hazardous materials	Not directly in installed systems but checks needed for the component supply chain e.g. for use of REACH materials
Economic Parameters/Indicators:	
LCC standards or best practices	Not known

Parameter/Indicator	Input
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 silver for mirrors in the solar field.
Resource efficiency and recycling	CSP: The H2020 PreFlexMS project 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 [37]. A more detailed breakdown is not available.
Contribution to GDP	No information
Rural development impact	Can provide jobs in rural areas both during construction and during operation
Industrial transition impact	Yes
Affordable energy access (SDG7)	Yes, CSP can contribute
Safety and (cyber)security	No technology-specific information available at this point in time

Parameter/Indicator	Input
Energy security	CSP and SHC 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

Annex 3 Energy system models and scenarios used in CETO

A3.1 POTEnCIA Model Overview

The Policy Oriented Tool for Energy and Climate Change Impact Assessment (POTEnCIA) is an energy system simulation model designed to compare alternative pathways for the EU energy system, covering energy supply and all energy demand sectors (industry, buildings, transport, and agriculture). Developed in-house by the European Commission's Joint Research Centre (JRC) to support EU policy analysis, POTEnCIA allows for the joint evaluation of technology-focused policies, combined with policies addressing the decision-making of energy users. To this end:

- By simulating decision-making under imperfect foresight at a high level of techno-economic detail, POTEnCIA realistically captures the adoption and operation of new energy technologies under different policy regimes;
- By combining yearly time steps for demand-side planning and investment with hourly resolution for the power sector, POTEnCIA provides high temporal detail to suitably assess rapid structural changes in the EU's energy system;
- By tracking yearly capital stock vintages for energy supply and demand, POTEnCIA accurately represents the age and performance of installed energy equipment, and enables the assessment of path dependencies, retrofitting or retirement strategies, and stranded asset risks.

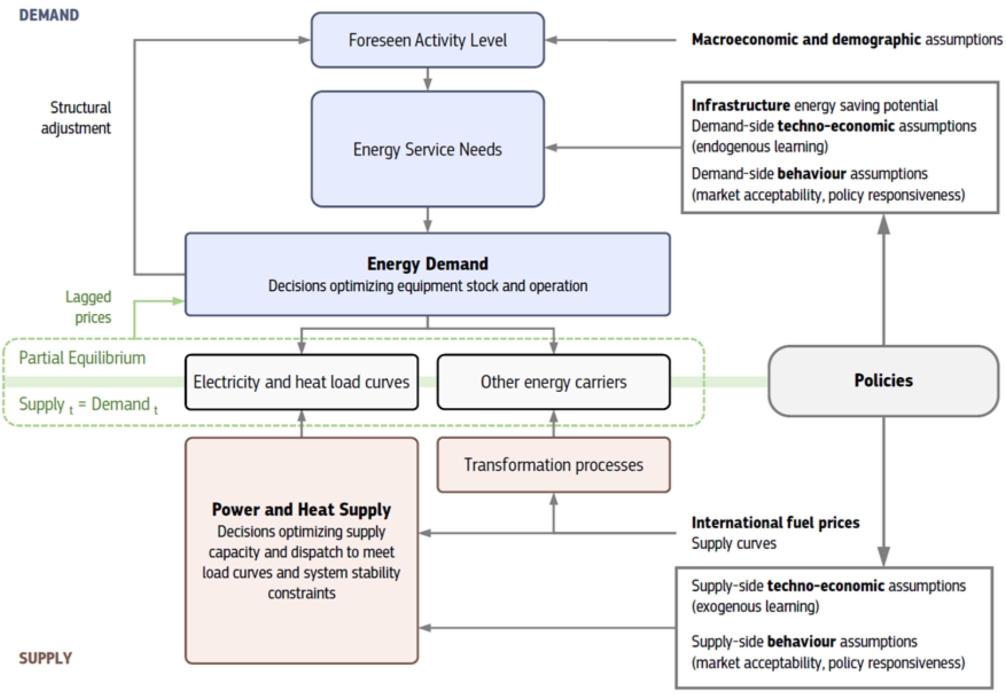
The core modelling approach of POTEnCIA (Figure A3-1; detailed in the POTEnCIA model description and in the POTEnCIA Central Scenario report) focuses on the economically-driven operation of energy markets and corresponding supply-demand interactions, based on a recursive dynamic partial equilibrium method. As such, for each sector of energy supply and demand, this approach assumes a representative agent seeking to maximize its benefit or minimize its cost under constraints such as available technologies and fuels, behavioural preferences, and climate policies. This core modelling approach is tailored to each sector, for instance to represent different planning horizons and expectations about future technologies under imperfect foresight. In particular, power dispatch modelling uses a high time resolution with full-year hourly dispatch to suitably depict the increasing need for flexibility from storage and demand response, and the changing role of thermal generation in a power system dominated by variable renewable energy sources. Within this sector modelling framework, investment decisions of the representative agents are simulated with discrete-choice modelling. The model then finds an overall equilibrium across different sectors using price signals for resources such as traditional and renewable energy carriers while accounting for efficiency and environmental costs.

This core modelling approach is implemented individually for each EU Member State to capture differences in macroeconomic and energy system structures, technology assumptions, and resource constraints. The national model implementation is supported by spatially-explicit analyses to realistically define renewable energy potentials and infrastructure costs for hydrogen and CO2 transport. Typical model output is provided in annual time steps over a horizon of 2000-2070; historical data (2000-2021) are calibrated to Eurostat and other official EU statistics to provide accurate initial conditions, using an updated version of the JRC Integrated Database of the European Energy System (JRC-IDEES). JRC-IDEES has been developed in parallel to POTEnCIA, and an updated release is planned in 2024 to ensure the transparency of POTEnCIA's base-year conditions and to support further research by external stakeholders.

A3.2 POTEnCIA CETO Climate Neutrality Scenario overview

The technology projections provided by the POTEnCIA model are obtained under a Climate Neutrality Scenario aligned with the broad GHG reduction objectives of the European Green Deal. As such, this scenario reduces net EU27 GHG emissions by 55% by 2030 versus 1990, and reaches the EU27´s climate neutrality by 2050 under general assumptions summarized in Table A3-1. To suitably model technology projections under these overarching GHG targets, the scenario includes a representation of general climate and energy policies such as emissions pricing under the Emissions Trading System, as well as key policy instruments that have a crucial impact on the uptake of specific technologies. For instance, the deployment of bioenergy and renewable power generation technologies to 2030 is consistent with the EU's Renewable Energy Directive target (42.5% share of renewables in gross final energy consumption by 2030). Similarly, the adoption of alternative powertrains and fuels in transport is also promoted by a representation of updated CO2 emission standards in road transport and by targets of the ReFuelEU Aviation and FuelEU Maritime proposals.

Figure A3-1. The POTEnCIA model at a glance



Source: Adapted from the POTEnCIA Central scenario report

Table A3-1. General assumptions of the POTEnCIA CETO Climate Neutrality Scenario

General scenario assumptions	Modelled scenario and policy assumptions
GDP growth by Member State	GDP projections based on EU Reference Scenario 2020, with updates to 2024 from DG ECFIN Autumn Forecast 2022
Population by Member State	Population projections based on EU Reference Scenario 2020, with updates to 2032 from EUROPOP 2019
International energy markets	Natural gas import projections consistent with REPowerEU targets for supply diversification and demand reduction. International fuel price projections to 2050 aligned with REPowerEU

Source: JRC, 2023

A3.3 POLES-JRC Model

POLES-JRC (Prospective Outlook for the Long term Energy System) is a global energy model well suited to evaluate the evolution of energy demand and supply in the main world economies with a representation of international energy markets. POLES-JRC is hosted at the JRC and is particularly adapted to assess climate and energy policies.

POLES-JRC covers the entire energy system, from primary supply (fossil fuels, renewables etc.) to transformation (power, biofuels, hydrogen) and final sectoral demand (Figure A3-2). International markets and prices of energy fuels are simulated endogenously. Its high level of regional detail (66 countries & regions covering the world with full energy balances, including all OECD and G20 countries) and sectoral description allows assessing a wide range of energy and climate policies in all regions within a consistent global framework: access to energy resources, taxation policy, energy efficiency, technological preferences, etc. POLES-JRC operates on a yearly basis up to 2050 and is updated yearly with recent data and model updates.

The POLES-JRC model is used to assess the impact of European and international energy and climate policies on energy markets and GHG emissions, by DG CLIMA in the context of international climate policy negotiations and by DG ENER in the context of the EU Energy Union.

POLES-JRC has also been applied for the analyses of various Impact Assessments in the field of climate change and energy, among them: the “Proposal for a revised energy efficiency Directive” (COM(2016)0761 final) and “The Paris Protocol – A blueprint for tackling global climate change beyond 2020” (COM(2015) 81 final/2).

Moreover, POLES-JRC provided the global context to the EU Long-Term Strategy (COM(2018) 773) and formed the energy/GHG basis for the baseline to the CGE model JRC-GEM-E3.

POLES-JRC forms part of the Integrated Assessment Modelling Consortium (IAMC) and participates in inter-model comparison exercises with scenarios that feed into the IPCC Assessment Reports process.

POLES-JRC results are published within the series of yearly publications "Global Climate and Energy Outlooks – GECO". The GECO reports along with detailed country energy and GHG balances and an on-line visualisation interface can be found at: https://ec.europa.eu/jrc/en/geco

A3.3.1 Power system

POLES-JRC considers 37 power generating technologies, covering existing technologies as well as emerging technologies. Each technology is characterised by its installed capacity, cost parameters (overnight investment cost, variable & fixed operating and maintenance cost), learning rate and other techno-economic parameters (e.g. efficiencies). The cost evolution over time is taken into account by technology learning driven by accumulated capacity.

For renewable technologies maximum resource potentials are taken into account. Similarly, the deployment of carbon capture and storage (CCS) technologies is linked to region-specific geological storage potential. In addition to these technical and economic characteristics, non-cost factors are applied to capture the historical relative attractiveness of each technology, in terms of investments and of operational dispatch.

With regard to the clean energy technologies covered by CETO, the model includes power generation using photovoltaics (utility and residential), concentrated solar power (CSP), on-shore and off-shore wind , ocean energy, biomass gasification and steam turbines fuelled by biomass, geothermal energy as well as hydropower. CCS-equipped combustion power technologies are considered as well. Moreover, electricity storage technologies such as pumped hydropower storage and batteries are also included.

A3.3.2 Electricity demand

The total electricity demand is computed by adding the electricity demand from each sector (i.e. residential, services, transport, industry and agriculture). The evolution over time of the sectoral electricity demand is driven by the activity of each sector and competition between prices for electricity and other fuels.

POLES-JRC uses a set of representative days with an hourly time-step in order to capture load variations as well as to take into account the intermittency of solar and wind generation. The usage of representative days also allows to capture hourly profiles by sector and end-uses.

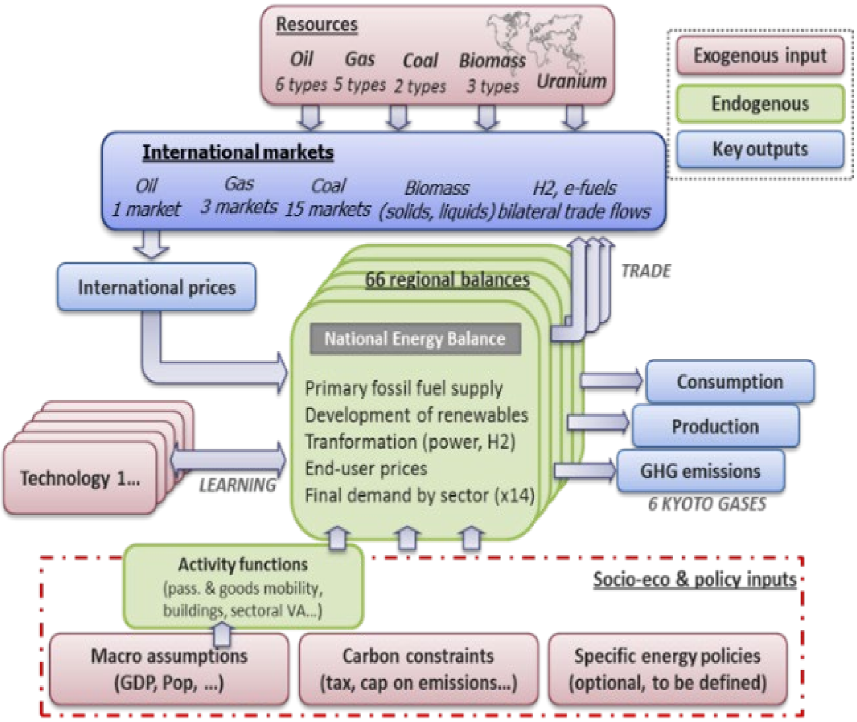
With a view to other CETO technologies influencing electricity consumption, the model includes heat pumps in the residential and service sector, batteries for electric vehicles and electrolysers.

A3.3.3 Power system operation and planning

The power system operation assigns the generation by technology to each hour of each representative day. The supplying technologies and storage technologies must meet the overall demand.

The capacity planning considers the existing structure of the power mix (vintage technology), the expected evolution of the demand, and the production cost of technologies.

Figure A3-2. *Schematic representation of the POLES-JRC model architecture*



Source: JRC, 2023

A3.3.4 Hydrogen

POLES-JRC takes into account several hydrogen production routes: (i) low temperature electrolysers using power from the grid or power from solar and wind, (ii) steam reforming of natural gas (with and without CCS), (iii) gasification of coal and biomass (with and without CCS), (iv) pyrolysis of coal and biomass as well as high temperature electrolysis using nuclear power.

Hydrogen can used as fuel in all sectors. Moreover, hydrogen is used to produce fertilisers as well as to produce fuels used in the transport sector (i.e. gaseous and liquid synfuels and ammonia). POLES-JRC models global hydrogen trade and considers various means of hydrogen transport (pipeline, ship, truck, refuelling station).

A3.3.5 Bioenergy

POLES-JRC receives information on land use and agriculture through a soft-coupling with the GLOBIOM model[23]. This approach allows to model bioenergy demand and supply of biomass adequately by taking into account biomass potential, production cost and carbon value. Moreover, the emissions from land use and forestry (CO2) as well as agriculture (CH4 and N2O) are derived from GLOBIOM.

Power generating technologies using biomass are biomass gasification (with and without CCS) and biomass fuelled steam turbines.

Hydrogen can be produced from biomass via gasification and pyrolysis. Moreover, the production of 1st and 2nd generation biofuels for gasoline and diesel is considered.

A3.3.6 Carbon Capture Utilization and Storage (CCUS)

POLES-JRC takes into account CCUS technologies for:

[23] Global Biosphere Management Model (GLOBIOM) model description. International Institute for Applied Statistical Analysis, Laxenburg, Austria. http://www.globiom.org

- Power generation: advanced coal using CCS, coal and biomass gasification with CCS, and gas combined cycle with CCS;
- Hydrogen production: Steam reforming with CCS, coal and biomass gasification with CCS, and coal and biomass pyrolysis;
- Direct air capture (DAC) where the CO2 is stored or used to produce synfuels (gaseous or liquid);
- CO2 storage in geological sites.

A3.3.7 Model documentation and publications

A detailed documentation of the POLES-JRC model and publications can be found at:

- https://publications.jrc.ec.europa.eu/repository/handle/JRC113757
- https://ec.europa.eu/jrc/en/poles

A3.4 POLES-JRC CETO Global 2°C Scenario

The global scenario data presented in this CETO technology report refers to a 2°C scenario modelled with the POLES-JRC model. The 2°C scenario assumes a global GHG trajectory consistent with a likely chance of meeting the long-term goal of limiting the temperature rise over pre-industrial period to 2°C in 2100.

The 2°C scenario was designed with a global carbon budget over 2023-2100 (cumulated net CO_2 emissions) of approximately 1150 $GtCO_2$, resulting in a 50% probability of not exceeding the 2.0°C temperature limit in 2100. A single global carbon price for all regions is used in this scenario, starting immediately (2023) and strongly increasing. The 2°C scenario is therefore a stylised representation of an economically-efficient pathway to the temperature targets, as the uniform global carbon price ensures that emissions are reduced where abatement costs are lowest. This scenario does not consider financial transfers between countries to implement mitigation measures.

The POLES-JRC model has been updated with the latest technologies costs from recent literature. Most of the historic data used in the 2°C scenario refers to data used in the GECO 2022 scenarios (energy balances, energy prices, capacities).

Annex 4 Horizon Europe projects on solar thermal technology

Acronym	Title	Type of Action	Budget	Start Date	Duration (months)
ABraytCSPfuture	Air-Brayton cycle concentrated solar power future plants via redox oxides-based structured thermochemical heat exchangers/thermal boosters	HORIZON-RIA	2,995,458	01-11-2022	48
ASTERIx-CAESar	Air-Based Solar Thermal Electricity For Efficient Renewable Energy Integration & Compressed Air Energy Storage	HORIZON-IA	5,270,925	01-10-2023	48
CoMeTES	Performance study of innovative Corrosion and Mechanically resistant coated materials against molten salts for next-generation concentrated solar power plants and Thermal Energy Storage systems	HORIZON-TMA-MSCA-PF-EF	165,313	01-10-2023	24
CST4ALL	Support To The Activities Of The Concentrated Solar Thermal Technology Area Of The Set Plan	HORIZON-CSA	599,529	01-10-2022	36
DynaMOST	Excited-State Dynamics of Molecular Solar Thermal Fuels	HORIZON-TMA-MSCA-PF-EF	199,441	01-10-2023	24
ONESTEP	Optimized Nanofluids for Efficient Solar Thermal Energy Production	HORIZON-TMA-MSCA-PF-EF	263,639	01-05-2023	30
PYSOLO	PYrolysis of biomass by concentrated SOLar pOwer	HORIZON-RIA	4,997,163	01-07-2023	48
SecRHC-ETIP2022-2025	Secretariat of the European Technology and Innovation Platform on Renewable Heating and Cooling in 2022-2025	HORIZON-CSA	1,049,387	01-09-2022	36
SolarHub	A Greek-Turkish Solar Energy Excellence Hub to Advance the European Green Deal	HORIZON-CSA	4,846,397	01-01-2023	48
SOLARX	Dispatchable concentrated Solar-to-X energy solution for high penetration of renewable energy	HORIZON-RIA	2,671,826	01-11-2022	36

Acronym	Title	Type of Action	Budget	Start Date	Duration (months)
SULPHURREAL	An innovative thermochemical cycle based on solid sulphur for integrated long-term storage of solar thermal energy	HORIZON-EIC	3,982,133	01-10-2023	36
SUNSON	Concentrated Solar energy storage at Ultra-high temperatures aNd Solid-state cONversion	HORIZON-RIA	2,999,938	01-12-2022	42
TOPCSP	Towards Competitive, Reliable, Safe and Sustainable Concentrated Solar Power (CSP) Plants	HORIZON-TMA-MSCA-DN	2,576,261	01-10-2022	48
Total			32,617,408		

Source: JRC, 2023, from CORDIS and COMPAS data

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