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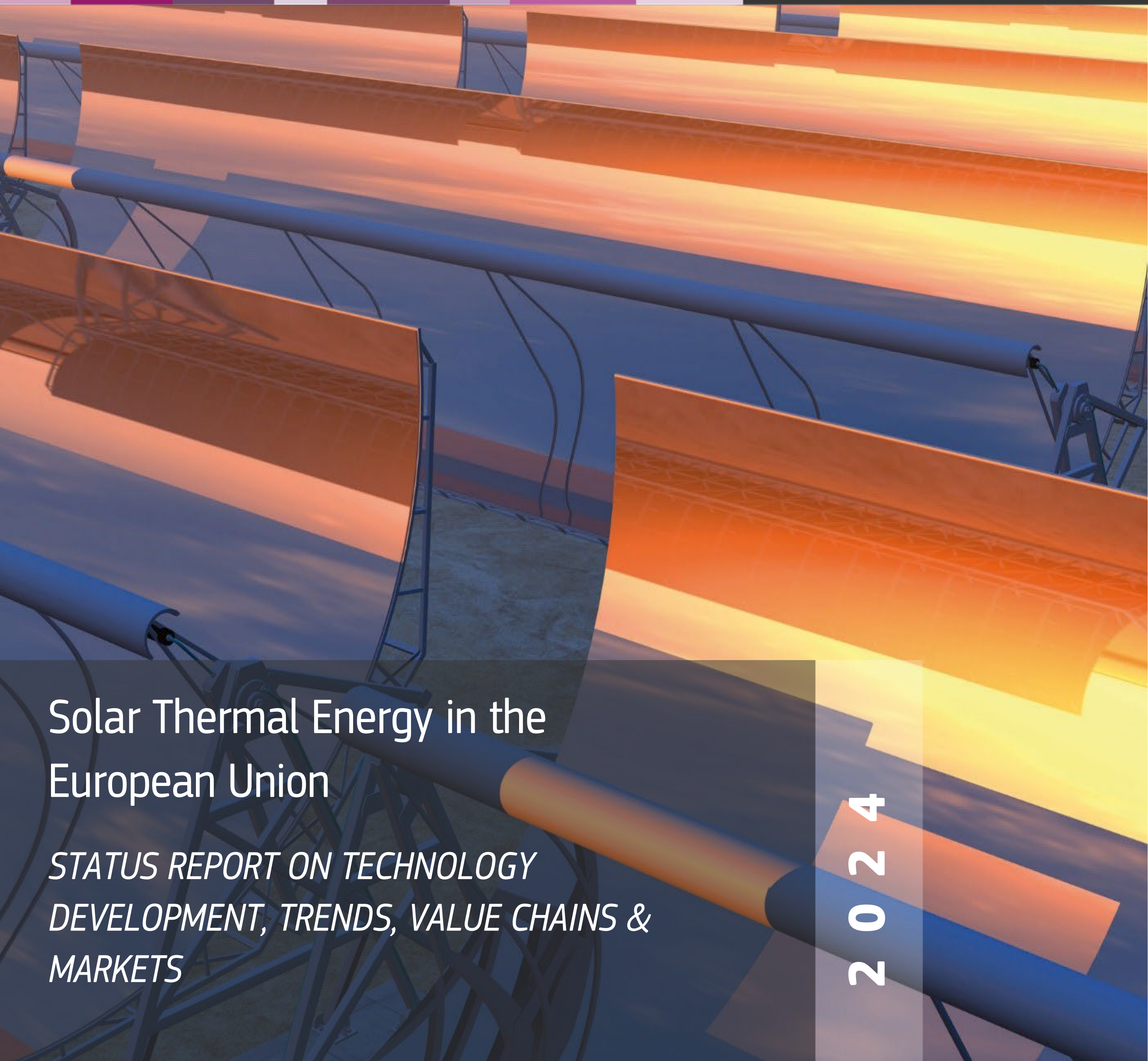

Solar Thermal Energy in the European Union

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

2024

EUR 40064

Joint Research Centre

Contact information
Names: Johan Carlsson (solar thermal), Nigel Taylor (CSP)
Emails: johan.calsson@ec.euroopa.eu, 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 and development 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 decarbonising the energy system, and global market growth remains modest. The EU has not added to the existing fleet of CSP plants since 2013 and targeted auctions may be needed to increase deployment.. In the meantime China is emerging as the main developer of CSP systems thanks to a steady project pipeline. Solar thermal technologies for heating and cooling had a challenging year, with a growth of only 3%. Investments slowed 24% due to competition from other technologies such as heat pumps, and because important support schemes ended in Italy, Germany and Poland. Some countries, such as Denmark, show robust growth in solar district heating, where 150 district systems use solar thermal heat. Also the solar heat market for industrial processes tripled globally in 2023 compared to 2022. 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

Carlsson, J, JRC.C.7

Taylor, N., JRC.C.2

Georgakaki, A., JRC.C.7

Letout, S., JRC.C.7

Mountraki, A. , JRC.C.7

Ince, E. , JRC.C.7

Schmitz A., JRC.C.6

Gea Bermudez, J., JRC.C.6

Executive Summary

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

Concentrated solar power currently plays a minor role in the energy system, providing much less than 1% of annual electricity generation worldwide (0.2% in the EU). The two main design types are parabolic trough power plants and central receiver systems, both with thermal storage sufficient for the plant to deliver power for several hours at the rated capacity after sundown. CSP can also be hybridised with other power generation technologies, in particular, with photovoltaics systems. Global CSP market growth remains modest. The majority of projects in development are in China. The EU has made little progress yet on its plans to add to the existing capacity of 2.33 GW. Much now relies on Spain's commitment in the draft 2023 NECP to add 2.4 GW of CSP capacity by 2030.

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. However, to become more competitive further standardisation in design and manufacturing is 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, but needs to be integrated with production processes to ensure cost cutting. Digitisation in all phases needs also to be fully embraced. In principle, EU companies manufacture all the components needed for CSP plants, but with the lack of new projects, many are exploring the industrial process heat market as an alternative.

In 2023, the installed capacity of solar thermal heat in the EU slowed down to an increase of 1.3 GWth (3.3%) to reach 41 GWth. This is far below the rate required to tripe capacity by 2030. A range of solar thermal technologies address the heating and cooling sector. Commercial options (including storage) are available for buildings, district heating networks, and industrial processes, although overall market penetration remains low. An exception is solar water heaters, widely used in several Mediterranean regions.

Large-scale solar thermal systems are used in 282 European cities' district heating systems (approximately 5% of DH systems and contribute 0.2% of the heat supply). Six new solar thermal systems for district heating networks started operation in 2023, and nine systems are under construction or in an advanced planning stage. The world market for solar heat for industrial processes tripled in 2023 compared to the previous two years, with 116 projects reaching a total of 0.95 GWth.

The levelised cost of heat can be competitive with other conventional sources, particularly in areas with good solar resources. EU companies are in a good position as technology suppliers. Traditionally, they have supplied 90% of the EU demand for solar thermal water heaters, but COMEXT trade data for 2022-2023 indicate significantly increased imports, particularly from China. As the market has not grown much, this indicates that EU companies are losing market share. Further efforts on cost reduction may be needed to maintain competitiveness.

Research funding for all solar technologies has decreased in real terms over the last decade, except for increasing late-stage venture capital investments. The USA, Japan, China, Germany, and France are the most innovative companies regarding patents by corporations and investments in VC companies. High-value patents in the sectors have declined globally since 2010, indicating reduced

interest from the industry actors. The EU employment in this sector also continued the downward trend in 2023.

Solar thermal energy faced deployment challenges similar to other renewable heating technologies. Higher interest rates have led to reduced investments and a slower pace of upgrading heat infrastructure. Competition among heating and cooling technologies, such as heat pumps and solar PV, negatively impacted solar thermal sales.

At the same time, the EU has a strong need to accelerate the decarbonisation of the heating and cooling sector. There is increasing European policy support for solar thermal heat applications. For example, the new Energy Performance for Buildings Directive requires new buildings to be prepared for solar PV and solar thermal, and the Renewable Energy Directive emphasises the introduction of solar thermal heat in individual buildings, district heating, and industry.

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, 2024

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, Energy Label, Renewable Energy Directive, and Energy Performance of Buildings Directive requirements for space and water heating – No use of critical raw materials s and good circularity potential)	– Cost competitiveness is strongly dependent on the price of fossil fuels – Not a standalone solution and requires integration with other heat or cool technologies 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 – Potential for larger use in District Heating and Cooling networks	– Competition from heat pump systems – Low-cost imported solar heating and cooling systems

Source: JRC, 2024

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 addresses technology maturity status, development and trends; value chain analysis and global market and EU positioning. For 2024, the scope covers:

a) Concentrated solar power (CSP[1]) 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) is used for buildings, district networks, and industrial processes; thermal storage is often integral to the systems.

This report builds to a large degree on previous Commission studies in this field [1, 2, 3], the 2024 EurObserv'ER barometer on solar thermal [4], and the Solar Thermal Market Outlook 2023/2024 [5].

For the power sector, CSP technologies have developed to a commercial scale but play only a minor role – in 2022 CSP generated-electricity provided 0.04% globally and 0.2% in the EU. 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 southern-most areas offer suitable conditions. The two major designs used today are parabolic trough power plants and central receiver (also called power tower) plants. 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. The use of concentrated solar energy to drive thermochemical fuel synthesis is addressed in the CETO solar fuels report [6].

The heating and cooling sector accounts for 50% of global energy consumption and 40% of CO_2 emissions in the EU, and solar thermal technologies can potentially provide a significant share of its renewable energy. The market for low (<100°C) and medium temperature (100-500°C) 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 [7].

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 indicative annual increase should be 2.2%. 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 cooling using absorption systems, 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 district heating applications, often as part of an integrated solution with

[1] *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.*

other heat sources to ensure supply continuity [8, 9, 10]. 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. The most common applications of solar thermal heat are space heat and domestic hot water for individual buildings. Low-temperature collectors are usually glazed flat panels combined with another heating supply and thermal storage. Medium-temperature collectors can have different designs, such as drain-back or batch systems.

Solar thermal technologies (concentrated and non-concentrated) are considered a strategic net-zero technology in the Net Zero Industry Act [11]. They are also part of the EU's 2024 joint research and innovation agenda on solar energy [12].

1.2 Methodology and Data Sources

The report addresses CSP and solar thermal technologies separately, with each section following the CETO structure of specific topics or indicators, as follows:

a) Technology maturity status, development and trends

- technology readiness level
- installed capacity & energy production
- technology costs
- public RD&I funding
- venture capital investments
- patenting trends
- scientific publication trends
- assessment of EU-funded R&I projects

b) Value chain analysis:

- Turnover;
- Environmental and socio-economic sustainability;
- EU companies and roles;
- Employment;
- EU industrial production.

c) Global markets and EU positioning

- 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 to EU competitiveness).

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

2 Concentrated Solar Power

2.1 Technology status and development trends

Table 3 sets out the technology characteristics of current commercial systems. Parabolic trough designs are the most widely deployed up to now. However 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	**Trough Designs**	**Solar Tower designs**
Reflectors	Parabolic or Fresnel Linear Reflectors	Heliostat field
Receiver	Line absorbers with high absorptivity (>95%) and low emissivity (<10%);	Central metallic point receivers
Heat Transfer Fluid	Thermal oil at max. 395 °C	Molten salt or steam; max. working fluid temperatures of 570 °C
Thermal 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 (recirculating evaporative cooling)	3.43 m^3/MWh[3] [13]	2.98 m^3/MWh [13]
CO_2 footprint	22 gCO_2/kWh Europe: 99.8 gCO_2/kWh, China 129.7 gCO_2/kWh (25 year life)	

Source: JRC, 2024

Hybrid PV-CSP plant design are also increasingly being considered to fully use grid connections. PV systems can also provide power to the ancillary systems (circulation pumps, control systems etc.),

[2] 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 (or full hour hours) 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] These values refer to the recirculating evaporative cooling system used in most plants. 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. This is consumed water (no return flows), and is dominated (>90%) by losses of from condensation of the cooling water. Water use for mirror cleaning contributes only 1.4 to 2 %..

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.

The SET-Plan implementation working group (IWG) has set the following targets as part of the 2023 planning document the "Initiative for Global Leadership in Concentrated Solar Power" [14]:

- 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% to 42.4% 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.

2.1.1 Technology readiness level

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 alternative heat transfer concepts, such air, supercritical CO2 or liquid metal concepts, coupled with high temperature and economic heat storage methods.

The SET-Plan IWG's "Initiative for Global Leadership in Concentrated Solar Power" [14] includes a series pf proposed research and innovation activities and associated TRL levels. Annex 2 provides a summary of these.

2.1.2 Installed Capacity and Production

The worldwide capacity of CSP plants is estimated at 6.7 GW at the end of 2023 [15, 16]. The global market has grown slowly over the last 12 years, with significant variations in the annual installations. There are now 83 operational plants in 11 countries. Spain has the largest fleet, followed by USA and China. REN21 report that China has 1 GW under construction and 3 GW planned, and is expected to become the global leader for deployment and technology supply in the coming years.

The medium to long term energy system models give mixed perspectives:

a) The IEA's 2023 *Net Zero by 2050 scenario* [17] projects 139 TWh (48 GW) from CSP in 2030, and 1 486 TWh (427 GW) by 2050. However, the current deployment rate is far from the level required to reach such values.

b) The JRC's *Global CETO 2°C scenario 2024* (POLES-JRC model, see Annex 3 for more details) [19] projects a doubling of installed capacity more to almost 17 GW in 2030 (26 TWh) and further increasing to 51 GW (78 TWh) in 2050.

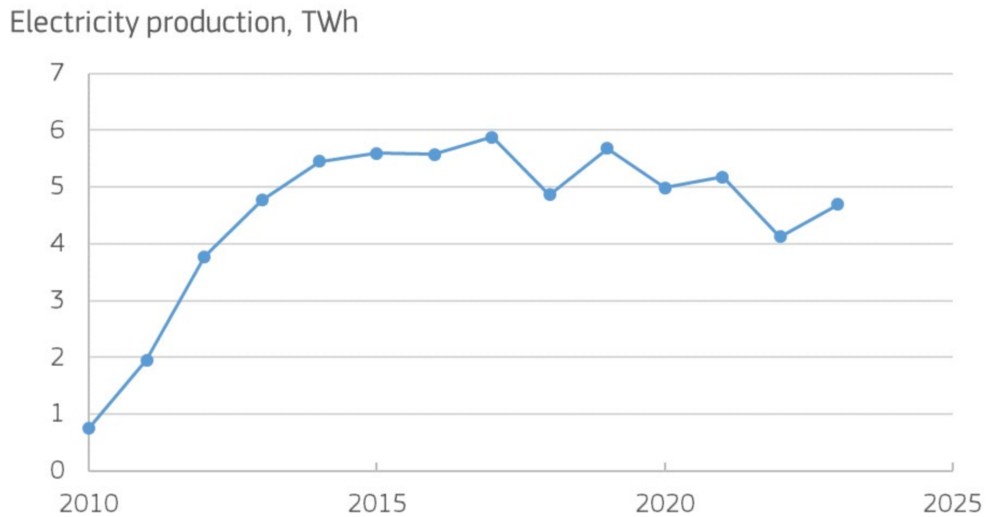
c) The IRENA *World Energy Transition Outlook 2023* [18] is the most ambitious, going as far as envisaging approximately 3000 TWh by 2050, with the main CSP markets are expected to be in the Middle East and Asia-Pacific regions, particularly China and India.

The EU has an installed CSP capacity of 2.33 GW [20] with an annual production of approximately 5 TWh (**Figure 1**), corresponding to approximately 0.2% of electricity generation. Almost all of this is located in Spain, where 45 plants were installed in the period 2009-2013.

Looking to the future, Spain's revised National Integrated Energy and Climate Plan [21] aims for 4.8 GW of CSP by 2030 i.e., an additional 2.4 GW. There has been little progress on this so far, apart from the proposed Solgest-1 110 MW plant, although construction is yet to begin. Italy's draft 2023 NECP [21] foresees over 800 MW of CSP by 2030, and currently a small 4 MW plant is under construction in Sicily. The EurObserv'ER barometer [20] foresees a small growth in total capacity to 3 GW by 2030.

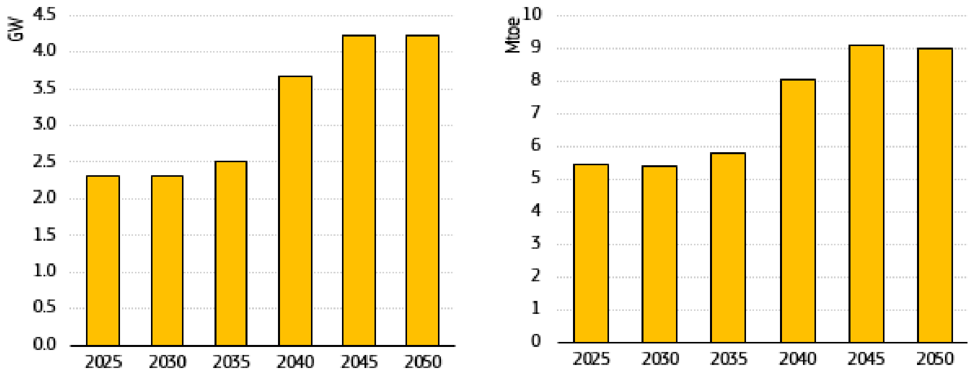
To create high detail energy scenarios for the EU27, JRC has developed the POTEnCIA model. Within the wider context of CETO, the model has been employed to create the POTEnCIA CETO 2024 Scenario [22] (see Annex 3 for more details). In this scenario, there is no increase in CSP capacity until 2030, but by 2050 capacities are projected to almost double towards 4.2 GW compared to 2020 values (**Figure 2**). In parallel, CSP generation increases from 5 TWh in 2025 to almost 9 TWh by 2050.

Figure 1 Electricity output of EU CSP plants.



Source: JRC elaboration of Eurostat data: NRG_BAL_PEH

Figure 2 CSP capacity (left) and generation (right) projections for the EU



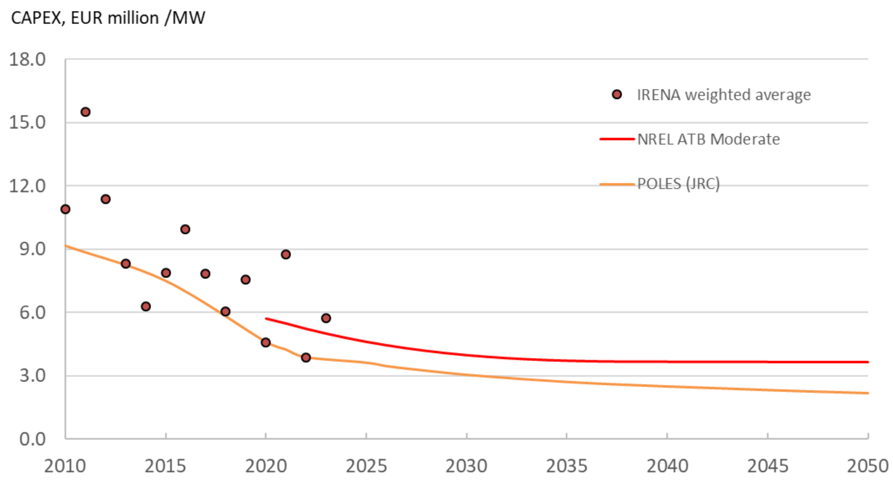
Source: POTEnCIA CETO 2024 Scenario

2.1.3 Technology Costs

Figure 5 shows the evolution in CAPEX for large CSP plants for 2010 to 2050. Up to 2023, IRENA data [23] is used. The 2010 to 2023 period saw a reduction of 40% in the annual average value (with significant variations in each year)) and is currently just under EUR 6 million/MW for a commercial-scale solar tower plant with at least 8 hours of thermal storage. The projections to 2050 are from the *Global CETO 2°C Scenario* based on the POLES-JRC model [19] and from NREL's *Annual Technology Baseline 2022* [24] (moderate scenario, solar resource class 7 with 2281 kWh/m2/y). Collectively these foreseen the potential to halve current CAPEX. This reflects the goals of both the EU SET Plan and US research programmes to reach a level of 3 EUR million/MW. Indeed CSP technology is considered to have significant scope for cost reductions in all areas: the solar field, the power block, high-temperature higher efficiency power cycles and thermal storage [25].

IRENA [23] also report that LCoE dropped by 70% from 2010 to2023 reaching an average of 106 EUR/MWh in 2023, but with a small sample of just two plants. It should be noted that the LCOE metric does not necessarily reflect the market value of CSP electricity sold to cover load peaks.

Figure 3. Historic and future CAPEX trends for CSP plants.

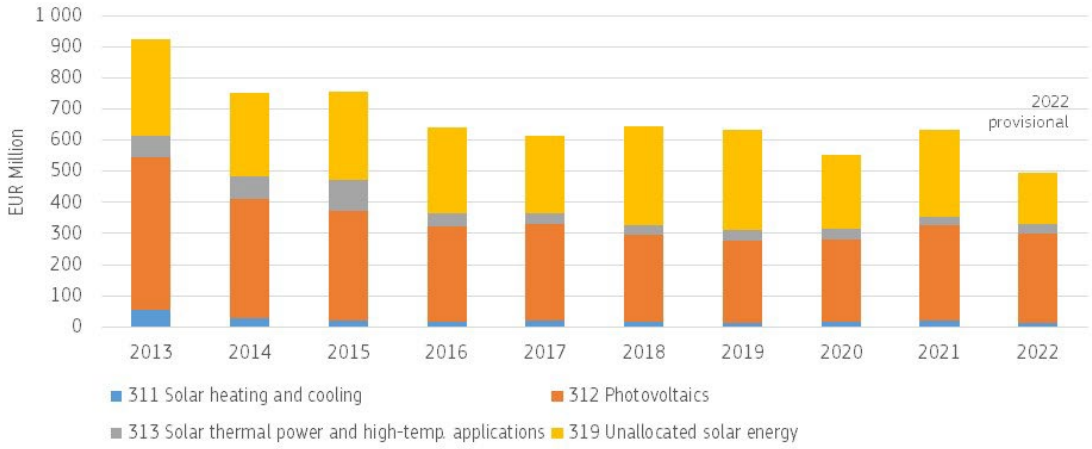


Source: JRC elaboration based on POLES-JRC, IRENA [23] and NREL ATB [24] data.

2.1.4 Public RD&I Funding and Investments

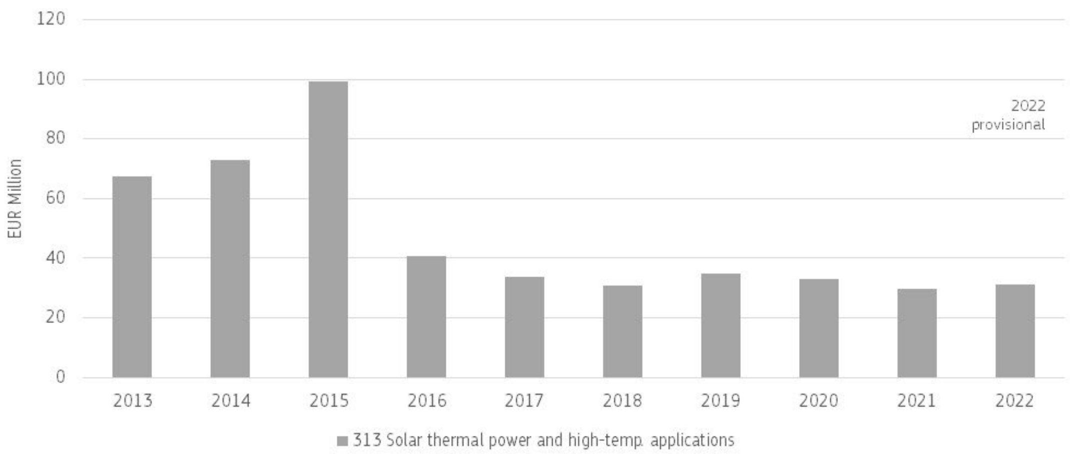
Data on public R&I investments in solar energy is collected annually by the IEA from its members [26]. In recent years over 50% of the declared budgets are reported as "unallocated", so without disaggregation to the various technology areas (e.g. such those reported by USA, the EU framework programme and Korea). **Figure 4** shows that for solar energy as a whole, the RD&D budgets have decreased in real terms from 2010 to 2022. For those countries that do report disaggregated values, the trend appears stable since 2016, so a decrease in real terms. (**Figure 5**). The data for the EU member states is rather incomplete, and several countries known to have active research in this area (e.g. Italy, Spain and Portugal) did not report disaggregated values. Hence no analysis can be reported.

Figure 4 Global data (current values) reported to the IEA for public RD&D funding for solar energy-



Source: JRC 2024 based on IEA data.

Figure 5 Available disaggregated public RD&D funding (current values) for solar thermal as reported to IEA NB the totals are current values. NB No data for the USA and for the EU Horizon programme.



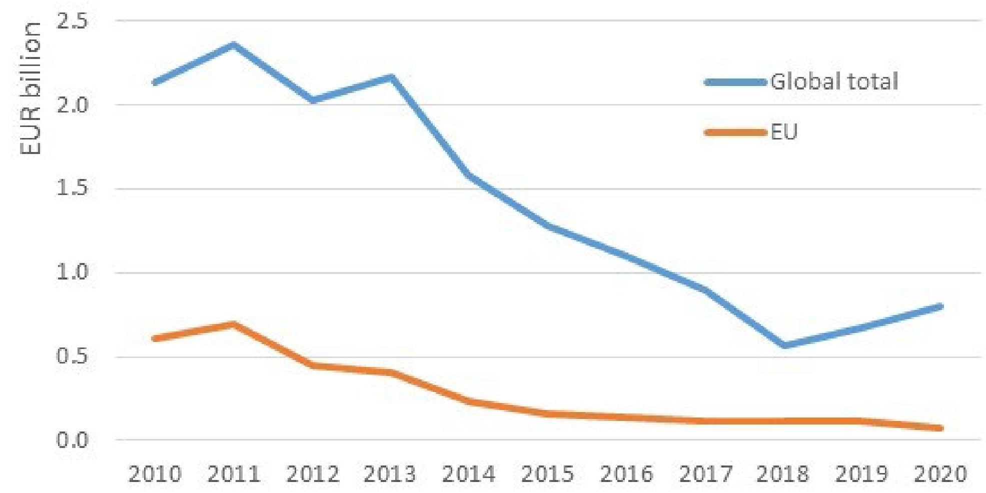
Source: JRC 2024 based on IEA.

2.1.5 Private RD&I funding

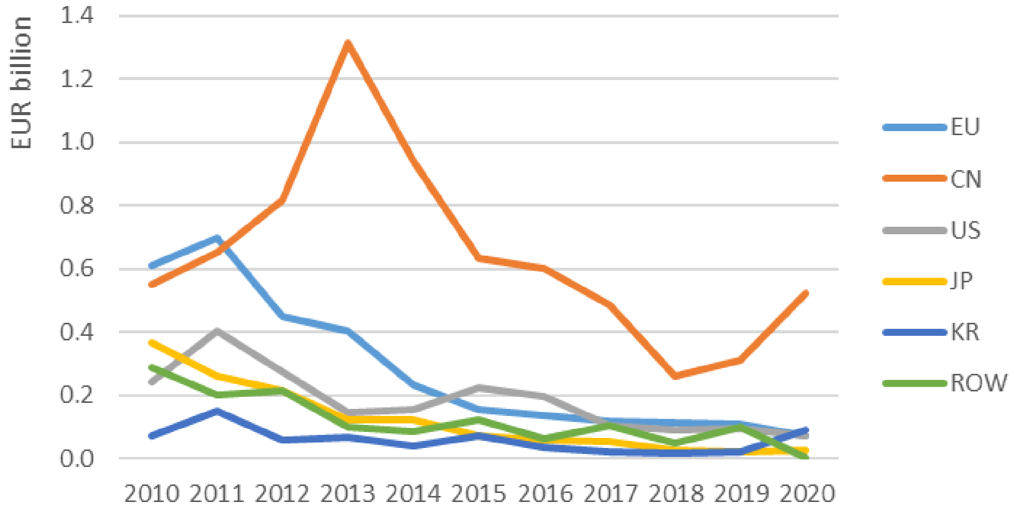
2.1.5.1 Overall private R&I investments based on patents

Figure 6 shows the overall decreasing trend during the decade 2010-2020 [27]. In the breakdown of the main economic regions, China is leader since 2012 and saw a marked upswing in 2019-2020. The EU was in second place, but was overtaken by Korea in 2020. **Table 4** shows the top organisations for R&D investments globally and those in the EU.

Figure 6. Trends in annual R&D investments for the EU and major economies, using patenting data as proxy.



a) global and EU totals



b) breakdown in major economies/regions

Source: JRC 2024 compilation of VC and corporate R&I investors with relevant high-value patents.

Table 4 Top private investors in CSP for the period 2015-202 in CSP, using patent data as proxy.

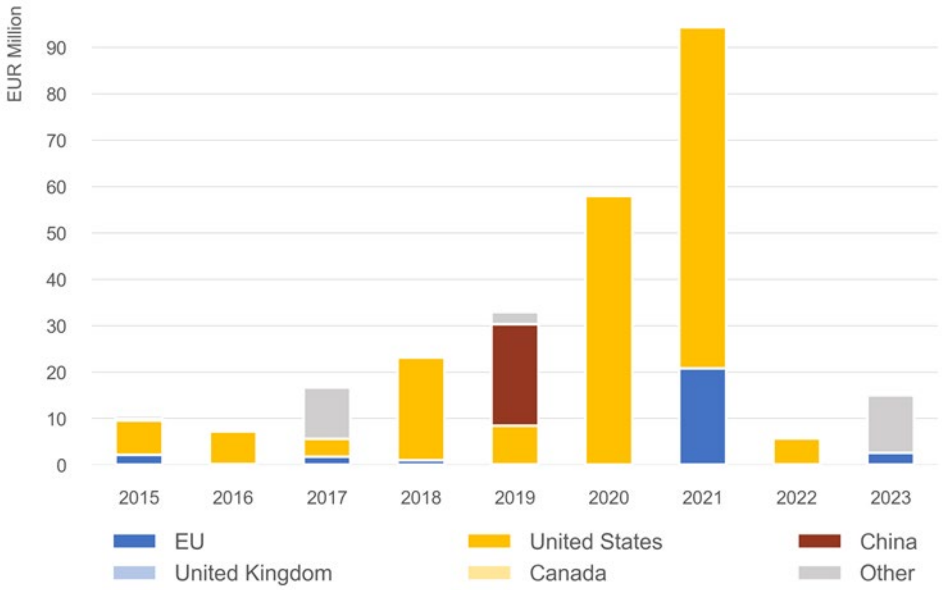
Top 20 - Global - 2015 onwards			**Top 20 - EU - 2015 onwards**	
Sunpower Corporation	Us		A Raymond Et Cie	FR
Ningbo High Tech Zone Shidai Energy Technology Co Ltd	CN		Robert Bosch Gmbh	DE
Ojjo Inc	US		Magaldi Power Spa	IT
Solarcity Corp	US		Solarisfloat Lda	PT
Xian Thermal Power Research Institute Co Ltd	CN		Viessmann Werke Gmbh Co Kg	DE
Binzhou Armour Force Solar Technology Co., Ltd.	CN		Absolicon Solar Collector Ab	SE
Zhejiang Supcon Solar Energy Technology Co Ltd	CN		Ritter Energie Und Umwelttechnik Gmbh Und Co Kg	DE
Huaneng Clean Energy Research Institute	CN		Eni Spa	IT
Qingdao Haier Joint Stock Co Ltd	CN		Cockerill Maintenance Ingenierie Sa	BE
Qingdao Economic Technology Development Zone Haier Water Heater Co.	CN		Abengoa Solar New Technologies Sa	ES
Gree Electric Appliances Inc Of Zhuhai	CN		Electricite De France	FR
Nextracker Inc	US		Frenell Gmbh	DE
Guangdong Fivestar Solar Energy Co Ltd	CN		Mounting Systems Gmbh	DE
Alion Energy Inc	US		Heliac Aps	DK
Chengdu Aonengpu Technology Co., Ltd.	CN		Nexans	FR
Zhejiang Jiadele Solar Energy Co Ltd	CN		Esdec Bv	NL
Toyoda Automatic Loom Works Ltd	JP		Kraftanlagen Muenchen Gmbh	DE
Zhejiang Hongle Solar Thermal Tech Co Ltd	CN		Jenaer Glaswerk Schott Gen	DE
Chengdu Angdijia Technology Co Ltd	CN		Ripasso Energy Ab	SE
Shandong Linuo Ritter New Energy Co Ltd	KR		Sabic Global Technologies Bv	NL

Source: JRC compilation, 2024.

2.1.5.2 *Venture capital investment*

An analysis has been performed for concentrated solar thermal power and heat applications following the JRC methodology [28]. Available data suggests that global VC investment rebounded in 2023 after a drop in 2022. In the EU, the analysis indicated that Denmark attracted the most significant investment.

Figure 7 Trends in global venture capital investment by region from 2015 to 2023



Source: 2024 JRC analysis based on Pitchbook data

2.1.6 Patenting trends

The analysis looked at CSP[4] only and followed the JRC methodology [29] using Patstat (European Patent Office) data for the period to 2021[5]. Globally, inventions[6] per year fell from a peak of 1564 in 2012 to 950 in 2021[7]. Looking at the most recent data in **Figure 8**, China is dominant in terms of overall numbers, and is now also leader for high value inventions. The EU was previously leader for almost all the decade 2010-2020. **Figure 10** shows the top organisations for high value inventions over 2017 to 2019, and includes two EU organisations.

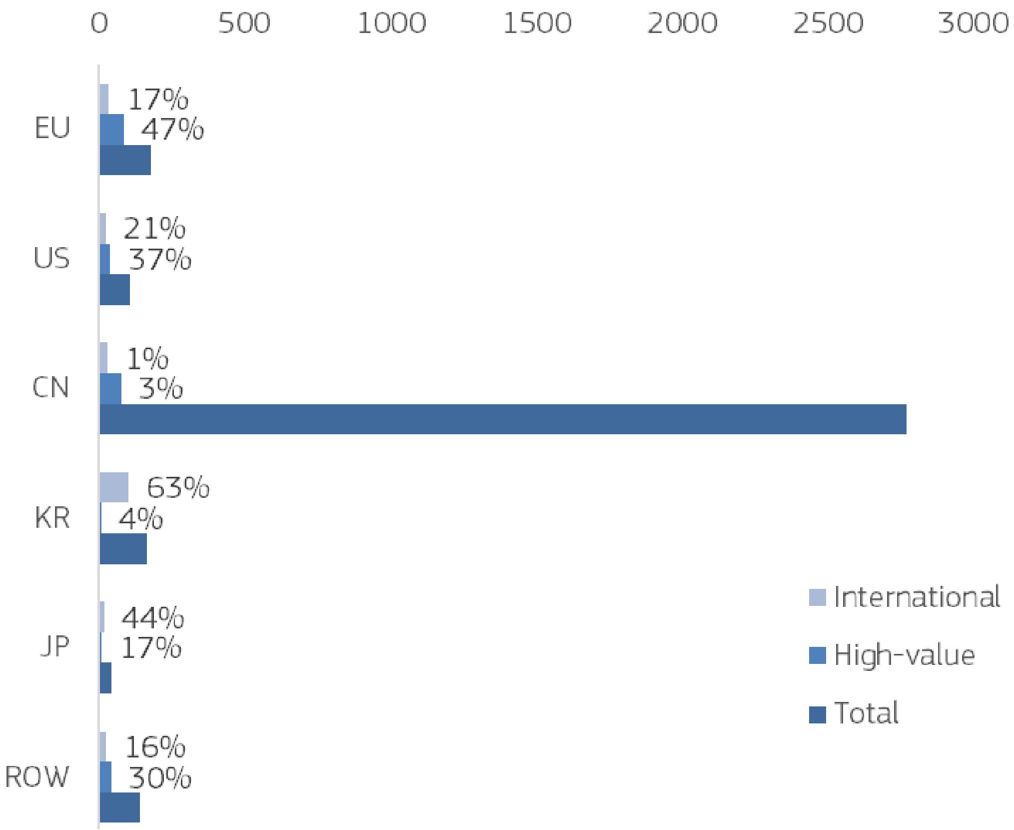
[4] The relevant CPC codes are: Y02E 10/40 - Solar thermal energy, Y02E 10/44 - Heat exchange systems, Y02E 10/46 - Conversion of thermal power into mechanical power, Y02E 10/47 - Mountings or tracking,

[5] *JRC update: July 2024 – for details on the processing methodology see [40 36, 39]).*

[6] 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.

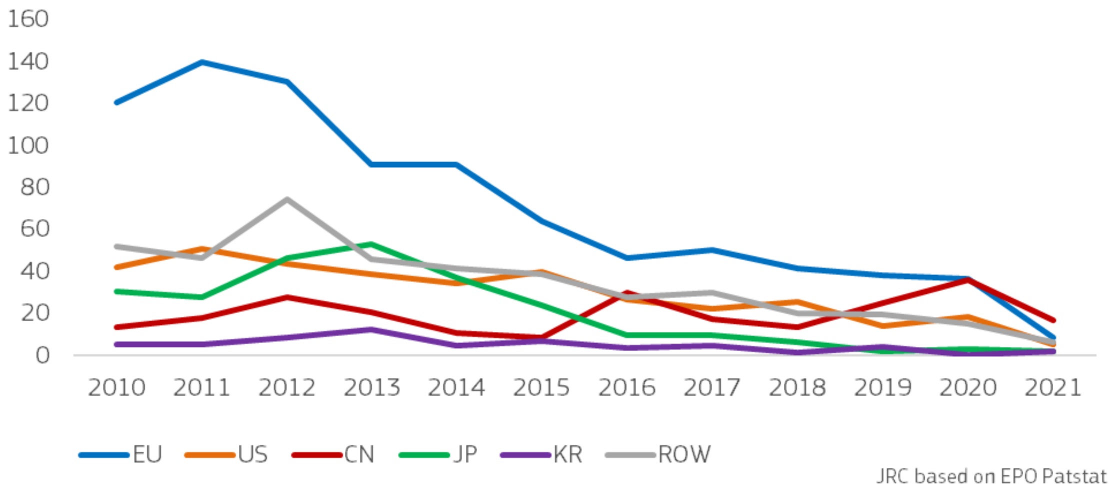
[7] *Since the analysis for the CPR 2020 SWD, the Chinese patents have been re-categorised, leading to a 50% drop.*

Figure 8. Number of inventions and international and high value shares for 2019-2021.



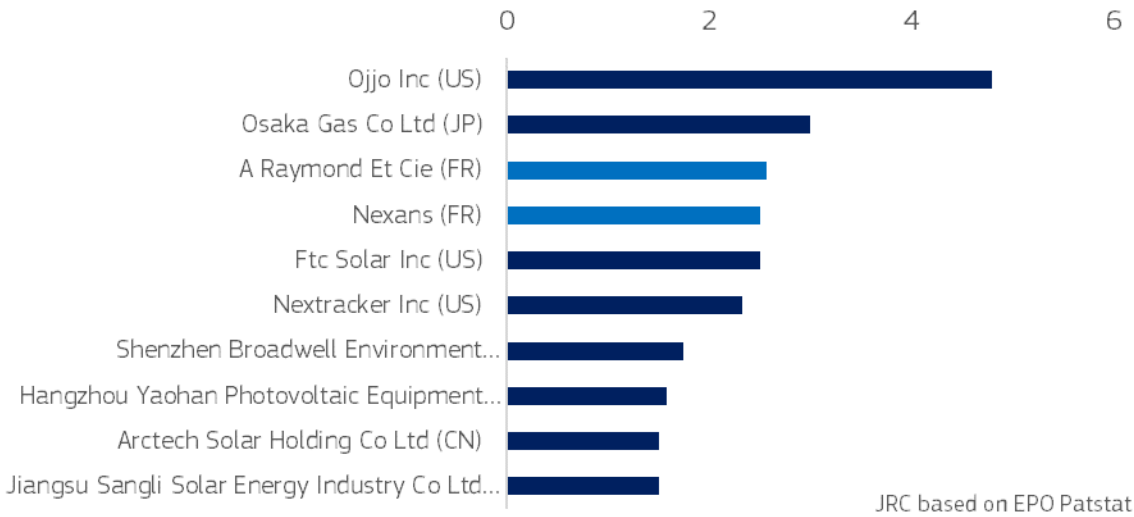
Source: 2024 JRC based on EPO Patstat

Figure 9. High value inventions for CSP from 2009 to 2021 (2021 data incomplete).



Source: JRC based on EPO Patstat 2024

Figure 10. Top 10 companies worldwide for high value inventions 2019-2021



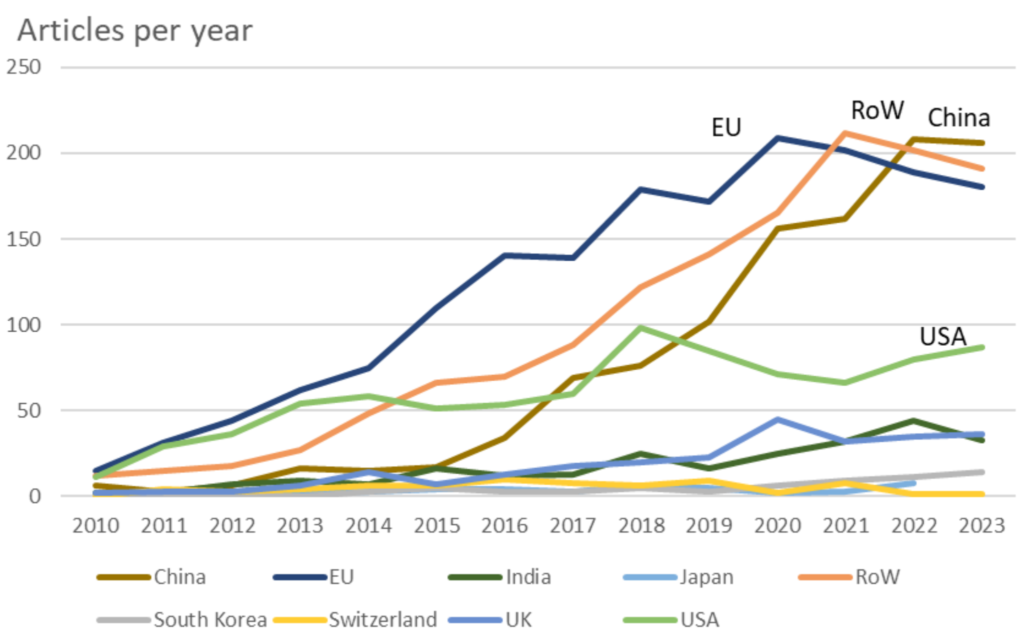
Source: JRC based on EPO Patstat 2024

2.1.7 Scientific publication trends

The JRC's Technology Innovation Monitor system (TIM) was used to analyse the scientific articles published over the period 2010 to 2023. The search string "topic: ("concentrated solar power" OR "solar thermal electricity" OR ("CSP" AND "solar")) AND class:article" retrieved 2,765 articles.

Figure 11 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 11. Trend in scientific publications on CSP for the leadings countries and regions



Source: JRC analysis of TIM data (2024)

2.1.8 Status of EU-funded R&D projects

Under Horizon 2020 (2014-2020) the EU supported 56 CSP and CSH-related projects with approximately EUR 186 m contribution. Spain, Germany, Italy and France were the main beneficiaries (see listing in Annex 4). The total budget for these projects was in excess of EUR 200m. CSP and the related coordination projects accounted for 81% of the grants, with the remainder for CSH.

Under Horizon Europe 18 research projects have been funded so far, with a total budget of EUR 60 million. Two projects (EUR 1.6 million) support coordination and strategic planning, while CSP is also included in the umbrella of RISENERGY project for research infrastructures for renewable technologies.

2.2 Value Chain Analysis

2.2.1 Turnover

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

2.2.2 Gross value added

No data is available at time of writing.

2.2.3 Environmental and socio-economic sustainability

Annex 5 provides summary of the available data and methods regarding environmental, social and economic sustainability according to the CETO scheme.

2.2.4 Role of EU Companies

Several European companies continue to play a significant role in international projects, 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. The last five years have seen the emergence of Chinese suppliers, engineering companies and finance houses as major players in the market.

Table 5 ESTELA members and roles

Company	Country	Role
CSP Services	Germany	Consultancy
SBP Sonne Gmbh	Germany	Consultancy
FICHTNER Gmbh & Co. KG	Germany	Consultants
ACS Cobra	Spain	Developer
Abengoa Solar	Spain	Manufacturer
CMI Solar	Belgium	Manufacturer
Eastman Chemical Company	Belgium	Manufacturer
Rioglass Solar Sa.	Spain	Manufacturer
Senior Flexonics	Germany	Manufacturer

SQM Europe	Belgium	Manufacturer
The Dow Chemical Company	Spain	Manufacturer
TSK FLAGSOL ENGINEERING Gmbh	Germany	Manufacturer
SENER	Spain	Manufacturer, engineering
CENER	Spain	R&I organisation
CRES	Greece	R&I organisation
DLR	Germany	R&I organisation
ENEA	Italy	R&I organisation
Fraunhofer ISI	Germany	R&I organisation
ik4-Tekniker	Spain	R&I organisation
Instituto Imdea Energía	Spain	R&I organisation
Promes - CNRS	France	R&I organisation
Azelio	Sweden	Technology developer
Protermo Solar	Spain	Trade association
Verband Der Deutschen Csp	Germany	Trade association
RWE Innogy	Germany	Utility
Engie	UK	Utility, developer

Source: JRC analysis of data from ESTELA web site (2024)

2.2.5 Employment

IRENA [30] reports 79 000 jobs globally in 2021, of which approximately 59 000 in China and 5 200 in the EU.

2.2.6 Energy intensity and labour productivity

No data has been identified for these indicators.

2.2.7 EU Production Data

CSP plant components do not have specific Prodcom (PRODuction COMmunautaire) codes or codes suitable to be considered a proxy. This probably reflects the small size of the market and that such plants comprise a broad mix of components: reflectors, solar absorbers/ receivers, heat transfer & storage equipment, steam boilers and the steam turbine & generator sets.

2.3 EU Market Position and Global Competitiveness

2.3.1 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).

2.3.2 Trade (Import/export) and trade balance

There are no 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).

2.3.3 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 on supply or availability.

In terms of the EU's critical raw material list, CSP plants use copper, potentially also aluminium in structural parts, and rare earths in generators.

3 Solar Thermal Heating and Cooling

3.1 Technology status and development trends

3.1.1 Technology readiness level

Solar thermal technologies offer a range of established solutions for all the heating and cooling application areas, as shown in **Table 6**. The EU Renewable Energy Heating and Cooling Technology Innovation Platform (RHC-ETIP) has a dedicated technology plan for solar thermal and, in 2022, issued a strategic research and innovation agenda [31] (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" [32]. The Clean Energy Technology Partnership has also assessed the R&I needs for SHIP under the challenge "Towards 100% renewable industrial heating" [33].

Table 6 Overview of solar heat technologies and application areas

Application	Temperature Range, °C	Solar thermal technology	TRL
Building water heating (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 (heating) 7-10 (cooling)	Non-concentrated (flat plate collectors, vacuum tube (glazed) collectors Concentrated designs with line or point receivers For district cooling the solar heat is usually converted to cold in absorption chillers	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 [31]

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

3.1.2 Installed Capacity and Production

The global overall solar thermal collector capacity reached 560 GWth by the end of 2023, corresponding to 800 million m^2 of collector area[8] and an annual solar thermal energy yield of 456 TWh [5]. Despite a modest growth of only 3% in 2023, the capacity has more than doubled over the last decade, up from 230 GWth in 2010. China, Turkey, USA, Germany and Brazil continue to lead in terms of installed capacity.

In 2023, the installed capacity of solar thermal heat in the EU increased by 1.3 GWth (3.3%) to reach 41 GWth [35]. The EU markets with the strongest growth were Germany, Greece, Italy, and Poland. Solar thermal systems are installed on approximately 10 million buildings, representing 3.9% of the

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

total stock of 259 million units [35]. According to EUROSTAT, the EU's final energy consumption from solar thermal[9] was 28.7 TWh in 2022. Although the overall market share for solar water heaters and space heating/cooling is low in the EU, it is widely used in buildings in several Mediterranean regions.

Large-scale solar thermal systems are used in 282 European cities' district heating systems (approximately 5% of DH systems and contribute 0.2% of the heat supply)[10]. Denmark alone has 150 DH systems using solar thermal as one of their heat sources, often facilitated by access to seasonal thermal storage. Six new solar thermal systems for district heating networks started operation in 2023, and nine systems are under construction or in an advanced planning stage [36]. The largest solar thermal field for DHC in Europe is in Silkeborg, Denmark, with 110 MWth capacity [35]. In Germany, the solar collector area for district heating grew by 30% in 2022, and in the Netherlands, the first large-scale solar district heating (34 GWth) system was commissioned in 2023 [36].

Solar heat for industrial processes (SHIP) is mainly used in the food and beverage sector. The world market for SHIP tripled in 2023 compared to the previous two years. One hundred sixteen projects with a total capacity of 94 MW were added in 2023. A noticeable trend worldwide is that more developers sign up for heat supply contracts for large-scale solar industrial plants. The largest SHIP plant in Europe has a capacity of 30 MWth and was inaugurated in 2023 in Seville, Spain [37].

Photovoltaic thermal systems[11] (PVT) attained a cumulative installed capacity of 822 MWth (1.5 million m^2) and 292 MWp electric in 2023. The majority of them are deployed in Europe. The PVT market fell 30% in 2023 after a fall of 51% in 2022 due to end of subsidies in key markets. [5]

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. According to Solar Heat Europe's roadmap [38], the potential for solar thermal heat is 560 GWth installed by 2030, with 140 GWth for buildings, 280 GWth for SHIP, and 140 GWth for DH applications[12].

The JRC's POTEnCIA CETO 2024 Scenario [22] predicts an increase in heat generation from solar thermal, projecting 65 TWh in 2030 and 93 TWh in 2050, up from 29 TWh in 2020. In that analysis, the residential sector accounted for 87% of the solar heat consumption in 2020, while in 2030 its share is expected to decrease to 51%, and later increase again to 69% by 2050. In the 2019 National Energy and Climate Plans, ten Member States analysed the potential role of solar thermal, predicting a contribution of 60-70 TWh by 2030 [39]. When writing this report, it is unknown whether these ambitions will be raised in the final versions of the revised NECPs [21].

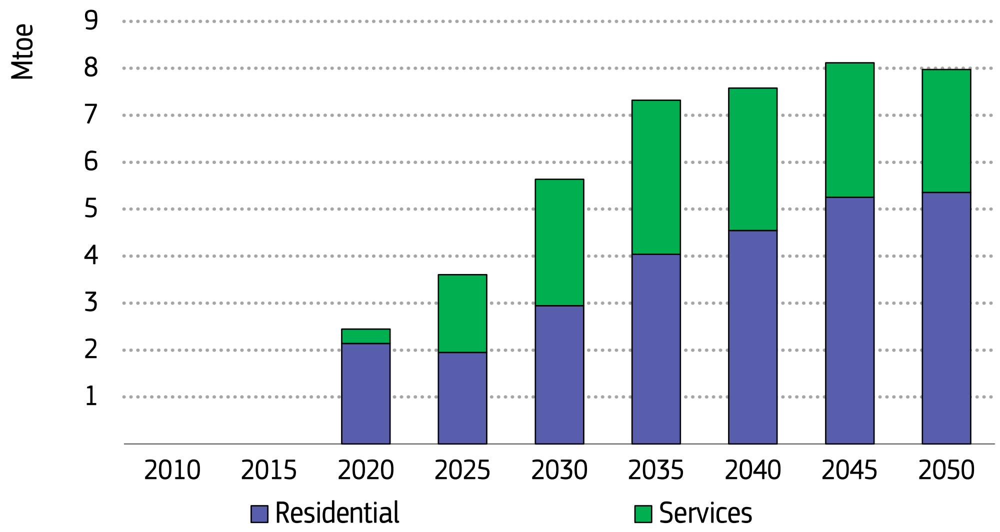
[9] Eurostat nrg_bal_c

[10] *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.*

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

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

Figure 12. POTEnCIA projections for solar thermal heat generation in the EU.



Source: JRC analysis, 2024

Solar thermal energy faced deployment challenges similar to other renewable heating technologies. Higher interest rates have led to reduced investments and a slower pace of upgrading heat infrastructure. Additionally, competition among heating and cooling technologies, such as heat pumps, and solar PV, negatively impacted solar thermal sales. Solar PV typically receives more financial support from authorities, giving it an advantage [35]. Changes to support mechanisms, such as the end of the superbonus in Italy, uncertainties surrounding new renewable energy heating system laws in Germany, and the conclusion of EU-funded projects in Poland, have also hindered deployment [35]

Solar thermal heat is becoming increasingly important in European Directives. For example, the new Energy Performance of Buildings Directive (EPBD) requires new buildings to be solar-ready, meaning they must be able to accommodate rooftop solar PV or solar thermal installations [40]. The revised Renewable Energy Directive emphasises the promotion of solar thermal heat in individual buildings, district heating, and industry [41]

3.1.3 Technology Costs

CAPEX for solar hot water systems is about EUR 700-1300/kW [42]. Cost calculations are complicated since, for buildings, the need for a backup system depends on the type of facility (open loop for DHW, closed loop for DHW or heating). CAPEX of solar heating plants for district heating was about EUR 480/kW [43] in 2017.

Solar Heat Europe [4] reports the following ranges for LCOH (reflecting technology scale and location):

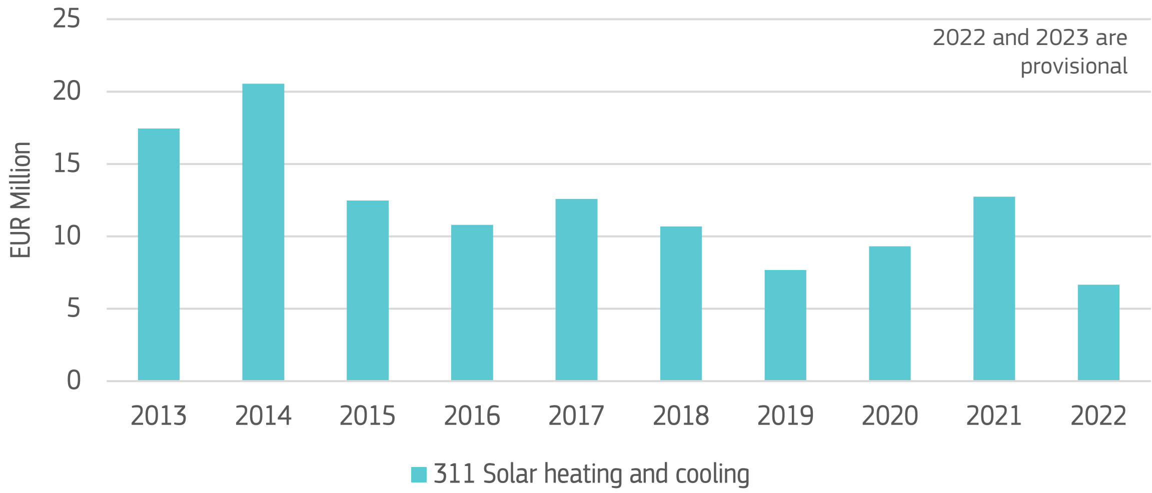
- Solar district heating: 20 to 45 EUR/MWh
- SHIP: 40 to 70 EUR/MWh
- Solar for DHW 20 to 110 EUR/MWh.

For large systems, the CAPEX for solar district heating in Denmark fell from EUR 431/kW in 2010 to EUR 365/kW in 2019, with a corresponding reduction in LCOH from EUR 50/MWh to EUR 40/MWh. In the same period, the CAPEX of new European SHIP systems fell from EUR 1265/kW to EUR 483/kW. A solar district heating system commissioned in 2022 had a CAPEX cost of EUR 621/kW.

3.1.4 Public RD&I Funding and investments

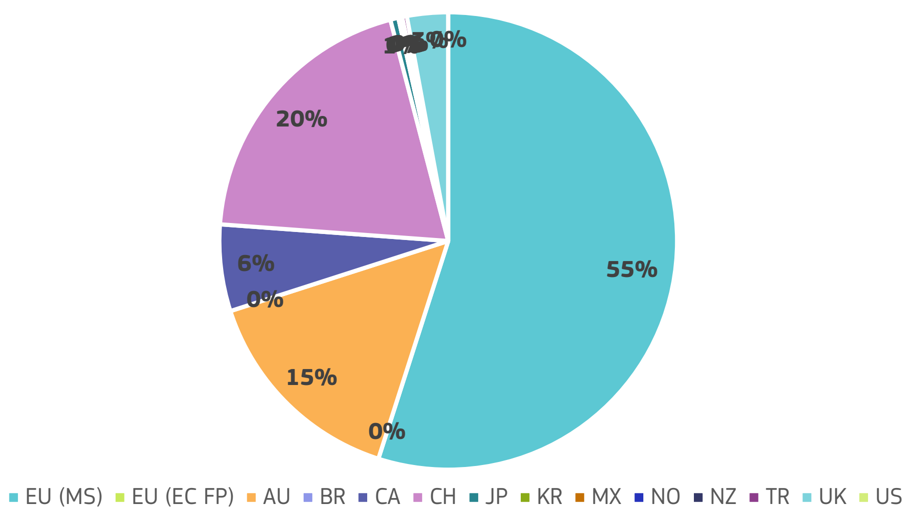
The EU's public investments in solar heating and cooling have decreased since 2013, see **Figure 13**. This investment trend is also observed globally. There has been a growing trend since 2019. The 2022 data is incomplete, so it is unknown if the upward trend continued that year. In 2021, more than half of the public investments in the EU were made in Germany, followed by Belgium and France. EU accounted for more than half of the public investments in solar heating and cooling from 2013 to 2023, see **Figure 14**. For example, in 2021, the EU share was 67%, followed by China's with 21%.

Figure 13 Public RDD investments in Solar Heating and Cooling in the EU.



Source: JRC based on IEA.

Figure 14 Shares of public RDD investments globally per region from 2013 to 2023.



Source: JRC based on IEA.

3.1.4.1 EU Horizon Funding

Under Horizon 2020 (2014-2020), the EU has supported 18 solar thermal heat-related projects with a total budget of about €70 million. Under Horizon Europe (2021-2027), four solar thermal heat-related projects have been funded, with a total budget of €27 million. See Annex 6 for a complete list of projects.

3.1.4.2 Private RD&I Funding

No data was found.

3.1.4.3 R&I investments based on patents

No data was found.

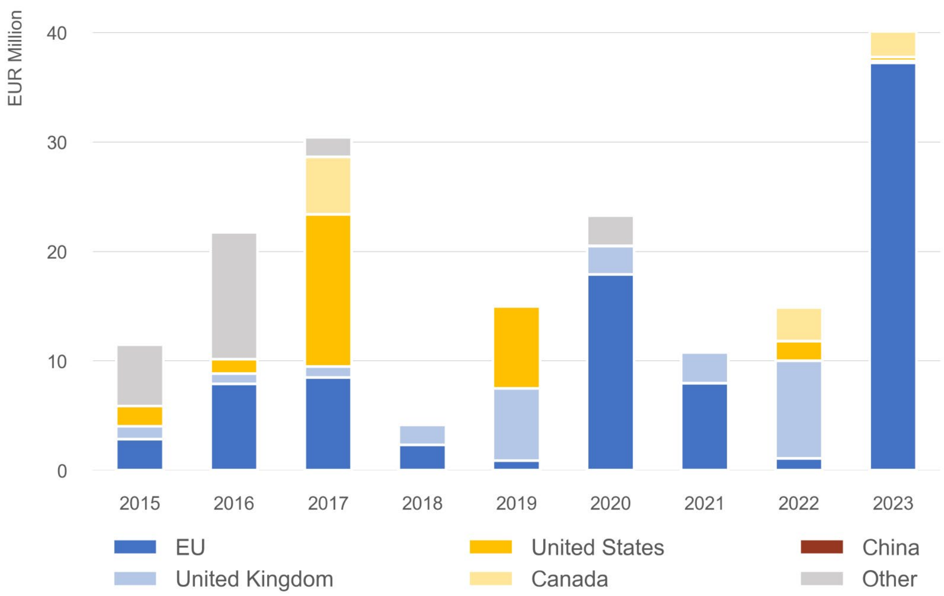
3.1.4.4 Venture capital investment

The share of the EU in global VC/PE investment increased significantly in 2023, see **Figure 15**. The EU received the most investment globally thanks to remarkable growth in later-stage investment and also increased its share of early-stage investment. French based company Newheat captured most of the venture capital investment total in the EU.

Comparing 2015-2019 and 2020-2023, the EU and the UK have surpassed the USA and the Rest of the World (ROW) as the most significant regions for VC/PE investments in solar thermal.

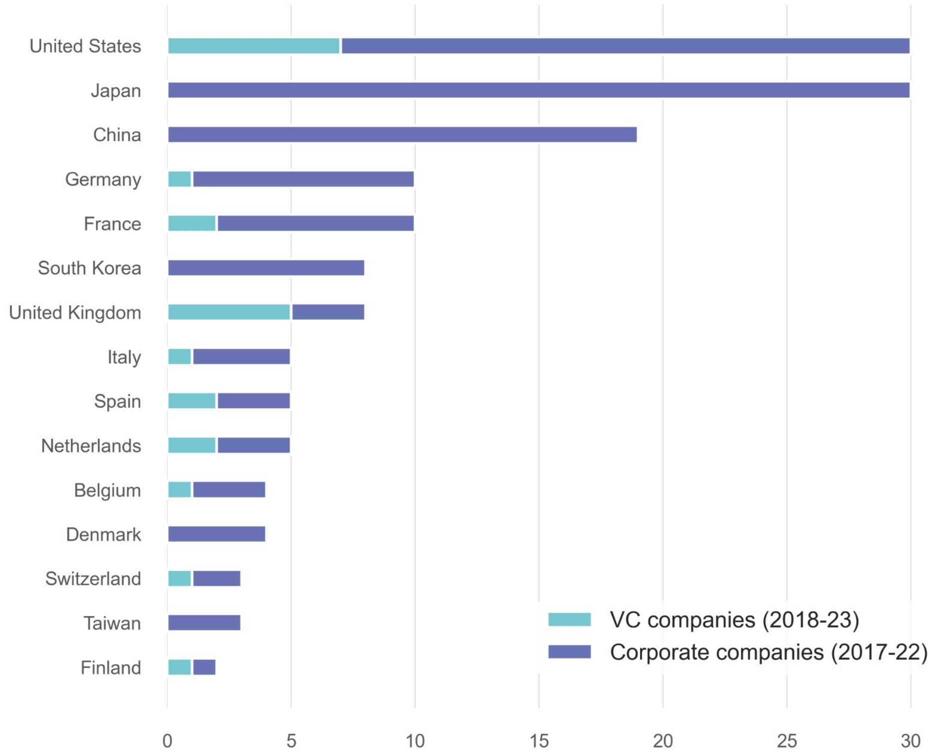
The countries with the largest number of innovative companies in the solar thermal sector are the USA, Japan, and China, followed by Germany and France, see **Figure 16**. The count corresponds to the number of corporate innovators with relevant high-value patents and of companies that were either founded or received venture capital investment over the considered period.

Figure 15. Global VC/PE investments by region for all deals.



Source: JRC based on PitchBook data, 2024

Figure 16. Number of innovating companies by type, ranking of top 15 countries



Source: JRC analysis, 2024

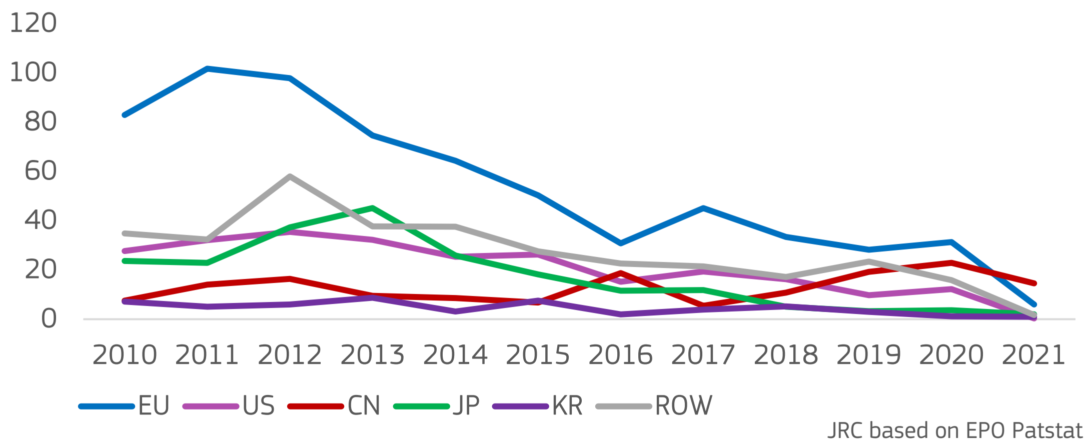
3.1.5 Patenting trends

The number of high-value patents in solar thermal heat technologies decreased in most countries, except for China, from 2010 to 2020 (**Figure 17**). In 2010, the EU filed the highest number of high-value patents, followed by the Rest of the World (ROW) and the USA. By 2020, China had filed the largest number of patents, followed by the EU and the ROW.

Osaka Gas Co Ltd (Japan) and Green Electric Appliances Inc of Zhuhai (China) were the companies that filed the most patents from 2019 to 2021 (**Figure 18**). Two of the top ten companies are from the EU, specifically Germany.[13]

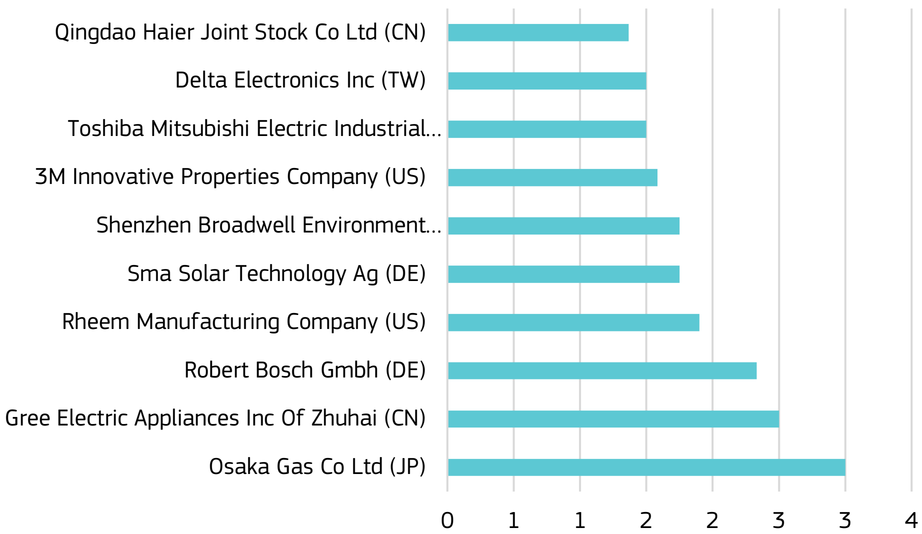
[13] The number of patents is not always an integer because a fractional count is used to avoid double-counting.

Figure 17. Number of high-value patents per region and year N.B. data for 2021 is incomplete.



Source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)[14], 2024.

Figure 18 Number of high-value patents globally per company between 2019 and 2021.



Source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO), 2024.

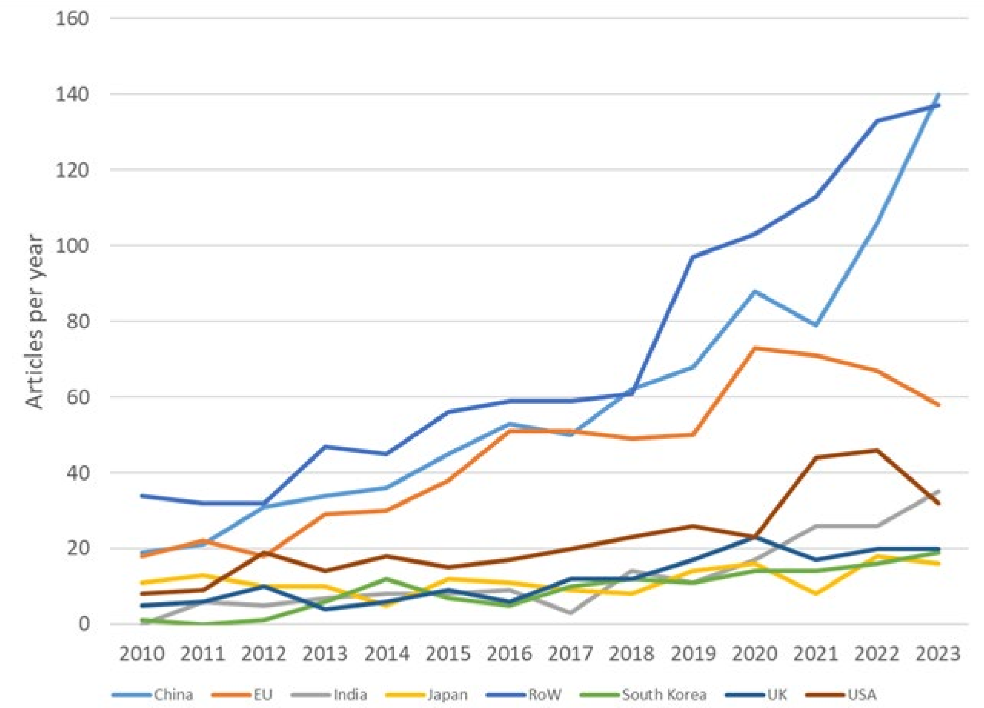
3.1.6 Scientific publication trends

The JRC's Technology Innovation Monitor system (TIM) was used to analyse the scientific articles published from 2010 to 2023. Using the search string "topic: ("solar thermal heat" OR "solar heat") AND class:article" retrieved 2 798 articles. There is a notable increase in publications, rising from 81 in 2010 to 271 in 2020 and 336 in 2023.

[14] Patent data based on PATSTAT database 2021 autumn version (JRC update: February 2021). The methodology behind the indicators is provided the references.

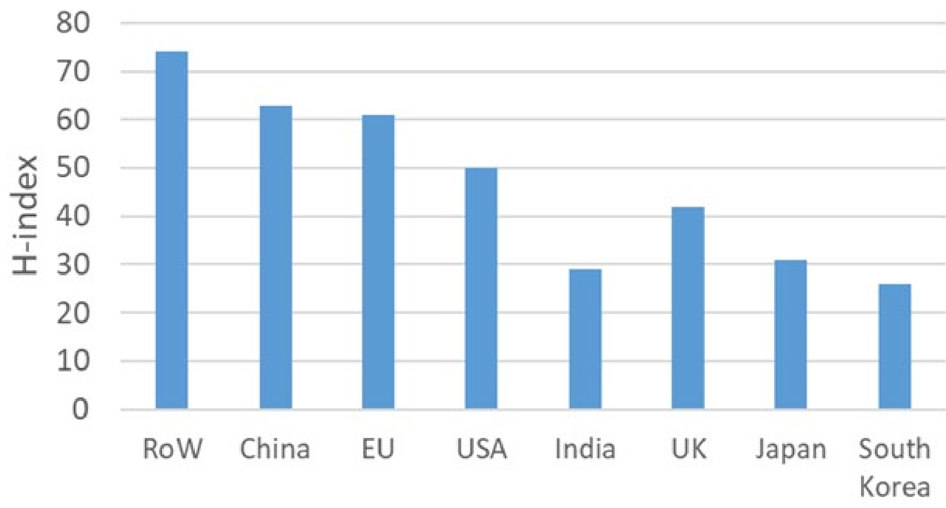
Figure 19 illustrates the significant growth of scientific publications in China and the ROW from 2010 to 2023. The publication trend for the EU increased until 2020, followed by a decline. **Figure 20** depicts the highly cited papers by region in 2023. The ROW had the highest number, with China and the EU having nearly equal amounts, followed by the USA and the UK.

Figure 19. Trend in scientific publications on solar thermal heat for major economies and regions.



Source: JRC TIM analysis 2024

Figure 20. H-value scores for scientific publications on solar thermal heat for leading countries and regions in 2023.



Source: JRC TIM analysis 2024.

3.1.7 Status of EU-funded R&D projects

Eighteen solar thermal heat projects received funding from the Horizon 2020 program. About €35 million was awarded to research projects focusing on solar thermal heat for buildings, while €35 million was dedicated to solar thermal heat production for industrial applications.

The projects related to solar heat for buildings are mainly concerned with optimising the use of solar thermal heat alongside other technologies such as heat pumps, biomass, and thermal storage. Some of these projects also involved solar PVT. The industrial application projects aimed to demonstrate the viability of solar thermal heat across different temperature ranges and its ability to provide continuous heat supply while integrating other renewable heat sources.

Under the Horizon Europe program, most funding was directed towards solar thermal heat for industrial applications combined with thermal storage and heat pumps. By mid-2024, the total funding of those projects was €27 million.

3.2 Value Chain Analysis

According to a report by Solar Heat Europe (SHE) 2024, EU manufacturers will supply over 90% of the EU's demand for solar thermal heat equipment [35]. The main challenge for solar thermal manufacturers is the rising prices of raw materials such as copper, aluminium, and components like glass. The war in Ukraine disrupted the supply, and some manufacturers had to seek alternative suppliers outside of Europe. Nonetheless, most manufacturers are operating smoothly and have the potential to increase their production [5].

3.2.1 Turnover

The global solar heat and cooling sector was estimated to have a turnover of EUR 17.4 billion in 2021. For Europe, Solar Heat Europe (EU+UK+CH) reports EUR 1.79 billion, about 10% of the global total. However, data has not been found on a breakdown between the building, district heat and industrial process sectors [5].

3.2.2 Gross value added

No data was found.

3.2.3 Environmental and socio-economic sustainability

Once installed, solar thermal collectors do not need any other energy source than free solar irradiation. This ensures a secure energy supply for a long-lasting period, as the average lifetime of a solar thermal panel is about 25 years [5].

3.2.4 Role of EU Companies

Global Chinese manufacturers are in the lead for solar thermal collectors, with several EU companies in the top 20. A 2023 report for the Commission [44] 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 EurObserv'ER barometer [4] notes different situations within Europe: the number of German manufacturers dropped from 38 to 23 from 2015 to 2022 [45], 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.

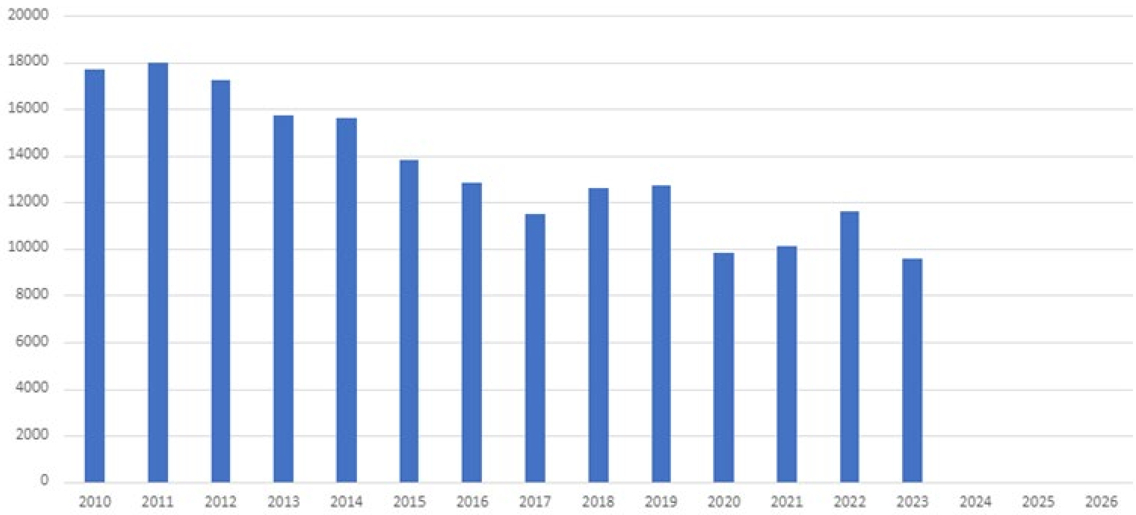
For SHIP, the Solar-Payback site[15] provides mapping of 72 suppliers of turnkey solar process heat systems, with 34 in the EU. Mexican and Chinese companies report the most projects, but EU companies are well represented: G2 Energy (NL), Ritter XL Solar (DE), Soliterm (DE), Sunoptimo (BE), Cona Solar (AT), Solid Solar Energy Systems (AT), Next source (NL).

[15] www.solar-payback.com/

3.2.5 Employment

The global solar heat and cooling sector is estimated to have provided 389 000 jobs in 2021 [30]. A CINEA study [46] estimated that employment in the EU27 was 9 600 people in 2023. However, employment has steadily declined and nearly halved since 2010, see **Figure 21**.

Figure 21. Employment in the solar thermal sector in the EU.



Source: JRC analysis of CINEA data, 2024.

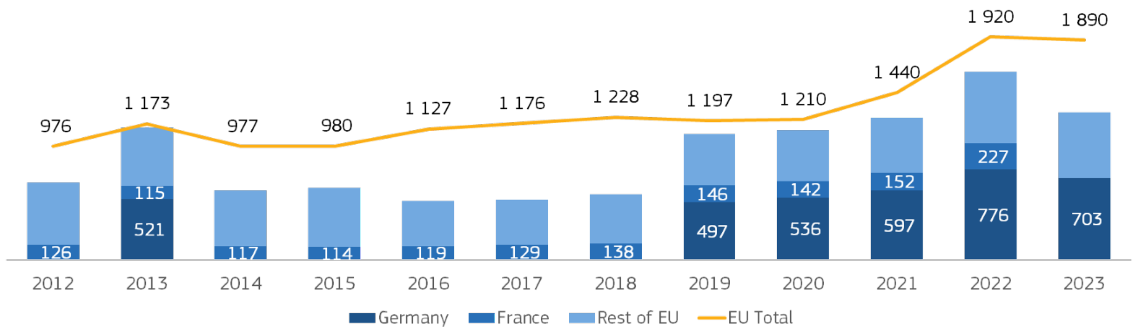
3.2.6 Energy intensity and labour productivity

No data found.

3.2.7 EU Production Data

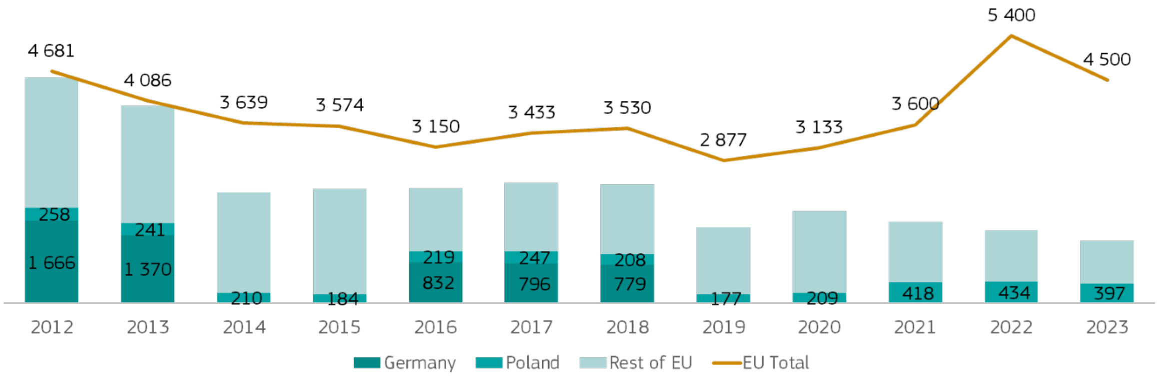
Since no direct production for solar thermal heaters exist, the non-electric water heaters are used as a proxy. In 2023, the EU production value of non-electric water heaters slightly declined at under €1.9 billion (**Figure 22**). Germany was the top EU producer, holding more than half of the total EU production, while France did not disclose its data for 2023. In terms of quantities, the EU production shrank by 17% in 2023, reaching 4.5 million pieces (**Figure 23**). Germany and Poland were the top producers (10-year average), while Germany hasn't disclosed its quantity data since 2019. In 2023, the EU production value per piece of non-electric heater increased by 18% at EUR 420 (**Figure 24**).

Figure 22 EU production value and top producers among the Member States disclosing data [EUR Million]



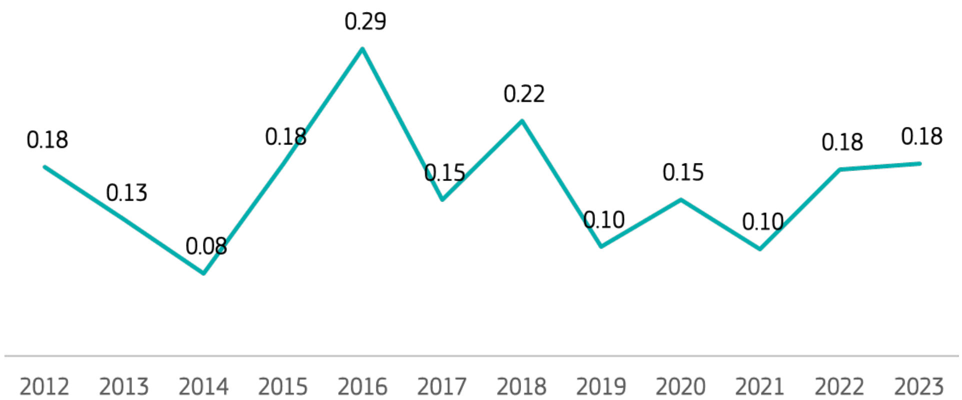
Source: JRC based on PRODCOM data, 2024.

Figure 23 EU production in quantities [Thousand pieces]



Source: JRC based on PRODCOM data, 2024.

Figure 24 EU production value per quantity of non-electric heaters [EUR per piece]



Source: JRC based on PRODCOM data, 2024

3.3 EU Market Position and Global Competitiveness

3.3.1 Global & EU market leaders

No reliable data was found.

3.3.2 Trade (Import/Export) and trade balance

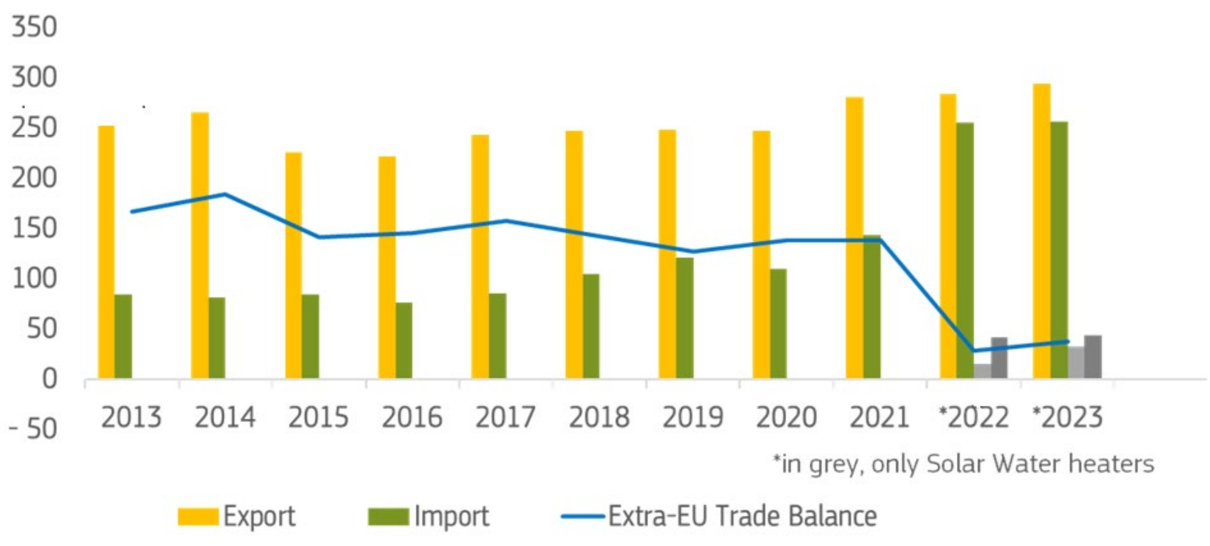
Figure 24 shows that in 2023, the EU imports of solar water heaters remained at the same level as in 2022 (around €40 million), while exports more than doubled, reducing the EU trade deficit from €26 million to €11 million. The combined extra-EU exports of solar and non-electric water heaters increased by almost 10%, reaching €327 million in 2023, while the extra-EU exports remained at the same level as in 2022 (€300 million), increasing the trade surplus from €2 million in 2022 to €27 million in 2023.
In 2022-2023, the extra-EU share in Global exports of solar water heaters was 42%, while 80% of the total imports were covered with internal trade, see **Figure 25**. China remained the top global exporter of solar water heaters, while the EU maintained a strong presence among the top 10 global exporters and importers

In 2022-2023, Germany, Italy, France, Romania and the Netherlands remained the top EU importers, bringing 89%, 10%, 33%, 100% and 88% of their extra-EU imports, respectively, from China. For the same period, France, Austria, and Germany were the top EU exporters of solar water heaters, which were exported mainly to other Member States.

3.3.3 Resource efficiency and dependence in relation to EU competitiveness

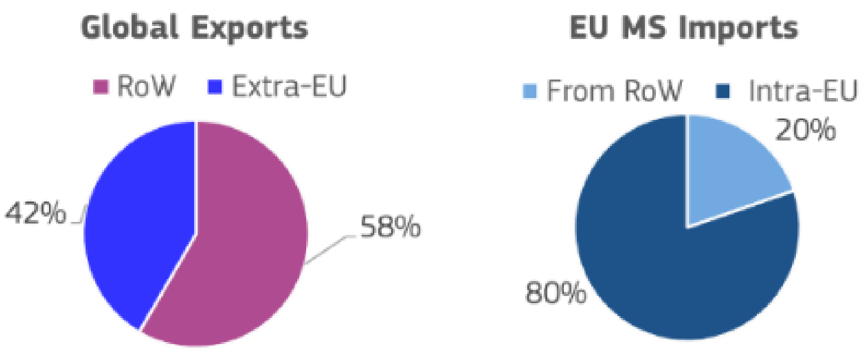
For solar thermal systems, the main materials in collectors include copper, aluminium and glass. The sector claims a 95% recycling rate (for both weight and volume) for systems [47]. There are considerable opportunities for improving circular economy concepts and reducing environmental impact.

Figure 25. Extra-EU trade for non-electric water heaters and solar water heaters (in grey) [EUR Million]



Source: JRC based on COMEXT data, 2024.

Figure 26. Share of global extra-EU exports (left) and intra-EU imports (right), 2022-2023.



Source: JRC based on COMTRADE and COMEXT data, 2024.

4 Conclusions

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

Although the concentrated solar power sector has made progress in reducing costs and establishing a reliable track record for electricity generation, the global market hardly grew in 2023. The latest generation of Concentrated Solar Power 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 CO_2, liquid sodium or other media. In Europe, no new commercial systems have been built for several years. China has emerged as the leading developer globally, with 1 GW in operation and a further 2 GW in development.

For solar thermal heat and cooling, the EU is a one of the leaders in terms of technology. High gas prices and security of supply concerns gave new impetus to the EU market in 2022, but 2023 saw a 20% drop in market size due to lower natural gas prices and reduced financial support to solar thermal. In 2023, the installed capacity of solar thermal heat in the EU slowed down to an increase of 1.3 GWth (3.3%) to reach 41 GWth.

Both concentrated and non-concentrated systems offer the potential for supplying industrial process heat and district heat systems. The world market for solar heat for industrial processes tripled in 2023, albeit at a low level. Large-scale solar thermal systems are used in 282 European cities' district heating systems (approximately 5% of DH systems and contribute 0.2% of the heat supply). Six new solar thermal systems for district heating networks started operation in 2023, and nine systems are under construction or in an advanced planning stage. Continued efforts on cost reduction, new incentives, more training of installers with expertise in hybrid solutions, and integrated system concepts are needed.

Research funding for all solar technologies has decreased over the last decade in the EU, except for increasing late-stage venture capital investments. The USA, Japan, and China, followed by Germany and France, have the most innovative companies regarding high-value patents by corporations and investments in Venture Capital companies. The number of high-value patents in the sector has declined globally since 2010.

Exports of solar water heaters from the EU remained stable, but imports increased significantly between 2022 and 2023. Although complete trade data for the whole solar thermal heat sector is missing, it can indicate that EU companies are losing market shares.

References

1. Taylor, N., Georgakaki, A., Mountraki, A., Letout, S., Ince, E., Shtjefni, D., Kuokkanen, A., Tattini, J. and Diaz Rincon, A., Clean Energy Technology Observatory: Concentrated Solar Power and Solar Heating and Cooling in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/322182, JRC135004.
2. Jakubcionis, M., Solar Thermal Heating and Cooling: Technology Development report, EUR 29915 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-12538-9, doi:10.2760/315917, JRC118301.
3. Carlsson, J., Solar Thermal Heating and Cooling: Technology Market report, EUR 29925 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-12571-6, doi:10.2760/828601, JRC118312
4. EurObsev'ER, Solar thermal and concentrated solar power barometers, July 2023.
5. Weiss, W., Spörk-Dür, M., Solar Heat Worldwide, 2023 edition
6. Taylor, N., Tattini, J. and Diaz Rincon, A., Clean Energy Technology Observatory: Direct Solar Fuels in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/753483, JRC135361.
7. Rehfeldt, M. et al, A bottom-up estimation of the heating and cooling demand in European industry, Energy Efficiency (2018) 11:1057–1082
8. Kumar, R. et al, Solar thermal energy technologies and its applications for process heating and power generation - A review, Journal of Cleaner Production 282 (2021) 125296
9. Schoeneberger, C.. et al Solar for industrial process heat: A review of technologies, analysis, approaches, and potential applications in the United States, Energy 206 (2020) 118083
10. McMillan, C. et al, Evaluating the economic parity of solar for industrial process heat, Solar Energy Advances 1 (2021) 100011
11. Regulation (EU) 2024/1735 of the European Parliament and of the Council of 13 June 2024 on establishing a framework of measures for strengthening Europe's net-zero technology manufacturing ecosystem and amending Regulation (EU) 2018/1724
12. European Commission SWD(2024) 160 final Commission Staff Working Document "Solar energy joint research and innovation agenda with Member States in the context of the European Research Area (ERA)"
13. Rohani, S. et al, Optimization of water management plans for CSP plants through simulation of water consumption and cost of treatment based on operational data, Solar Energy, Volume 223, 2021, 278-292, https://doi.org/10.1016/j.solener.2021.05.044.
14. SET-Plan IWG CST: Initiative for Global Leadership in Concentrated Solar Thermal Technologies Updated Implementation Plan, February 2023,
15. REN21. 2024. Renewables 2024 Global Status Report Collection: Energy Supply (Paris: REN21 Secretariat). ISBN 978-3-948393-15-1
16. Thonig, R, Gilmanova, A. & Lilliestam, J. (2023). CSP.guru 2023-07-01 [Data set]. Zenodo.https://doi.org/10.5281/zenodo.1318151
17. IEA, Net Zero by 2050 A Roadmap for the Global Energy Sector, update 2023

18. IRENA (2023), World Energy Transitions Outlook 2023: 1.5°C Pathway, Volume 1, International Renewable Energy Agency, Abu Dhabi

19. Schmitz, A., Schade, B., Garaffa, R., Keramidas, K., Dowling, P., Fosse, F., Díaz Vázquez, A., Russ, P., Weitzel, M., Impacts of enhanced learning for clean energy technologies on global energy system scenarios, Forthcoming.

20. EurObserv'ER, Solar thermal and concentrated solar power barometer 2024

21. National energy and climate plans, EU countries' 10-year national energy and climate plans for 2021-2030, available on the Commission web site for NECPs

22. Neuwahl, F., Rózsai, M., Jaxa-Rozen, M., Salvucci, R., Sikora, P., Gea Bermudez, J., and Wegener, M., The POTEnCIA CETO 2024 Scenario, Forthcoming

23. IRENA (2024), Renewable power generation costs in 2023, International Renewable Energy Agency, Abu Dhabi. ISBN: 978-92-9260-621-3

24. NREL Annual Technology Baseline, ATB | NREL

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

26. IEA (Spring 2024), Energy Technology RD&D Budgets: Overview, IEA, Paris https://www.iea.org/reports/energy-technology-rdd-budgets-overview

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

28. Forthcoming, Clean Energy Technology Observatory: Overall Strategic Analysis of Clean Energy Technology in the European Union: 2024 Status Report, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/3507717, JRC139529.

29. 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

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

31. Calderoni, M., Dias, P., di Padua, I., Kriedemann, F. (eds), Strategic Research & Innovation Agenda for Solar Thermal Technologies, Brussels, 2022. www.rhc-platform.org

32. ETIP SNET White Paper, Coupling of heating/cooling and electricity sectors in a renewable energy-driven Europe, 2022

33. 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

34. Toleikyte, A. and Carlsson, J., Assessment of heating and cooling related chapters of the national energy and climate plans (NECPs), EUR 30595 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-30234-6, doi:10.2760/27251, JRC124024.

35. Solar Heat Europe, 2024, Solar Thermal Market Outlook 2023/2024

36. Solarthermalworld.org, 2024, The Netherlands and Spain drive SHIP market 2023, available at: https://solarthermalworld.org/news/the-netherlands-and-spain-drive-ship-market-2023/

37. PV magazine, 2023, Europe's largest CSP plant for self-consumption goes online in Spain, available at: https://www.pv-magazine.com/2023/europes-largest-csp-plant-goes-online-in-spain/

38. Solar Heat Europe Roadmap 2021

39. European Commission, Directorate-General for Energy, Bacquet, A., Galindo Fernández, M., Oger, A. et al., District heating and cooling in the European Union – Overview of markets and regulatory frameworks under the revised Renewable Energy Directive, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2833/962525

40. EC, Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast) (Text with EEA relevance)

41. EC, 2023, Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652

42. Hofmeister, M. and Guddat, M., Techno-economic projections until 2050 for smaller heating and cooling technologies in the residential and tertiary sector in the EU, EUR28861, Publications office of the European Union, Luxembourg, 2017, ISBN 978-92-79-76014-3, doi:10.2760/110433, JRC109034

43. Grosse, R., Christopher, B., Stefan, W., Geyer, R. and Robbi, S., Long term (2050) projections of techno-economic performance of large-scale heating and cooling in the EU, EUR28859, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-75771-6, doi:10.2760/24422, JRC10900

44. ENTEC consortium, Supply chain risks in the EU's clean energy technologies, 2023, ISBN 978-92-68-02700-4 doi 10.2833/413910

45. Solarthermalworld.org, 2022, Strongly downsized, but crisis-ridden solar collector industry in Germany, available at: https://solarthermalworld.org/news/strongly-downsized-but-crisis-ridden-solar-collector-industry-in-germany/

46. CINEA/2022/OP/0008 "Assessment of the competitiveness of clean energy technologies"

47. Milousi, M. and Souliotis, M., A circular economy approach to residential solar thermal systems, Renewable Energy, Volume 207, 2023, Pages 242-252, https://doi.org/10.1016/j.renene.2023.02.109.

List of abbreviations and definitions

CAPEX	Capital Expenditure
CPC	common patent
CR(S)	central receiver (system), aka solar tower system
CSH	Concentrated (concentrated) Solar [thermal] Heat
CSHIP	Concentrated Solar Heat for Industrial Processes
CSP	Concentrated (concentrated) Solar [thermal] Power
DH	District heating
DHC	District heating and cooling
DNI	Direct normal irradiance
EPC	engineering, procurement and construction
ETS	Emission Trading System
EU	European Union
FiT	feed-in tariff
FOAK	First–of-a-Kind
FP7	Seventh Framework Programme
H2020	Horizon 2020,
HE	Horizon Europe
HTF	heat transfer fluid
IA	Innovation Action
IEA	International Energy Agency
IP	Implementation Plan
IRENA	International Renewables Energy Agency
ISCC	integrated solar combined cycle
IWG	Implementation Working Group
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
RHC	Renewable Heating and Cooling
RHC ETIP	European Technology and Innovation Platform on Renewable Heating and Cooling
RIA	Research and Innovation Action

SET Plan	Strategic Energy Technology Plan
SHIP	Solar Heat for Industrial Processes
STE	solar thermal electricity
TES	thermal energy storage
TRL	Technology Readiness Level

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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 Baromoter 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	CORDIS CINEA dashboard
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 3
	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

Source: JRC elaboration

Annex 2 SET-Plan R&I activites and associated TRL levels

Areas of activity	Defined R&I activities	TRL
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	From TRL 5 to TRL 8 From TRL 7 to TRL 8 (some components, like the steam generator, are still at TRL 6)
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	Final TRL: prototypes evaluated at real working conditions Goal: TRL 5-6 TRL 5 to TRL 8
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	TRL 5 to TRL 7 From TRL 4 to TRL 6. TRL may be also related to integration and validation of developed systems for at least 100 cycles of operation, or the key components only
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 CO_2 cycles	- TRL3 (proof of concept of most promising technologies) - TRL6 (technology potential demonstrated) - TRL7 (technology demonstrated in system prototype) TRL8 TRL6
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	From TRL 3 to TRL 7-8 From TRL 4 to TRL 6
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	from TRL 4 (start) to TRL 6 (target) From TRL 4 to TRL 6 From TRL 2-3 to TRL 4
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	TRL:5-8 From TRL 3/4 to TRL 6 From TRL 7 to TRL 8 (some components, like the optimized large-scale PT collector, are still at TRL 6) N/A

Source : JRC elaboration of SET-Plan CST Implementation Plan 2023 [14].

Annex 3 Energy System Models & Scenarios: POTEnCIA and POLES-JRC

A3.1 POTEnCIA Model

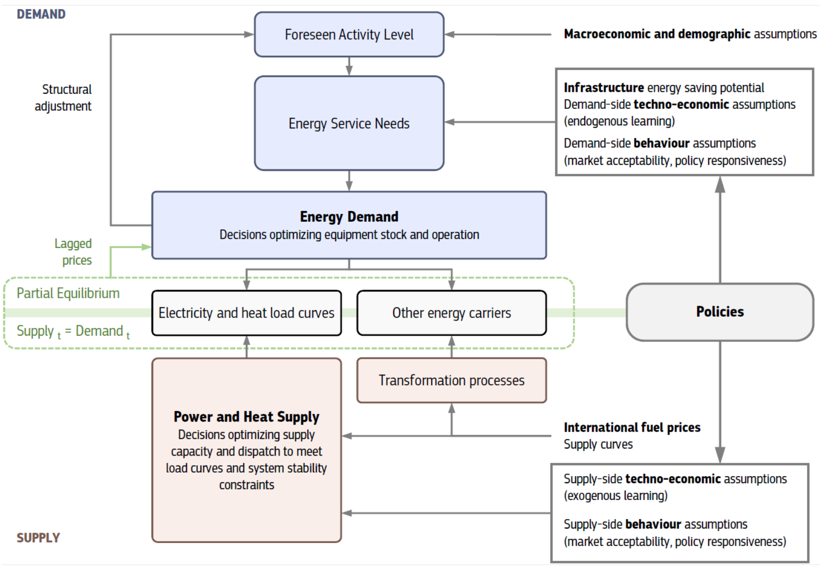
A3.1.1 Model Overview

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 (detailed in Mantzos et al., 2017, 2019) 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.

Figure A3.1 The POTEnCIA model at a glance



Source: JRC adapted from (Mantzos et al., 2019)

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 CO_2 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; Rózsai et al., 2024).

A2.1.2 POTEnCIA CETO 2024 Scenario

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 EU GHG emissions by 55% by 2030 and 90% by 2040, both compared to 1990, and reaches net zero EU emissions by 2050. To model suitably the uptake of different technologies under this decarbonisation trajectory, the scenario includes a representation at EU level 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 2030 energy consumption and renewable energy shares reflect the targets of the EU's Renewable Energy Directive and of the Energy Efficiency Directive. Similarly, the adoption of alternative powertrains and fuels in transport is consistent with the updated CO_2 emission standards in road transport and with the targets of the ReFuelEU Aviation and FuelEU Maritime regulations. A more detailed description of the POTEnCIA CETO 2024 Scenario will be available in the forthcoming report (Neuwahl et al., 2024).

A3.2 POLES-JRC model

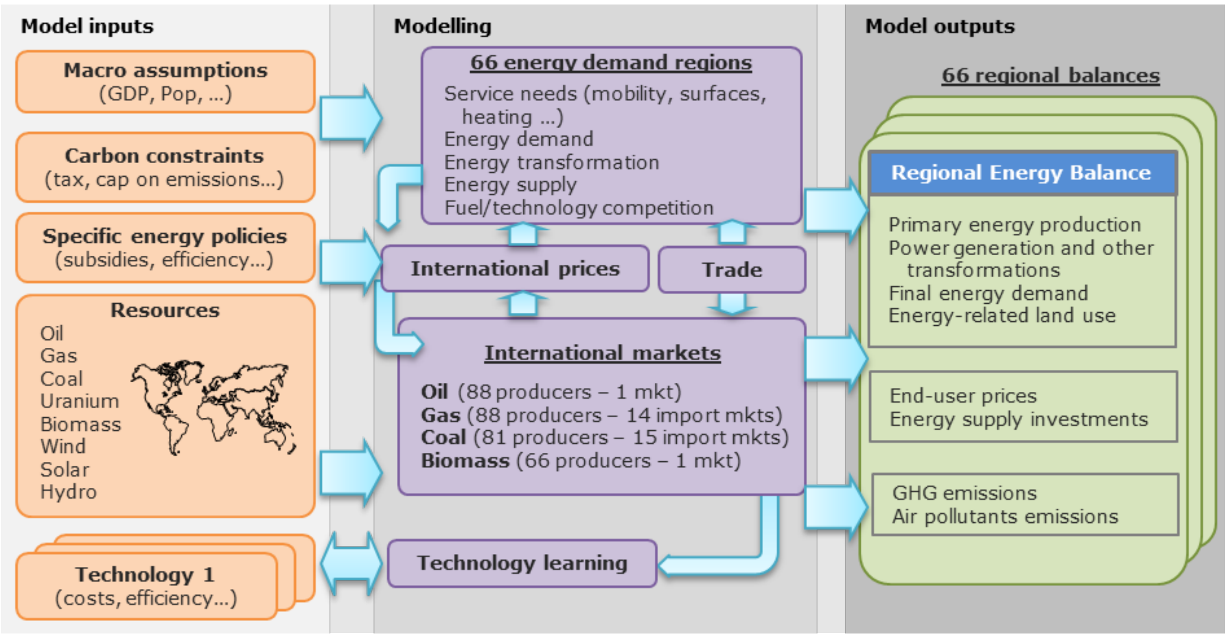
A3.2.1 Model Overview

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. It is a simulation model that follows a recursive dynamic partial equilibrium method. POLES-JRC is hosted at the JRC and was designed to assess global and national climate and energy policies.

POLES-JRC covers the entire energy system, from primary supply (fossil fuels, renewables) to transformation (power, biofuels, hydrogen and hydrogen-derived fuels such as synfuels) and final sectoral demand (industry, buildings, transport). International markets and prices of energy fuels are calculated endogenously. Its high level of regional detail (66 countries & regions covering the world with full energy balances, including all detailed OECD and G20 countries) and sectoral description allows assessing a wide range of energy and climate policies in all regions within a consistent global frame: access to energy resources, taxation policy, energy efficiency, technological preferences, etc. POLES-JRC operates on a yearly basis up to 2100 and is updated yearly with recent information.

The POLES-JRC model applied for the CETO project is specifically enhanced and modified to capture learning effects of clean energy technologies. 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://joint-research-centre.ec.europa.eu/scientific-activities-z/geco_en- A detailed documentation of the POLES-JRC model is provided in (Després et al., 2018).

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



Source: POLES-JRC model

A3.2.2 POLES-JRC Model description

Power system

The power system considers all relevant power generating technologies including fossil, nuclear and renewable power technologies. Each technology is modelled based on its current capacities and techno-economic characteristics. The evolution of cost and efficiencies are modelled through technology learning.

With regard to the power technologies covered by CETO, the model includes solar power (utility-scale and residential PV, concentrated solar power), wind power (on-shore and off-shore), hydropower and ocean power. Moreover, clean thermal power technologies are taken into account with steam turbines fuelled by biomass, biomass gasification, CCS power technologies and geothermal power. Furthermore, electricity storage technologies such as pumped hydropower storage and batteries are also included.

For solar and wind power, variable generation is considered by representative days with hourly profiles. For all renewables, regional resource potentials are considered.

Electricity demand
Electricity demand is calculated for all sectors taking into account hourly fluctuations through the use of representative days. Clean energy technologies using electricity consist of heat pumps (heating and cooling), batteries and fuel cells in transport, and electrolysers.

Power system operation and planning
Power system operation allocates generation by technology to each hour of representative days, ensuring that supplying and storage technologies meet overall demand, including grid imports and exports. Capacity planning considers the existing power mix, the expected evolution of electricity demand as well as the techno-economic characteristics of the power technologies.

Hydrogen

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

Hydrogen is used as fuel in all sectors including industry, transport, power generation and as well as feedstock for the production of synfuels (gaseous and liquid synfuels) and ammonia. Moroever, hydrogen trade is modelled, considering hydrogen transport with various means (pipeline, ship, truck) and forms (pressurised, liquid, converted into ammonia).

Bioenergy

POLES-JRC receives information on land use and agriculture through a soft-coupling with the GLOBIOM-G4M model (IIASA, 2024). This approach allows to model bioenergy demand and supply of biomass adequately by taking into account biomass-for-energy potential, production cost and reactivity to carbon pricing.

Biomass is used for power generation, hydrogen production and for the production of 1st and 2nd generation of liquid biofuels.

Carbon Capture Utilization and Storage (CCUS)

POLES-JRC uses CCUS technologies in:

- 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 gas and biomass pyrolysis.
- Direct air capture (DAC) where the CO_2 is either stored or used for the production of synfuels (gaseous or liquid).
- Steel and cement production in the industrial sector.
- Second generation biofuels production.

The deployment of CCS technologies considers region-specific geological storage potentials.

Endogenous technology learning

The POLES-JRC model was enhanced to capture effects of learning of clean energy technologies. To capture these effects, a one-factor learning-by-doing (LBD) approach was applied to technologies and technology sub-components, aiming at endogenising the evolution of technology costs.

POLES-JRC considers historical statistics and assumptions on the evolution of cost and capacities of energy technologies until the most recent year available (this report: 2022/2023). Based on the year and a capacities threshold, the model switches from the default time series to the endogeneous modelling with the one-factor LBD approach. Within the LBD, the learning rate represents the percentage change of the cost of energy technology based on a doubling of the capacity of the energy technology.

This generic approach is applied on a component level to capture spillover effects as well. For instance, a gasifier unit is used as component for several power generating technologies (e.g.

integrated gasification combined cycle, IGCC) as well as for several hydrogen production technologies (e.g. gasification of coal and biomass). Therefore, the component-based LBD approach allows to model spillover effects not only across technologies, but also across sectors. Also, it allows to estimate costs for emerging technologies for which historical experience does not yet exist.

Moreover, for each component a floor cost is specified which marks the minimum for the component's investment cost and serves as limitation for the cost reduction by endogenous learning. Cost reductions by learning in POLES-JRC slow down when the investment cost approaches the floor cost.

The described method above applies not only for the overnight investment cost of energy technologies, but as well for operation and maintenance (OM) costs, which also decrease as technologies improve, and for efficiencies. In the model, OM costs diminish synchronously to the decrease of total investment cost of the technology. The efficiency of renewables is implicitly taken into account in the investment cost learning and the considered renewable potentials. For most technologies the efficiencies are endogenously modelled.

A3.2.3 Global CETO 2°C scenario 2024

The global scenario data presented in the CETO technology reports 2024 refers to a 2°C scenario modelled by the POLES-JRC model in a modified and enhanced version to address the specific issues relevant for the CETO project.

The *Global CETO 2°C scenario 2024* and its specific POLES-JRC model configuration is described in detail in the forthcoming report "*Impacts of enhanced learning for clean energy technologies on global energy system scenario*" (Schmitz et al., 2024).

The *Global CETO 2°C scenario 2024* is designed to limit global temperature increase to 2°C at the end of the century. It is driven by a single global carbon price for all regions that reduces emissions sufficiently so as to limit global warming to 2°C. This scenario is therefore a stylised representation of a pathway to the temperature targets. This scenario does not consider financial transfers between countries to implement mitigation measures. This is a simplified representation of an ideal case where strong international cooperation results in concerted effort to reduce emissions globally; it is not meant to replicate the result of announced targets and pledges, which differ greatly in ambition across countries.

As a starting point, for all regions, it considers already legislated energy and climate policies (as of June 2023), but climate policy pledges and targets formulated in Nationally Determined Contributions (NDCs) and Long-Term Strategies (LTSs) are not explicitly taken into account. In particular, the EU Fit for 55 and RePowerEU packages are included in the policy setup for the EU. Announced emissions targets for 2040 and 2050 for the EU are not considered.

The *Global CETO 2°C scenario 2024* differs fundamentally from the *Global CETO 2°C scenario 2023* used in the CETO technology reports in 2023 in various aspects:

- The version of the POLES-JRC model used for the Global CETO 2°C scenario has been further enhanced and modified to capture effects of endogenous learning of clean energy technologies and, furthermore, several technology representations were further detailed, e.g. DAC (composition of renewable technologies, batteries and DAC unit), fuel conversion technologies (for hydrogen transport) and batteries in transport.

- The techno-economic parameters have been thoroughly revised and updated taking into account the expertise of the authors of the CETO technology reports.

As a result, major scenario differences occur in the *Global CETO 2°C scenario 2024* regarding DAC, synfuels, CCS power technologies, wind power and ocean power.

A3.3 Distinctions for the CETO 2024 Scenarios - POLES-JRC vs. POTEnCIA

The results of both models are driven by national as well as international techno-economic assumptions, fuel costs, as well as policy incentives such as carbon prices. However, on one side these two JRC energy system models differ in scope and level of detail, on the other side the definitions of the POTEnCIA and POLES-JRC scenarios presented in this document follow distinct logics, leading to different scenario results:

- The *Global CETO 2°C scenario 2024* (POLES-JRC) scenario is driven by a global carbon price trajectory to limit global warming to 2°C, where enacted climate policies are modelled, but long-term climate policy pledges and targets are not explicitly considered. Scenario results are presented for the global total until 2100.
- The *POTEnCIA CETO 2024 scenario* is a decarbonisation scenario that follows a trajectory for EU27's net GHG emissions aligned with the general objectives of the European Climate Law (ECL) taking into consideration many sector-specific pieces of legislation. Scenario results are presented for the EU27 until 2050.

A3 References

Després, J., Keramidas, K., Schmitz, A., Kitous, A., Schade, B., Diaz Vazquez, A., Mima, S., Russ, H. and Wiesenthal, T. (2018), *POLES-JRC model documentation*, Publications Office of the European Union, Luxembourg, doi:10.2760/814959, JRC113757.

IIASA (2024), International Institute for Applied Systems Analysis, *GLOBIOM documentation*, Laxenburg, https://globiom.org/documentation.html

Mantzos, L., Matei, N. A., Rózsai, M., Russ, P., & Ramirez, A. S. (2017, June). *POTEnCIA: A new EU-wide energy sector model*. In Proceedings of the 14th International conference on the European Energy Market (EEM) (pp. 1-5).

Mantzos, L., Wiesenthal, T., Neuwahl, F., & Rózsai, M. (2019). *The POTEnCIA Central Scenario. An EU Energy Outlook to 2050*. Report EUR 29881 EN. Publications Office of the European Union, Luxembourg.

Neuwahl, F., Wegener, M., Jaxa-Rozen, M., Salvucci, R., Sikora, P., Gea Bermudez, J., and Rózsai, M. *The POTEnCIA CETO 2024 Scenario*, Forthcoming.

Rózsai, M., Jaxa-Rozen, M., Salvucci, R., Sikora, P., Tattini, J. and Neuwahl, F., (2024) *JRC-IDEES-2021: the Integrated Database of the European Energy System – Data update and technical documentation*, Publications Office of the European Union, Luxembourg, doi:10.2760/614599, JRC137809.

Schmitz, A., Schade, B., Garaffa, R., Keramidas, K., Dowling, P., Fosse, F., Díaz Vázquez, A., Russ, P., Weitzel, M., *Impacts of enhanced learning for clean energy technologies on global energy system scenarios*, Forthcoming.

Annex 4 Horizon Europe projects on concentrated solar power

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
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

Source: JRC analysis of Cordis data, 2024

Annex 5 Sustainability Assessment Framework

Parameter/Indicator	**Input**
Environmental Parameters/Indicators:	
LCA standards	No sector-specific guidelines or databases, but LCA typically performed to ISO 14040 and ISO 14044 standards See examples: Le Quyen Luu et al, A Comparison of the Life-Cycle Impacts of the Concentrating Solar Power with the Product Environmental Footprint and ReCiPe Methods, Energies 2024, 17(17), 4461; https://doi.org/10.3390/en17174461 Gasa, G. et al, Life cycle assessment (LCA) of a concentrating solar power (CSP) plant in tower configuration with different storage capacity in molten salts, Journal of Energy Storage, Volume 53, 2022, 105219
GHG emissions	CSP: Studies for installations in the EU typically arrive at values below 40 gCO2eqv/kWh SHC: Flat plate collector: 23.8 gCO2eqv/kWh; vacuum tube collector 22.2 gCO2eqv/kWh
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 (net withdrawals 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. Mirror cleaning is a very small part, 1.4-2%. See also Duvenhage, D.F. et al, The need to strategically manage CSP fleet development and water resources: A structured review and way forward, Renewable Energy, Volume 132, 2019, Pages 813-825, Rohani, S. et al, Optimization of water management plans for CSP plants through simulation of water consumption and cost of treatment based on operational data, Solar Energy, Volume 223, 2021,Pages 278-292
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:	

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 silver for mirrors in the solar field.
Resource efficiency and recycling	CSP: There is considerable scope for recycling steel and other structure of materials at end of life.
Industry viability and expansion potential	Yes, see markets sections 2.3 and 3.3
Trade impacts	Yes, see section 3.2.2 and 3.3.2
Market demand	Yes, see markets section 2.3 an 3.3
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 [0]. 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

Parameter/Indicator	**Input**
Affordable energy access (SDG7)	Yes, solar thermal can contribute
Safety and (cyber)security	No technology-specific information available at this point in time
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

Source: JRC elaboration 2024

Annex 6 Horizon 2020 and Horizon Europe projects on solar thermal heat technology

Horizon 2020

Name and cost	**Start/end date and cost [EUR]**	**Objective**
SunHorizon	01/10/2018 – 30/09/2023 Total cost: 11.604.928	The SunHorizon project aims to improve energy efficiency in buildings by developing and demonstrating innovative solar-powered heat pump systems that are coupled and managed to provide heating and cooling to residential and tertiary buildings. TRL objective; 7
CHESS-SETUP	01/06/2016 - 30/09/2020 Total cost: 3.718.455	To design, implement and promote a reliable, efficient and profitable system able to supply heating and hot water mainly from renewable sources to both new and existing buildings. The system is grounded in the optimal combination of solar energy production, heat storage and the use of a heat pump in a single system managed by an intelligent monitoring and control system. TRL objective: Not provided.
ASTEP	01/05/2020 - 30/05/2025 Total cost: 4.999.360	ASTEP aims to develop a new industrial solar heating system with innovative collectors, thermal storage, and controls to address current limitations and enable continuous operation. TRL objective: 5
Innova MicroSolar	01/09/2016 - 30/11/2022 Total cost: 3.999.384	Create a new solar power and heat for application in both homes and small businesses. This system uses high temperatures (250-280 degrees Celsius) and will be tested in a lab and real-world setting. TRL objective: Not provided
Hybrid-BioVGE	01/06/2019 - 30/11/2022 Total cost: 3.701.857	To create a cost-effective and efficient heating and cooling system for buildings. This system will use an integrated solar and biomass energy air conditioning system for space heating and cooling, which is driven by heat. TRL objective: 7
Re-Deploy	01/02/2016 - 31/01/2019 Total cost: 2.893.153	Addresses the market for solar process heat to industrial thermal processes up to 250°C. To develop cost competitive re-deployable solar boilers, i.e. turn-key and easy-to-install concentrating solar thermal systems of at least 1MWt which can be used to sell heat. TRL objective: Not provided
FRIENDSHIP	01/05/2020 - 30/04/2024 Total cost: 4.999.423	To demonstrate that solar heat can also be a reliable, user-friendly, high quality and cost-effective resource to meet the heat requirements for other industrial sectors as textile, plastics, and wood. It investigates for example different coupling of technological and control innovations will be investigated, and optimization of heat transfer coefficients. TRL objective: Not provided
INSHIP	01/01/2017 - 31/12/2020 Total cost: 2.858.799	INSHIP is a program that aims to connect major European research institutes working on shipbuilding (SHIP) to collaborate more effectively and share knowledge. By bringing these institutes together, INSHIP hopes to avoid duplication of effort and accelerate innovation in European shipbuilding. TRL objective: develop coordinated TRLs 2-5 activities
RES4BUILD	01/05/2019 - 30/12/2020 Total cost: 2.858.799	Designs custom renewable energy systems to reduce a building's reliance on fossil fuels for heating, cooling, and electricity. Their innovative approach uses a multi-source heat pump system that can be adapted to different building types and climates and combined with different technologies, including solar PVT. TRL objective: Not provided.

Name and cost	Start/end date and cost [EUR]	Objective
SHIP2FAIR	01/04/2018 - 30/06/2023 Total cost: 10.141.361	Aims to foster the integration of solar heat in industrial processes (SHIP) from the agrifood sector, by developing and demonstrating a set of tools and methods for the development of industrial solar heat projects during its whole life cycle. TRL objective: Not provided.
SOLPART	01/01/2016 - 31/12/2019 Total cost: 4.558.688	This project is developing a high-temperature solar process (reaching 950°C and running continuously) to treat particles in energy-intensive industries like cement production. By using solar heat for calcination (decomposition) of calcium carbonate (CaCO3), the project aims to reduce the environmental impact of these processes and make renewable energy more attractive in industrial settings. TRL objective: 4-5
HyCool	01/05/2018 - 31/10/2022 Total cost: 7.740.440	Coupling of a new Fresnel CSP Solar thermal collector with specially build Hybrid Heat Pumps for a wider output temperature range in industry processes, and to provide a wide range of design and operational configurations to better fit each case. TRL objective: Not provided.
EGO Portable	01/12/2019 - 31/03/2020 Total cost: 71.429	Introduce to the market a light and small solar water heater that is compact, portable and modular. It provides can be installed wherever the customer needs hot water (balconies, campers, yachts, boats etc.). TRL objective: Not provided
SDHp2m	01/01/2016 - 31/12/2019 Total cost: 2.087.297	This project aims to develop better policies for sustainable urban development (SDH) in 9 EU regions. By improving these policies, the project hopes to attract more investment and significantly increase the use of SDH practices. TRL objective: Not applicable.
ZEOSOL	01/06/2017 - 29/02/2020 Total cost: 2.741.375	To develop a new advanced solar cooling and heating product, using advanced heat exchanger technology and integrating a heat pump for covering peak demand. TRL objective: Not provided
PROMETEO	01/01/2021 - 30/04/2024 Total cost: 2.765.206	Aims to develop a system that produces green hydrogen through high-temperature electrolysis by using excess renewable heat and power sources like solar and wind power. The challenge addressed is to optimise the coupling of the electrlyser with the intermittent energy sources. TRL objective: 5
Socool	01/09/2017 - 31/10/2021 Total cost: 1.997.825	Develop three solar cooling packages based on concentrating solar technology for the co-generation of electricity and heat with a total efficiency of 75%, together with thermal chillers to create standardized packages for the supply of electricity, cold and heat. TRL objective: Not provided. It is at 7 now.
ECOMESH	01/02/2018 - 31/05/2018 Total cost: 71429	Objective is not clearly explained in CORDIS, but it is assumed is that it is to develop the technology further. For example optimising the production of heat and power. TRL objective: Not provided.

Source: JRC analysis of Cordis data, 2024

Horizon Europe

Name and cost	Start/end date and cost [EUR]	Objective
INDHEAP - Solution for solar systems in industrial heat processes	1 Jan 2024 – 31 Dec 2027 Total cost [EUR] 8.528.816	Aims to demonstrate the viability of combining solar thermal and photovoltaic technologies to meet the heat and power needs of mid-temperature industrial processes up to 250 degrees Celsius. It will integrate thermal energy storage, boosted by electric heaters. TRL objective: 9
SOLINDARITY	01/01/2024 - 31/12/2027 Total cost: 8.939.331	Develop, demonstrate and validate the feasibility of an integrated solar energy-based heat upgrade system comprising solar energy resources, innovative high temperature heat pumps, thermal energy storage and waste heat recovery for the deep decarbonisation of industrial processes with temperatures up to 280°C. The project will address all major technical challenges related to the integration of the aforementioned modules to the main process plant. TRL objective: Not provided.
Circular Fuels - Production of sustainable aviation fuels from waste biomass by coupling of fast pyrolysis with solar energy	01/07/2023 - 30/06/2027 Total cost: 4.997.354	The Circular Fuels project aims to develop a new sustainable way to produce jet fuel by combining concentrated solar heat, solar power and conversion of bio-waste. Their goal is to not only maximize jet fuel production but also explore other valuable fuels like gasoline and diesel from the process. TRL objective: Not provided
PYSOLO	01/07/2023 - 30/06/2027 Total cost: 4.997.163	The PYSOLO project aims to develop a new process that combines concentrated solar power with biomass pyrolysis to create bio-oil, biochar, and pyrogas in an environmentally friendly way. This project focuses on developing two key parts of this system: a solar particle receiver and a pyrolysis reactor with a particle-char separator. TRL objective: 4

Source: JRC analysis of Cordis data, 2024

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