European Commission

LOW CARBON ENERGY OBSERVATORY

SOLAR THERMAL ELECTRICITY

Technology market report

Joint Research Centre

EUR 29921 EN

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EU Science Hub
https://ec.europa.eu/jrc

JRC118313

EUR 29921 EN

PDF	ISBN 978-92-76-12564-8	ISSN 2600-0466 ISSN 1831-9424 (online collection)	doi:10.2760/975583
Print	ISBN 978-92-76-12563-1	ISSN 2600-0458 ISSN 1018-5593 (print collection)	doi:10.2760/332783

Luxembourg: Publications Office of the European Union, 2019

How to cite this report: N. Taylor, Solar Thermal Electricity Technology Market Report 2018, EUR 29921 EN, European Commission, Luxembourg, 2019, ISBN 978-92-76-12564-8, doi:10.2760/975583, JRC118313.

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Foreword on the Low Carbon Energy Observatory

The LCEO is an internal European Commission Administrative Arrangement being executed by the Joint Research Centre for Directorate General Research and Innovation. It aims to provide top-class data, analysis and intelligence on developments in low carbon energy supply technologies. Its reports give a neutral assessment on the state of the art, identification of development trends and market barriers, as well as best practices regarding use private and public funds and policy measures. The LCEO started in April 2015 and runs to 2020.

Which technologies are covered?

- Wind energy
- Photovoltaics
- Solar thermal electricity
- Solar thermal heating and cooling
- Ocean energy
- Geothermal energy
- Hydropower
- Heat and power from biomass
- Carbon capture, utilisation and storage
- Sustainable advanced biofuels
- Battery storage
- Advanced alternative fuels

How is the analysis done?

JRC experts use a broad range of sources to ensure a robust analysis. This includes data and results from EU-funded projects, from selected international, national and regional projects and from patents filings. External experts may also be contacted on specific topics. The project also uses the JRC-EU-TIMES energy system model to explore the impact of technology and market developments on future scenarios up to 2050.

What are the main outputs?

The project produces the following report series:

- Technology Development Reports for each technology sector
- Technology Market Reports for each technology sector
- Future and Emerging Technology Reports (as well as the FET Database).

How to access the reports

Commission staff can access all the internal LCEO reports on the Connected LCEO page. Public reports are available from the Publications Office, the EU Science Hub and the SETIS website.

Acknowledgements

Thanks to Piero De Bonis (DG RTD) for his valuable review.

The author would also like to thank a number of JRC colleagues who contributed to preparing this report:

- The energy modelling work has been performed by the JRC-EU-TIMES team: Wouter Nijs, Pablo Ruiz Castello, Aliki Geogakaki, Darius Tarvydas and Ioannis Tsiropoulos.
- Data on patent statistics and R&I investments at EU, national and corporate level have been provided by the SETIS R&I team: Alessandro Fiorini, Francesco Pasimeni and Aliki Georgakaki.

Acronyms and abbreviations

CAGR	compound annual growth rate
CSP	concentrated solar [thermal] power
EPC	engineering, procurement and construction
FiT	feed-in tariff
GW	Giga Watt
HTF	heat transfer fluid
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ISCC	integrated solar combined cycle
LCoE	levelised cost of electricity
MENA	Middle East and North Africa
PPA	power purchase agreement
PV	photovoltaic
STE	solar thermal electricity
TES	thermal energy storage

1 Introduction

1.1 Scope

Solar thermal electric plants[1] generate electricity by converting concentrated solar energy to heat, which is then converted to electricity via a thermal power block. When combined with a thermal storage system, they can provide dispatchable renewable electricity. This can help achieve the EU's energy transition [1] and support EU jobs and economic growth.

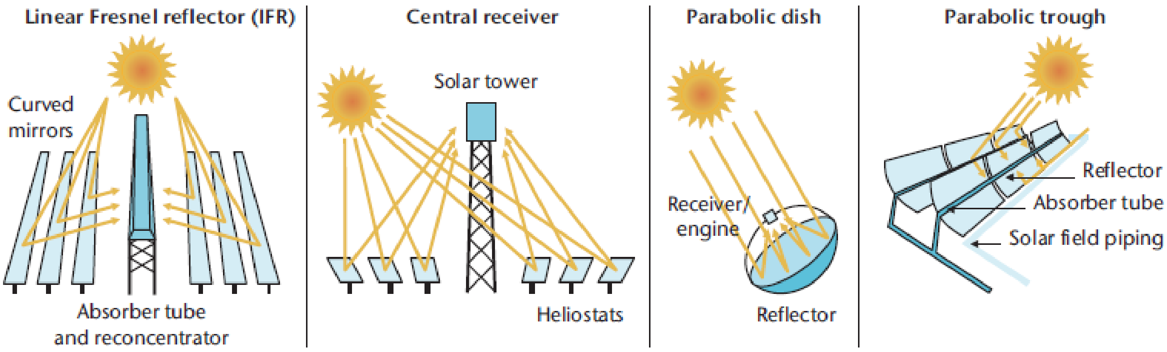
This LCEO Technology Market Report aims to provide a short assessment of recent developments and future perspectives for CSP technology markets, highlighting the role of EU stakeholders. Wherever possible, data coverage is to the end of 2018. A companion LCEO Technology Development Report [2] covers the technology development trends.

1.2 STE Technology and Market Readiness

STE is a commercially available technology. The two major designs used are parabolic trough power plants and central receiver or power tower plants (Figure 1). Both can include a heat storage system, which allows electricity generation in the evening and night. Systems with linear Fresnel receivers (essentially a variation on the parabolic trough concept, but using flat mirror elements to concentrate the light) are also in commercial operation. Research continues on parabolic dish concepts with a Stirling engine receiver, but there are no plants in commercial operation.

A STE plant comprises the following main elements:
- solar field
- receiver and heat transfer system
- thermal storage system
- power conversion unit (heat to electricity) and balance of plant.

Figure 1 Main solar thermal electricity generation concepts.



source IEA [5]

[1] Here the term solar thermal electricity (STE) is used interchangeably with concentrated solar power (CSP). In principle STE also includes non-concentrating solar technologies (e.g. the solar chimney/solar updraft tower) that are not addressed here. The term CSP also covers non-power use of solar thermal heat (e.g. solar chemistry).

STE plants require high levels of steady, direct normal insolation (DNI > 1900 kWh/m^2/year[2]). This limits the range of potential locations, as shown in [3]. Southernmost Europe offers suitable (but not good) locations (Figure 2). Applying further site exclusion criteria such as land slope and land cover leads to an even more restricted range of potential locations [4]. On the other hand, the relative proximity of good locations in several MENA countries has led to proposals for high capacity connectors to the EU.

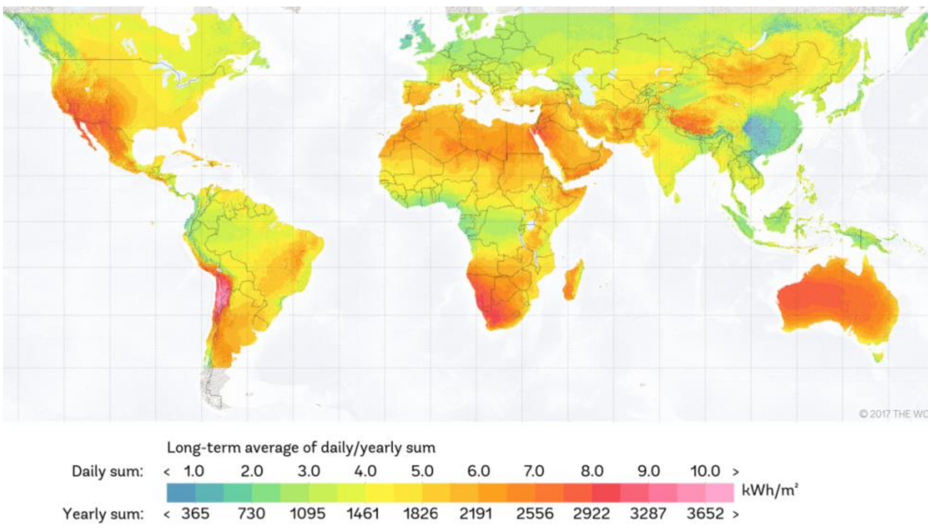
STE can also be combined with other power generation technologies, either for solar-assisted power generation (where the solar heat is used to boost performance of a high-availability fossil plant) or in hybrid configurations (where the STE plant is supported by other sources, for instance biogas, geothermal heat sources or PV).

A further consideration is that the locations most favourable for STE are also amongst those for which water supply is already a major issue or at risk in the future. In this context STE-powered water desalination can help, although a broad range of cost and environmental factors need to be taken into account [6].

The power generation capacity of STE plants is rated in terms of the maximum rated power output in MW (AC electricity output). The annual load capacity factor for commercial plants is approximately 27% i.e. 2 300 to 2 400 MWh/MW. However since the nominal power output of a STE generator is fixed, the capacity factor can be increased by increasing the size of the solar field and adding a thermal storage system. In this way the power generator can run after sundown and capacity factor values of up to 60% are proposed. It is also noted that STE plants require an auxiliary power source at certain times, in particular for start–up of heat transfer and storage pumping systems. If gas or diesel generators are used, as is usually the case, the CO2 footprint is increased

The cost of STE –generated electricity has decreased substantially over the last 10 years (Figure 3). For plants that recently entered operation the estimated levelised cost of electricity (LCoE) ranges from 90[3] to 210 EUR/MWh. Several recent auctions for new to-be-constructed plants foresee values well below this range, at 62 EUR/MWh. This should allow STE to be fully cost competitive with fossil fuel plants. Compared to other renewables in Figure 3, up to now STE generated electricity has been markedly more expensive than wind or solar PV, although the latest developments promise significantly increased competitiveness. It is stressed that STE can offer predictable output and dispatchability, which may add to its market value.

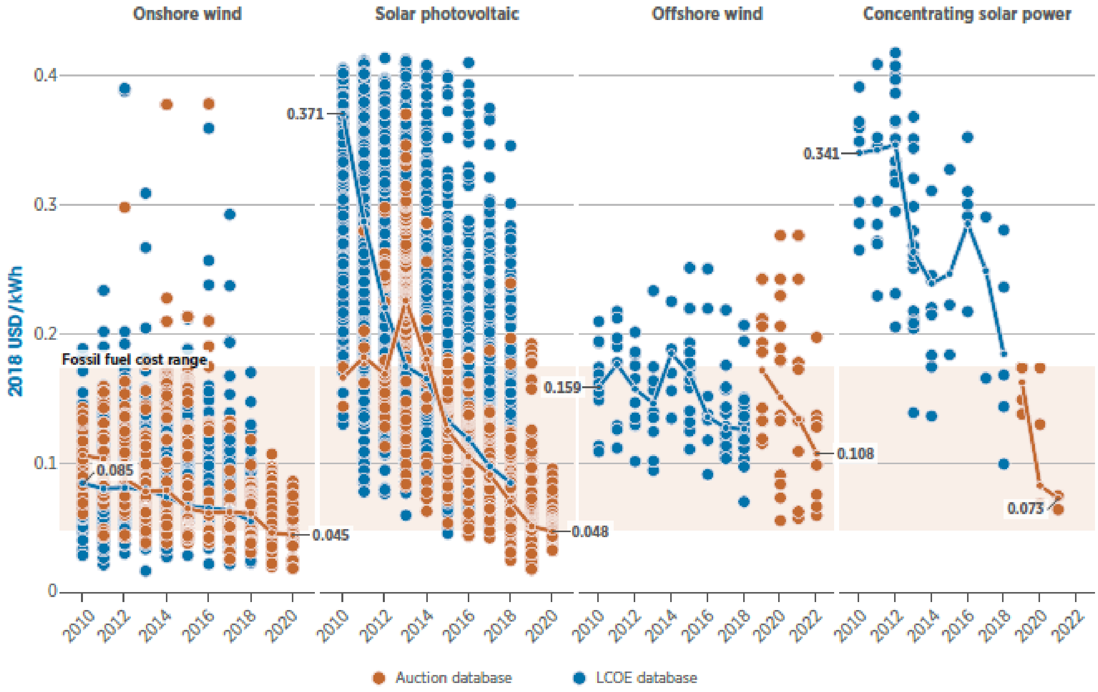
Figure 2 Distribution of direct normal solar irradiation: STE requires a level of 1900 kWh/m^2 or more (effectively the orange/red areas) (source © 2017 The World Bank, Solar resource data: Solargis)



[2] The average DNI at existing plants worldwide is 2214 kWh/m^2/year (SolarPaces database)

[3] A US$ to EURO conversion rate of 0.88 is used in this report.

Figure 3 IRENA analysis of LCoE and PPA values for operational and planned renewable energy technologies worldwide; the year refers to the actual or planned entry in operation. (source IRENA [7])



1.3 Deployment and Market Status

The current worldwide capacity of solar thermal electricity plants is approximately 5.6 GW, which represents <<1% penetration in the overall electricity market. This corresponds to 83 operational plants (Figure **4**) in 11 countries. The recent growth has been modest (Figure **5**), with the annual market generally well below 1 GW. Overall the deployment of this technology remains well behind the major renewables such as wind, solar photovoltaics and bioenergy. The parabolic trough technology accounts for more than 80% of STE plants in operation. However for projects under construction or in development, the breakdown is 50-50.

While Spain and the USA are the traditional deployment leaders, the latest developments are taking place elsewhere, in China, the Middle East, Morocco, South Africa and Chile. There has been a move to larger plants, >100 MW, which can bring economies of scale and reduced capital costs Up to now however operating experience with the new generation of large-scale central receiver plants is scarce. Annex 1 provides a listing of STE plants > 20 MW, based on data extracted from the NREL/SolarPACES database [8].

Figure 4 Global cumulative installed capacity of STE plants (source: NREL/SolarPACES data base and JRC analysis)

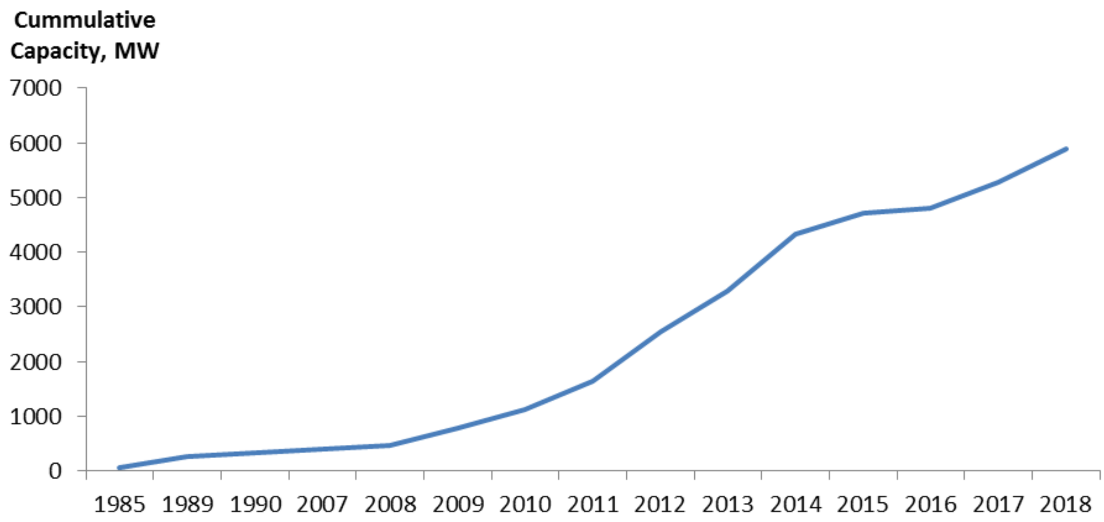


Figure 5 Annual STE capacity additions and country breakdown (source: NREL/SolarPACES data base and JRC analysis)

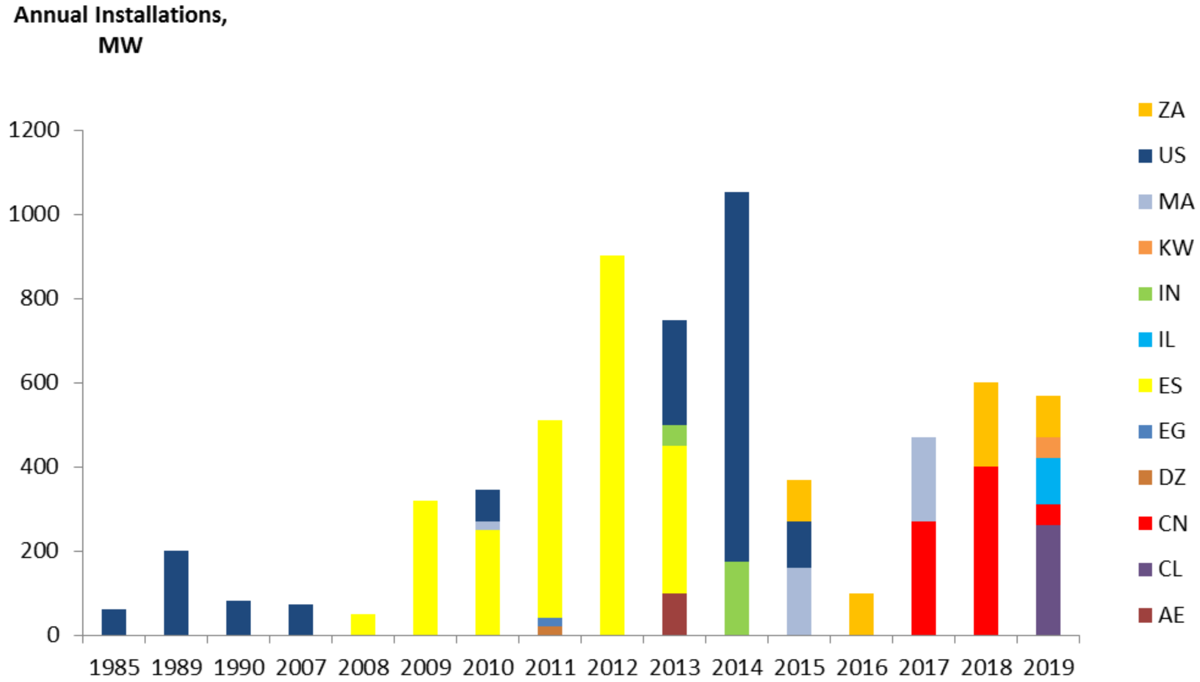


Table 1 Global breakdown of STE plants of 20 MW capacity or more (source: NREL/SolarPACES data base and JRC analysis).

Plant Technology/Status	Parabolic trough	Power tower	Linear Fresnel	Total
No. of Plants				
Operational	73	8	2	83
Under construction	10	8	1	19
Under development	5	8	1	14
Non-Operational	1	2	2	5
Development suspended		1		1
Grand Total (plants)				*122*
Installed capacity (MW)				
Operational	4 659	777	155	5 591
Under development	624	1 672	50	2 346
Under construction	1 218	831	50	2 099
Non-Operational	30	235	100	365
Development suspended		150		150
Grand Total (MW)	***6 531***	***3 665***	***355***	***10 551***

2 Trends and Prospects

2.1 Technology Development

Table 2 summarises the baseline technology characteristics for the STE systems. As mentioned in the introduction, parabolic trough designs are the most widely deployed and considered the most bankable for project financing. Nonetheless several recent developments have opted for solar tower designs, which allow a higher maximum temperature and hence increased efficiency for power generation and thermal heat storage. On the other hand, they can be more sensitive to site climatic conditions due to attenuation of the light between the mirrors and the receiver. Linear Fresnel reflectors potentially offer a cheaper solution than parabolic trough designs, mainly due to simpler manufacturing of the flat mirrors segments and lower overall land use.

In terms of technology development, there are a wide range of options for improving the performance and cost effectiveness of STE plants. The LCEO 2018 STE Technology Development Report [2] analyses the options. At EU level, the SET-Plan Implementation Working Group on CSP is coordinating planning of R&D and demonstration activities [9] based around the following two targets:

- Short-term: > 40% cost reduction by 2020 (from 2013) translating into a supply price[4] < 10 c€/kWh for a radiation of 2050 kWh/m^2/year (conditions in Southern Europe)
- Longer-term: develop the next generation of CSP/STE technology: new cycles (including supercritical ones) with a first demonstrator by 2020, with the aim to achieve additional cost reductions and opening new business opportunities.

Table 2 Main characteristics of state-of-the-art commercial plants (source: JRC collation of multiple data sources).

Design	Parabolic Trough	Solar Tower
Receiver	Line absorbers with high absorptivity (>95%) and low emissivity (<10%);	Metallic point receivers
Heat Transfer Fluid	Thermal oil at max. 395 °C	Molten salt or steam; max. working fluid temperatures of 570 °C
Thermal energy storage (TES)	Sensible heat with two-tank molten salt system	
Power cycle	Rankine with superheated steam (ORC for smaller facilities)	Rankine with superheated steam
Capacity factor (2050 DNI location)	27%, or greater with TES	26%, or greater with TES
Land area required	2.4 – 3.2 hectares/MW (direct area, including TES)	
Water consumption	3.5 m^3/MWh (with wet cooling[5], as for fossil plants)	
CO_2 footprint	22 gCO_2/kWh	

[4] The targeted price for 25-year power purchase agreements

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

2.2 Research and Innovation Investments

IEA data provides an estimate of the level of public support to R&D for solar technologies including STE and CSP, as shown in Figure **6**. A detailed analysis is hindered by several factors: a) only IEA member states are covered, so for instance the recent surge of interest in China is not captured, b) European Commission data is only included for H2020 and c) the disaggregation is incomplete, with a substantial part not allocated to any of the three solar sub-sectors. Overall STE/CSP appears to have followed the general trend of the solar sector, with a substantial increase in funding around 2008-2010, followed by some levelling off and even a decreasing trend more recently. Currently public funding is in the range EUR 70-100m (again excluding China). The main declared contributors in 2016 were USA, Australia, Germany, Switzerland, France and Denmark.

Patent data provides an alternative route to assessing R&D investments made by public and private organisations (albeit with a 3 to 4 time lag given the process for processing applications). The JRC [10] analysed data from Patstat (European Patent Office) for the period to 2014, focussing on the CPC code Y02E 10/40 (solar thermal energy) and its various sub-classes (see the [2] for detailed analysis). Figure **7** shows the time trend of investments as estimated from the patent data, and confirms a fall-off in EU and the USA investments over the last 5 years. Nonetheless, for the EU this data indicates private/public innovation investments of approximately EUR 300m in 2014. Compared to the values reported above for pure public R&D, the data suggests that EU private/industrial organisations are making investments of the order of EUR 200m per year. It remains to be seen whether the declining trend is confirmed by more recent data, or whether it has stabilised, aided by the latest market developments. For China, the estimates are considered to contain substantial uncertainties, also evidenced by the year-to-year fluctuations. Nonetheless they confirm that Chinese organisations are making substantial investments in STE technology, as in all forms of clean power generation, and can be expected to compete strongly with European and US firms in the international market in the coming years.

Figure 6 Historical trends in public investment in solar technologies (source: IEA data and JRC analysis)

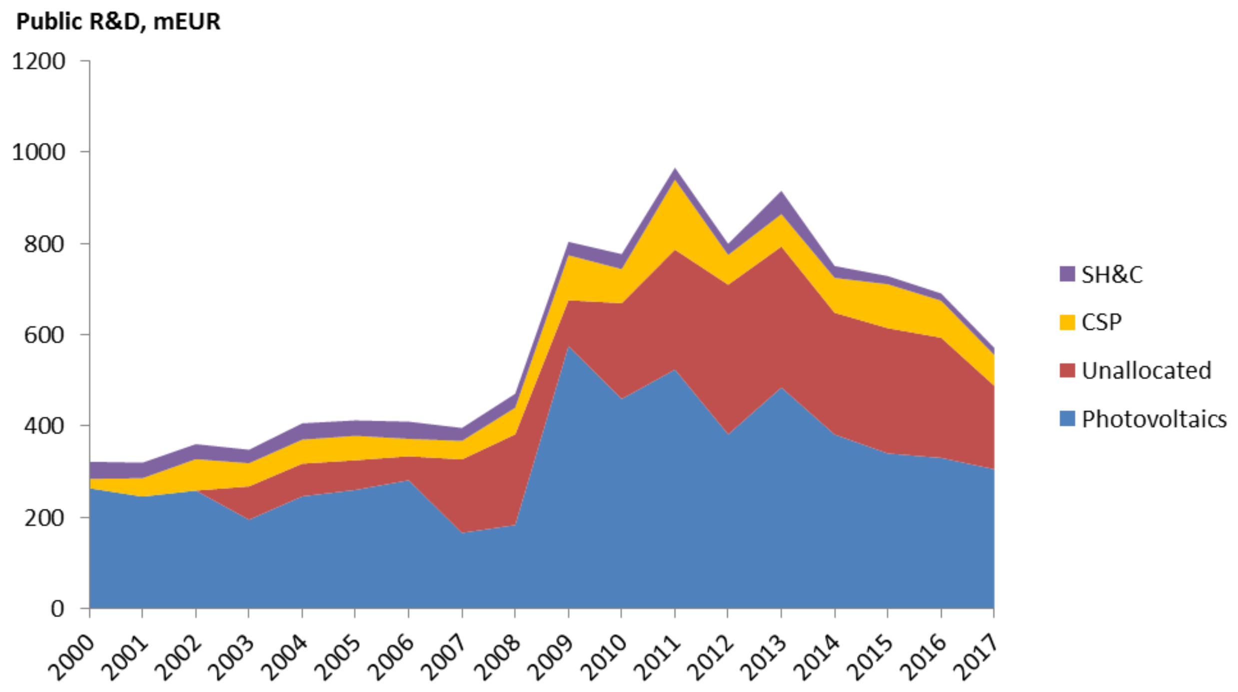
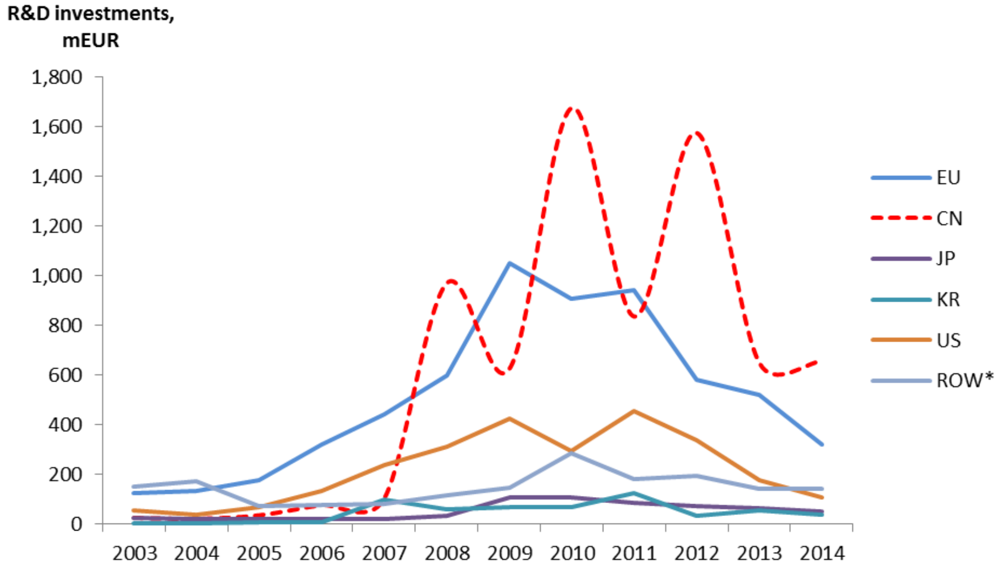


Figure 7 Estimates of R&I investments in CSP/STE technology based on patent data (sources: data – PATSAT, analysis - JRC)

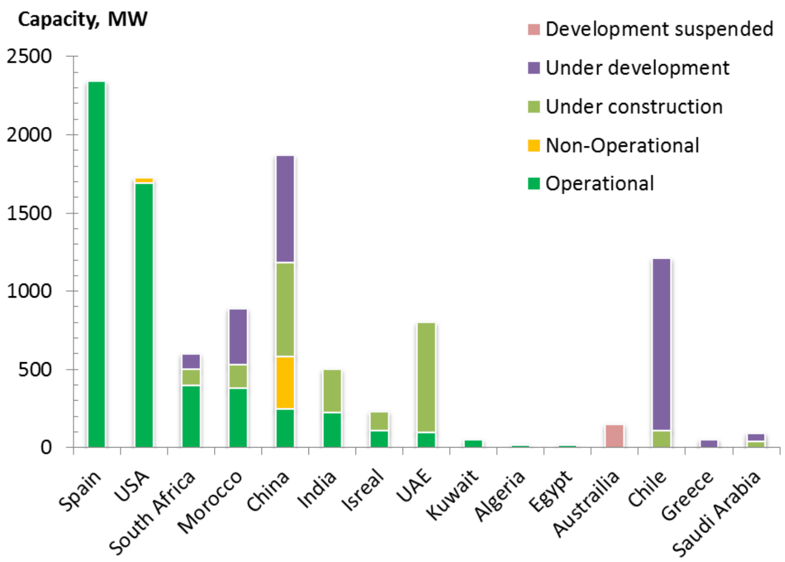


*) ROW = rest of world

2.3 Deployment Plans and Targets

The STE market has grown on average by about 500 MW per year since 2010. At present about 2 GW are in construction and a further 2 GW are various stages of planning and development. Figure **8** describes the situation per country and further details are included in the listing of STE plants > 20 MW in Annex 1. The following sections present the situation in the main regional markets, considering also relevant policies and market prospects.

Figure 8 Breakdown of the global STE plants (source: NREL/SolarPACES data base and JRC analysis)



2.3.1 Europe

In the EU current capacity is 2.4 GW, but growth is stalled and only the plant in development is MINOS in Crete. Spain has approximately 45 plants of 50 MW size, which were installed in the period 2009-2013 until a change in Spanish government policy effectively halted further developments. However, the good operational experience with these plants is a positive factor for new project financing at international level.

EU projections for 2030 are for modest growth. The 2018 IRENA REMap analysis for Europe [11] includes 6 GW of CSP by 2030 in the EU, as part of a 34% renewables scenario. More optimistically, the draft National Energy and Climate Plans submitted by the Member States in early 2019 indicate a total of 8.9 GW by 2030, with the bulk in Spain (see Table **3**).

Further policy relevant aspects include:

- The SET-Plan Implementation Plan for CSP [9] stresses the need to develop at least three first–of-a-kind (FOAK) commercial-scale plants in Europe in the coming 10 years.
- Possible use of the proposed Connecting Europe Facility programme (COM (2018) 483) for a CSP solar park in Southern Europe financed by other Member States and offering energy to Northern Europe.
- Plans for development of high capacity interconnectors with MENA countries may create possibilities for STE plants to supply power locally and to the EU. These include:
    - 3rd Spain-Morocco interconnector with 700 MW capacity by 2026.
    - EuroAsia interconnector (construction is starting on the first phase 1 000 MW of the Cyprus-Crete and Crete-Attica segments)
    - EuroAfrica Interconnector (proposed 2 000 MW interconnector between the Greek, Cypriot, and Egypt power grids)
    - Elmed (Italy and Tunisia plans for 600 MW interconnector)
    - Other proposed HVDC (e.g. interconnector between Algeria - Spain, Algeria – Sardinia and Tripoli – Sicily and a Morocco and Portugal study for a 1 000 MW interconnection)

Table 3 Plans for STE power capacity in the EU member states with high DNI solar irradiation (source: draft National energy and climate Plans, 2019)

Member State	2030 MW	Comments
Spain	7 300	2 300 MW in 2019
Italy	880	

Greece	< 200	
Cyprus	50	
Portugal	-	Only mentioned under R&D
France	-	STE not mentioned
Total	**8 880**	

2.3.2 Americas

In the USA there are no new plants currently under construction or development[6]. Nevertheless, various concepts are being explored and the US continues to fund a substantial R&D programme with a goal to obtain a levelised electricity cost of less than US$ 60/MWh by 2030 i.e 53 EUR/MWh. There is particular focus on the business case for potential plants in the merchant market, for instance flexible "peaker" designs operating to compete with gas turbines during the late afternoon – evening period.

From the policy perspective, there are no renewable energy targets at Federal Level but 29 states (plus the District of Columbia, Guam, Puerto Rico, and Virgin Islands) have Renewable Portfolio Standards[7] and 21 of them (plus the District of Columbia) have solar or distributed generation provisions. At the Federal Level, the Environmental Protection Agency regulates carbon emissions and has proposed rules for carbon emissions reductions of 30 % (from 2005 levels) by a state-by-state approach to be implemented between 2020 and 2030. These rules are currently on hold, but if implemented, could encourage STE in several areas. A further possibility concerns access to federal lands under the responsibility of the Bureau of Land Management.

Chile: the 110 MW Cerro Dominador plant is in construction, after being on old for two years during Abengoa's financial restructuring and should be operational by May 2021. Further CSP projects with environmental certification (RCA, Resolución de Calificación Ambiental) include:

- Likana Solar, (SolarReserve Chile, 450 MW)
- Tamarugal Solar (SolarReserve Chile, 450 MW)
- Copiapó Solar (SolarReserve Chile, 240 MW)

On the policy side, Chile has an overall 2050 energy plan that includes 70% renewable electricity, but without details of specific technologies.

2.3.3 Asia & Pacific

China is actively supporting the deployment of STE plants, as it is for all renewable and clean energy technologies, in the framework of its 13th Electricity Development Five Year Plan for 2016-2020. The target is to reach 5 GW of installed STE capacity by 2020.

2018 saw substantial progress, in which 3 projects came on-line (CGN Delingha 50 MW parabolic trough plant, Shouhang Dunhuang 100 MW solar tower plant and the SUPCON Delingha 50 MW molten salt tower plant). These are able to take advantage of a FiT of CNY 1.5 (EUR 0.20)/ kWh. In early 2019 the Qinghai Gonghe plant (50 MW, power tower) became operational and a further 16 projects are at various stages of development (see Annex 1 listing). Many of these plants form part of large "solar park" areas that combine PV and CSP development, as for example the Delingha Solar Park with 40 separate projects and over 1 GW of capacity (Figure **9**). Some of these developments have encountered difficulties: the industry news site CSP Focus China reported earlier this year that *"The »Shenzhen Jinfan Akesai« 50 MW molten salt project was stopped construction due to some financial problem"*, while *"Ten projects totalling 749 MW capacity are still under development, pending with little progress, mainly because of financial or internally political obstacles.*"

Figure 9 Satellite view of the Delingha Solar Park, Haixi, Qinghai Province, China with 40 separate projects and over 1 GW of capacity. The STE projects are outlined in yellow (source: PV Magazine 2019/6/11)

[6] SolarReserve had plans to develop a 2 GW plant at Sandstone, Nevada on federal land managed by the Bureau of Land Management. This is apparently not going ahead.
[7] Regulatory mandate to increase production of energy from renewable sources.

In Australia there are currently no STE plants are operating or under construction. Vast Solar has announced plans to build a 50 MW CSP-PV plant in New South Wales. The CSP part would be 30 MW, using an innovative design with liquid sodium as heat transfer fluid. It is noted that in 2017 SolarReserve (USA) signed a power purchase agreement for USD 0.06 /kWh with the South Australian government to supply up to 125 MW power from the 150 MW solar tower plant Aurora. However in April 2019 it abandoned the project due to difficulties in securing finance. An interesting feature of the project had been that the PPA did not cover the full plant capacity, so that the operator could supply the merchant market with the remainder (potentially at a higher price level).

2.3.4 Middle East and Africa

The MENA region is one of the most interesting for STE plant development, with major projects in development in the UAE and in Morocco. The DEWA project in Dubai has grabbed many headlines for size (700 MW CSP and almost 1 GW in total) and the PPA (aggregate 64 EUR/MWh for 35 years). The developers attribute the low PPA costs to:

- Economies of scale (e.g. re-thinking all components, use of "non-traditional" suppliers)
- Using "bankable" power trough technology for a major part
- Financing flexibility with banks and other institutions
- Professional and flexible tendering process

In Morocco Noor 1&2 projects are operational and Noor 3 is under construction (total 510 MW). Plans for a new project (Noor Midelt 1) with two 180 MW plants have also recently been announced.

South Africa now has 500 MW of CSP in operation and a further 100 MW in development. However the new draft national plan for 2030 does not include any further developments.

Recently plants in Egypt, Israel and Kuwait have also become operational. The industry continues to have high hopes that Saudi Arabia will commit to developing major STE plants.

2.4 Incentives and Support Policies

Investment in STE plants has been up to now driven largely by specific policy decisions. Feed-in tariffs were central to the boom in STE in Spain in the 2007-2013 period and to recent series of Chinese plants, and although the implementation of current international developments is largely driven by market-oriented mechanisms, these are often part of a policy framework that mandates a certain share of renewables in the energy system. Such mechanisms typically take the form of power purchase agreements, with the price level set directly with a contracting authority, by tendering or in a reverse auction for a pre-determined power allocation. Such tenders and auctions can be technology-

.specific, or may allow several renewable technologies to compete. STE can benefit in particular from auctions with a time-of-day- tariff system, as for instance the Renewable Energy Independent Power Producer Procurement Programme (REIPPP) in South Africa. This benefits STE's dispatchability in the peak evening tariff period.

In the USA many state and federal policies and programmes have been adopted to encourage the development of markets for renewable technologies. These comprise direct legislative mandates (such as renewable content requirements) and financial incentives (such as tax credits). The DSIRE[8] online database from North Carolina State University Solar Centre provides comprehensive information on the different support schemes across the country.

[8] Website http://www.dsireusa.org/

3 Industry and Market Overview

The global STE market is approximately EUR 3 billion annually and supports an extensive value chain in terms of activities, materials and technologies (Figure 10). The market and industry is truly international. A recent trend is the emergence of Chinese companies as major project developers (e.g. Shanghai Electric's role in the DEWA project in Dubai) and to a lesser but growing extent as technology providers. Annex 2 provides a short description of a selection of the main engineering and technology development companies. IRENA estimates that the industry supports 34 000 jobs worldwide, of which 6 000 in the EU [11].

EU-based organisations maintain a strong presence in the market. The trade association ESTELA lists 49 organisations (Table **4**) in its industry directory [13]. Activities are spread over 9 EU countries (Table **5**), with a strong Spanish presence. 70% are involved in R&D activities.

Figure 10 Overview of the STE value chain.

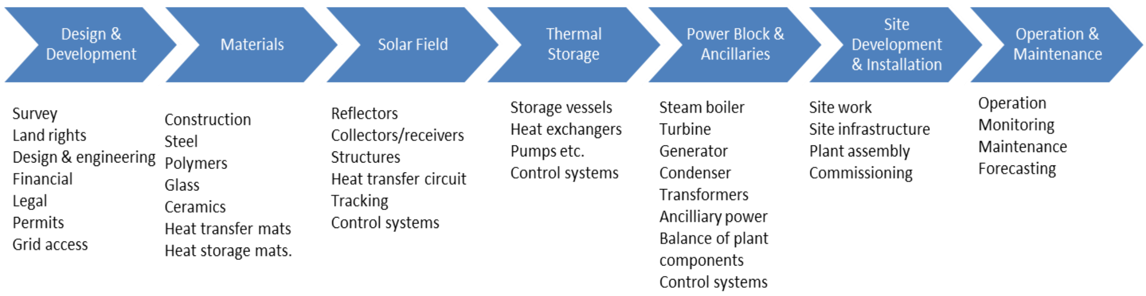


Table 4 Companies listed in in the ESTELA European solar thermal industry directory [13]

Aalborq CSPA	Exera Enerqia Srl	sbp sonne qmbl
Abengoa	Fichtner GmbH 8 Co. KG	JENER
ĄTEG	Fraunhofer ISE	SENIOR FIEXONICS
ATA Insĺghts.	Grupo Cobra	Seried Consultores S.l.
ATA Renewables	IA Tech GmbH	Solarlite CSP Technoloqy GmbH
BASF ESPAÑOLA	IK4 TEKNIKER	SQM International N.V.
CENER	IMDEA Energy	SUAVAL Group
CMI sa - BU SOLAR	Innogy SE	Suntrace GmbH
CSP Services GmbH	Kraftanlagen München GmbH	Tecnalia Research & Innovation
DLR	LEITAT Technoloqical Center	The Cyprus Institute
Eastman Chemical - Theminol	Meteo	The Dow Chemical Company
Products	NEMATIA Technologies, SL	TSK
ECILIMP TERMOSOLAR	PROMES-CNRS	TSK Flagsol Engineering GmbH
Empresarios Agrupados	Protarget AG	Universidad Carlos III de Madrid
ENEA	PSA CIEMAT	VIRTUALMECH
Enel Green Power	Rioglass	Wacker Chemie AG
ENGIE	ROBA Piping Projects	

The analysis of patent data confirms the role of EU organisations as innovators. Figure **11** shows a count of patents[9] in 2014 for three categories: all patent families, so-called "high-value" patent families i.e. applications made to two or more patent offices, and granted patent families. China took the largest share when considering all patent applications, but for the "high-value" patents the EU was leader, ahead of the USA[10]. Table **6** lists the top organisations globally – these have a strong

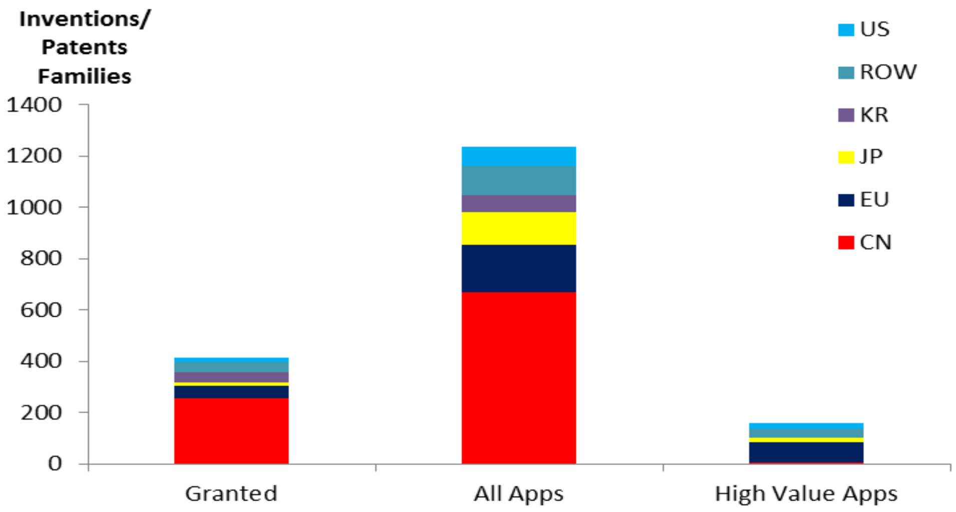
[9] Patent documents are grouped in families, with the assumption that one family equals one invention.
[10] The LCEO Technology Development Report for STE [2] has details on the breakdown of the patent classes.

representation of both European research institutions (e.g CEA, DLR) and industries (e.g. Robert Bosch, BASF, Heliovis[11]). At the same time, several major European-based technology companies in the ESTELA solar thermal industry directory (Table **4**) appear not to be active in patenting.

Table 5 Distribution by country of STE related industrial activities according to the ESTELA solar thermal industry directory [13]

	Member State	DE	DK	CZ	ES	FR	NL	IT	PT	BE
Activitity	Developer	✓			✓	✓		✓		
	Civil works				✓			✓	✓	
	Solar field	✓			✓	✓				✓
	Tower				✓			✓	✓	
	Receiver	✓	✓		✓		✓			
	Storage	✓			✓					✓
	Control	✓	✓		✓	✓	✓	✓	✓	
	Piping/Valves	✓			✓	✓		✓	✓	✓
	Steam generation	✓	✓		✓		✓	✓		
	Turbine	✓		✓				✓		
	Cooling system				✓			✓	✓	
	Electrical system	✓	✓	✓	✓	✓	✓	✓	✓	
	Auxiliary system				✓			✓	✓	
	Assembling				✓			✓	✓	
	Research	✓			✓	✓		✓	✓	

Figure 11 Regional breakdown of CSP/STE related patents for 2014.



[11] Owner of the HELIOtube technology, a proposed inflatable cylindrical concentrator.

Table 6 Ranking of organisations by number of patent families generated in 2014; EU-based are in bold. (source: JRC)

	Name	All	High Value	Granted
FR	**CEA**	**10.0**	**10.0**	**1.8**
DE	**Robert Bosch Gmbh**	**8.3**	**6.3**	
AT	**Heliovis Ag**	**5.0**	**5.0**	**0.2**
TW	Au Optronics Corp	4.5	4.5	4.1
JP	Mitsubishi Hitachi Power Sys	3.7	3.2	1.5
JP	Yazaki Energy System Corp	4.7	3.2	0.7
DE	**Basf Se**	**3.0**	**3.0**	**0.3**
JP	Chiyoda Corp	3.5	3.0	
FI	**Savo Solar Oy**	**2.4**	**2.4**	
JP	Sumitomo Electric Industries	2.0	2.0	
AT	**Sunlumo Technology Gmbh**	**3.0**	**2.0**	**1.0**
KY	Tahoe Technologies Ltd	2.0	2.0	
NL	**Sabic Global Technologies B V**	**2.0**	**2.0**	
US	Babcock & Wilcox Co	2.0	2.0	0.1
ES	**Sener Ingenieria Y Sistemas S.A.**	**1.9**	**1.9**	**0.5**
DE	**DLR**	**11.9**	**1.9**	**4.5**
CH	Alstom Technology Ltd	2.8	1.8	0.9
BE	**Cockerill Maintenance & Ingenierie Sa**	**1.8**	**1.8**	
US	Babcock & Wilcox Power Generation Group	2.5	1.5	0.3
US	Sunpower Corp	3.6	1.3	0.2
MX	Fricaeco America Sapi De C V	1.3	1.3	0.7
CN	Zhongying Changjiang Int. New Energy Investment Company	1.2	1.2	0.0
SE	**Cleanergy Ab**	**1.0**	**1.0**	**0.3**
US	Mit (Massachusetts Institute Of Technology)	1.5	1.0	
US	Rodluvan Inc	1.0	1.0	
DE	**Schott Ag**	**1.0**	**1.0**	**0.2**
AU	Vast Solar Pty Ltd	1.0	1.0	0.1
ES	**Abengoa Solar New Tech Sa**	**10.8**	**1.0**	**7.0**
US	Georgia Tech Res Inst	2.0	1.0	1.0
CH	Bartholet Maschb Ag	1.0	1.0	0.5
DE	**Solar Tower Technologies Ag**	**1.0**	**1.0**	**0.5**
IN	Council Of Scientific And Industrial Research (CSIR)	1.0	1.0	0.5
KR	Xl Co Ltd	1.0	1.0	0.5
TW	Nat Univ Tsinghua	1.0	1.0	0.5
TW	Sun Rise E & T Corp	1.0	1.0	0.5
DE	**Ophthalmosystem Gmbh**	**1.0**	**1.0**	**0.3**
DE	**Siemens Ag**	**1.5**	**1.0**	**0.3**
LT	**Uab Saules Vejo Aruodai**	**1.0**	**1.0**	**0.3**

4 Market Outlook

4.1 Technology Readiness and Costs

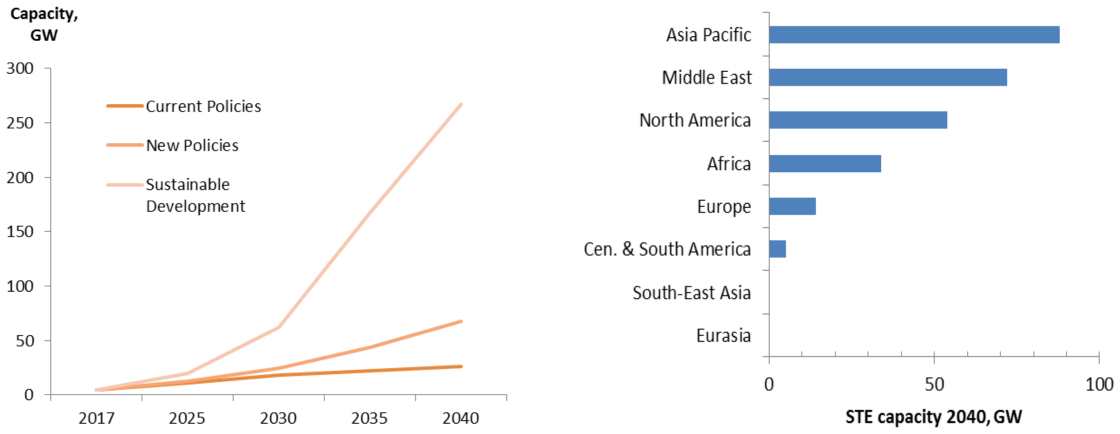
The further commercial development of STE plants is strongly dependent on achieving reductions in the cost of electricity generated, in common with all renewable technologies. As shown in Figure 3, the LCoE values have recently decreased significantly. This is consistent with the goals of the major R&D programmes such as the SET-Plan and the US Sunshot initiative (under the Sunshot initiative, the CAPEX for a nominal large plant - 100 MW or greater - with 8 hours of storage needs to come down to the level of EUR 3 million/MW from a 2018 level of over EUR 6 million/MW). The lower prices of recent PPAs in the Middle East and North Africa indicate that progress is being made, but the values strongly reflect other critical factors such as financing conditions. The LCEO Technology Development Report [2] gives further details on CAPEX and OPEX trends.

4.2 Global Market Analysis

At global level, the IEA envisages a modest role for CSP in the long-term (Figure **12**a), with installed capacity rising to 68 GW by 2040 under the new policies scenario[12] and to 267 GW under the sustainable development scenario [14]. These correspond to 0.3% and 2% shares of overall electricity generation respectively. It's notable that the projected sector growth is non-linear, accelerating strongly in the 2030 to 2040 period. For instance in the SD scenario, capacity increases from 62 GW in 2030 to 267 GW in 2040. The main markets are foreseen to be in the Middle East and Asia-Pacific regions, particular in China and India (Figure **12**b). The EU market is modest; by 2050 installed capacity would amount to 14 GW, providing about 1% (45 TWh[13]) of its electricity.

The IRENA ReMAP global analysis [15] is more ambitious, with a 2050 scenario including 633 GW of CSP (contribution 3.7% of electricity generation).

Figure 12 Regional breakdown for STE technology deployment in the IEA hi-REN scenarios [14].



a)STE capacity growth scenarios

b) regional distribution in 2040, SD scenario

[12] Under the New Policies Scenario, renewables grow to reach 26% of primary energy demand by 2040. The Sustainable Development Scenario foresees a substantial reduction of CO2 emissions, and 40% renewables in primary energy demand.

[13] The IEA data implies that the capacity factor for the EU CSP fleet in 2040 would be approximately 0.36, implying substantial storage capacity

4.3 EU Market - JRC-EU-TIMES Model

The JRC-EU-TIMES model offers a tool for assessing the possible impact of technology and cost developments[14]. It represents the energy system of the EU28 plus Switzerland, Iceland and Norway, with each country constituting one region of the model. It simulates a series of 9 consecutive time periods from 2005 to 2060. Table **7** lists the scenarios considered, while the LCEO report D4.7 [16] presents the model and the overall results. Here the focus is on the medium-to-long term STE market volume and the factors influencing it.

Figure **13** shows the power generation mix under the baseline, diversified (Div1), pro-renewables (Res1), and near zero-carbon (RES8_Near_ZeroCarbon) scenarios from 2010 to 2050. Total electricity production increases in all the scenarios, but particularly in the Pro-RES scenario (Res7), reflecting a deep electrification of transport and the use of electricity to produce hydrogen, synthetic fuels and other previously petrochemical-based products.

Although solar plays a significant role in the JRC-EU-TIMES future scenarios, PV dominates this contribution, with STE taking a marginal share.

Table 7 Overview of the JRC-EU-TIMES model scenarios.

Global Scenarios	Model Scenarios	Features
Baseline	Baseline	- 48 % CO_2 by 2050 (continuation of current trends)
Diversified	Div1	-80% CO2 by 2050
use of all known options including CCS and new nuclear plants	Div2_LowLR	Lower cost learning rate for all technologies
	Div3_HighLR	higher cost learning rate for all technologies
	Div4_DAC	Includes direct air capture of CO2
	Div5_CheapFossil	Oil price declines to $40/barrel
	Div6_NoCC_InPower	No carbon capture on power plants
Pro-Renewables	Res1	-80 % CO_2 by 2050
no new nuclear; no CCS	Res2_LowLR	Lower cost learning rate for all technologies
	Res3_HighLR	Higher cost learning rate for all technologies
	Res4_SET	CAPEX values reach the targets in the SET-Plan
	Res5_DAC	Includes direct air capture of CO2
	Res6_HighForest	Uses full forest potential with forest area equilibrium
	Res7_Near_ZeroCarbon	-95 % CO2 by 2050
	Res8_NoCCU	Further restriction on CO2 use (promotes re-use)

[14] The Commission's "Clean Planet for All - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy" communication (COM(2018) 773) includes results of a range of decarbonisation scenarios (LTS), but the results are reported without disaggregation of solar energy technologies. Several LTS scenarios have a 80% GHG reduction however the comparison with the Diversified and ProRES scenarios is difficult due to the diverging assumptions. There are some similarities, however always for a limited part of the energy system. For wind and solar power, the JRC-EU-TIMES diversified scenario is closest to the LTS Baseline scenario, but in the Pro-RES scenarios their contributions are much larger than any LTS scenario. This large increased in electricity use reflects a higher degree of electrification that in turn needs to be zero carbon to reduce the overall GHG emissions..

Figure 13 JRC-EU-TIMES results for power generation (TWh) for the baseline, diversified (Div1), pro-renewables (Res1), and near zero-carbon (RES-7_Near_ZeroCarbon) scenarios.

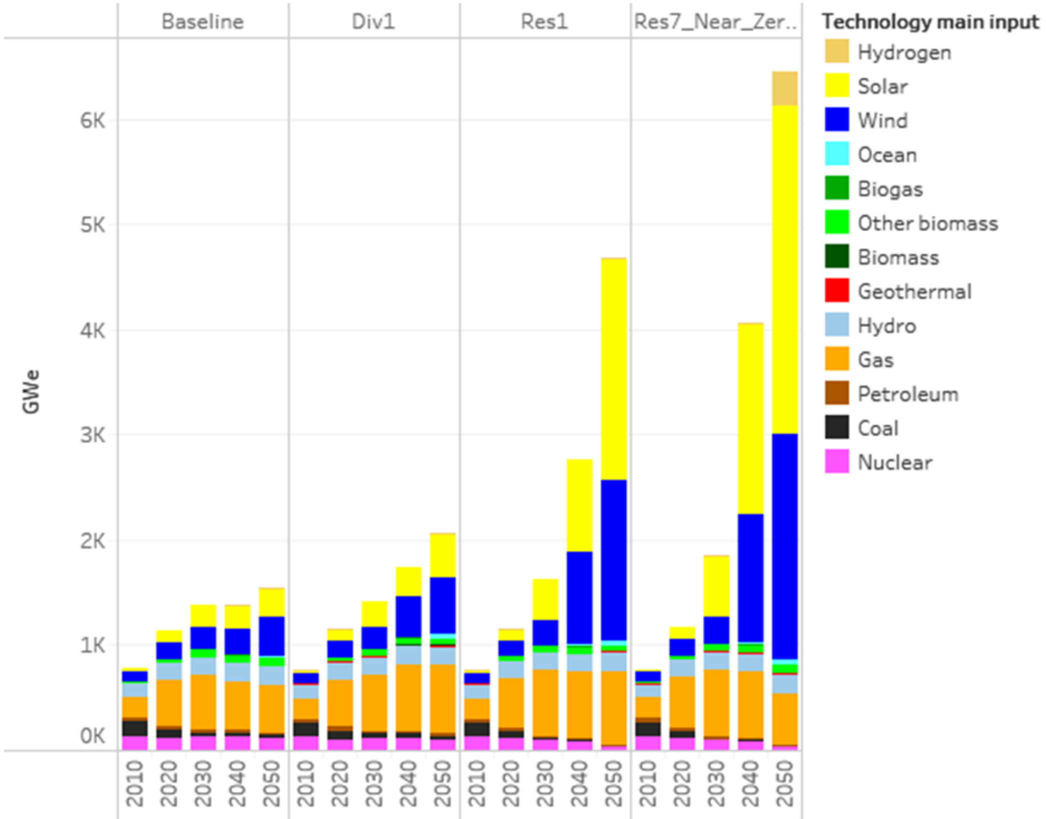


Figure **14** summarises the growth in STE for the scenarios in the 2030 to 2050 time periods. For the main diversified scenario (Div1), the capacity reaches 12 GW by 2050 and for the pro-renewables scenario (Res1) this increases by over an order of magnitude to 134 GW. For the near-zero carbon scenario, the STE capacity rises further to 202 GW by 2050. The baseline scenarios show no STE uptake. Both the diversified and pro-res scenarios are sensitive to variations in technology cost learning rates.

Figure **15** shows the country breakdown of STE electricity generated in the EU for the 2050 time period under Res-1. The deployment is confined to five "Mediterranean" member states, with Spain leading the way. In this scenario, STE provides 4% of the electricity generated in the EU. At country level, the penetration is highest in Portugal at 29% and lowest in Italy at 10%.

Figure 14 Growth of STE capacity in the various diversified and res scenarios of JRC-EU-TIMES

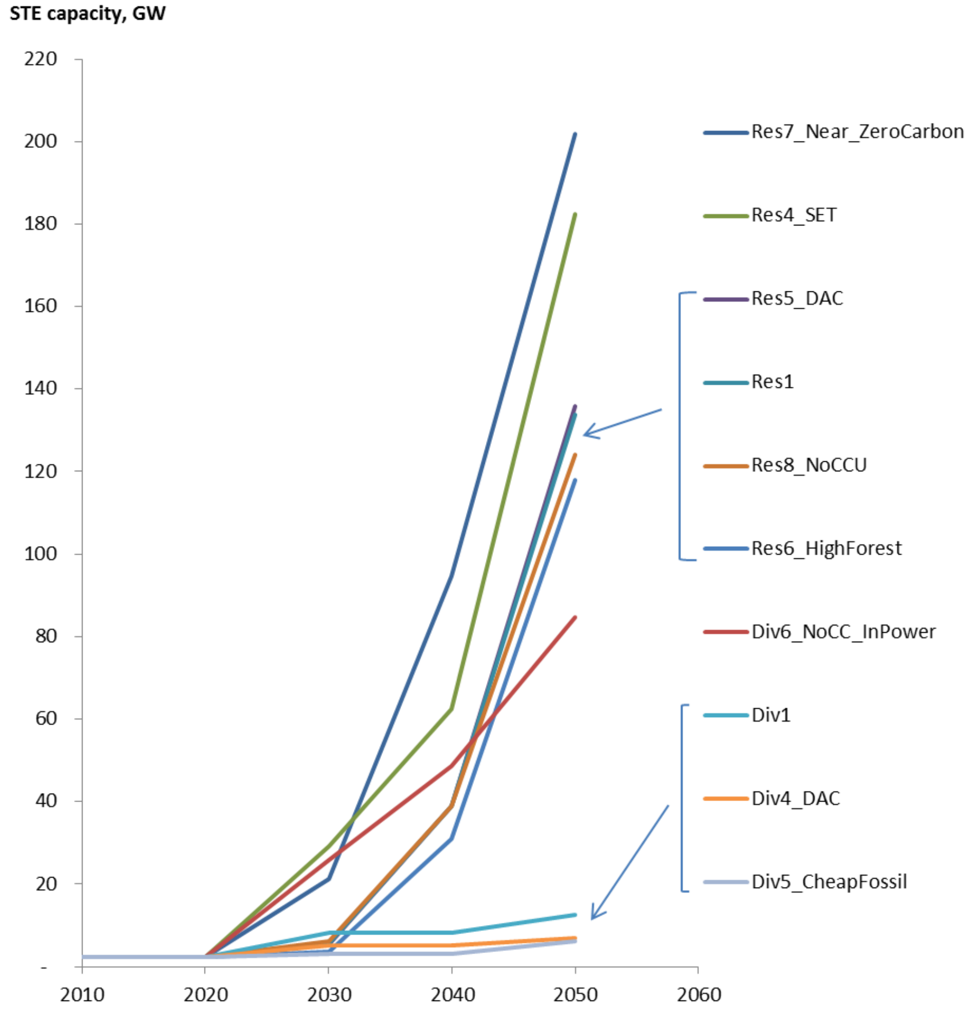
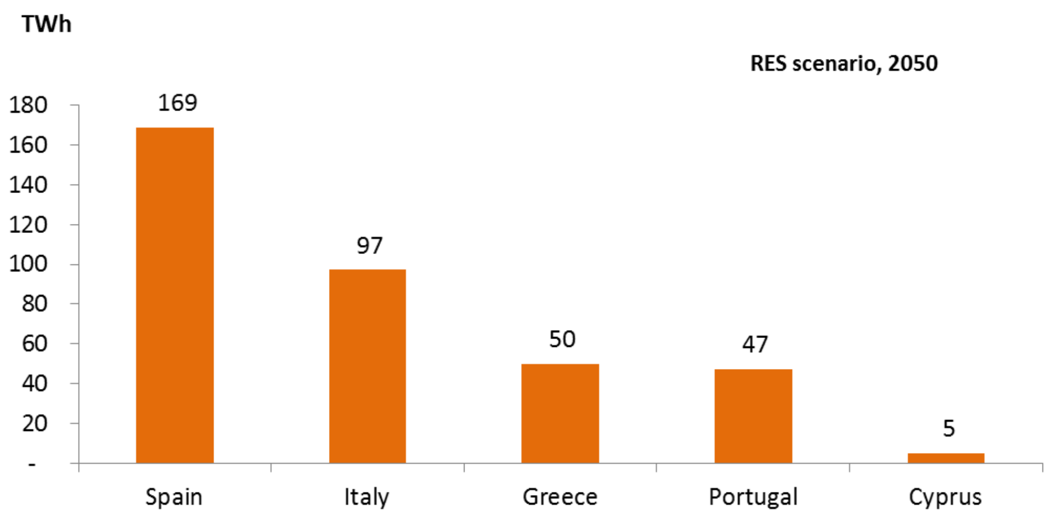


Figure 15 STE share of electricity production for European countries in 2050 under the RES1 scenario.



4.4 Key sensitivities and barriers to market expansion

The STE technology is fighting to keep its foothold in the global market for electricity generation, while also striving to introduce the innovations needed to support the competitiveness in the medium-term. Concepts promising significant efficiency increases such as super-critical steam cycles still have to be demonstrated at commercial level.

The recent PPAs awarded at well below EUR 100/MWh for new large plants in some MENA countries are an encouraging sign and demonstrate the technology's capability to deliver dispatchable power at prices competitive on the market. In this respect, storage is important and state-of-the-art STE plants can offer capacities an order of magnitude greater than the largest current battery systems[15]. The future use of "standardised" designs could help reduce construction times, which are currently 2-3 years (i.e. from breaking ground on the site to commissioning).

Distance from production sites to centres of major consumption is also a factor. The most favourable locations for STE in terms of high irradiation and low land cost are often not close to major sources of consumption (cities, industrialised areas), so transmission costs and development of new transmission networks needs to be considered in relation to any major expansion of capacity.

A key factor for financing is the reliability and confidence that operation performance will match design specifications. On the one hand, the fleet of Spanish STE plants is providing a positive demonstration of sustained performance as well as experience with maintenance issues. On the other, operating experience with the new generation of large-scale central receiver plants is scarce. A 24 month ramp-up to nominal performance is not considered unusual. Brightsource's Ivanpah plant in California experienced difficulties to reach the contracted performance levels, although these are apparently now resolved. Performance issues were also reported for the Shams (UAE), Cresent Dunes (US) and several Chinese plants. Overall, there is a need for reliable information on long-term operating and maintenance costs to help build up investor confidence.

Finally, environmental concerns include water consumption (although dry cooling concepts may mitigate this) and, for central receiver plants, the impact of the intense light beams.

[15] A 150 MW STE plant with a 10-hour thermal storage system provides a nominal 1500 MWh capacity, while the large Tesla battery in Australia has a capacity of 129 MWh.

5 Summary and Conclusions

This LCEO Technology Market Report has assessed recent developments and future perspectives for solar thermal electricity (CSP) technology markets, highlighting the role of EU stakeholders. Wherever possible, data coverage is to the end of 2018. At this point STE has a current worldwide installed capacity of 5.5 GW, with 2 GW in construction and further 2 GW at project development stage. For now, the added capacity per year remains well below 1 GW. The sector provides some 34 000 jobs worldwide.

The current phase of STE development is truly international, but there is only one commercial-scale plant in development in the EU (MINOS, Crete, Greece). Dispatchable STE electricity can be an interesting option for some countries with high insolation and without access to cheap natural gas (Morocco, South Africa). China and India foresee strongly growing electricity demand and wish to maintain a broad range of technology options. For other countries (e.g. the Gulf States), hybrid applications, including desalination and enhanced oil recovery, may provide additional stimulus. Potential for creating local employment can be higher than for some other low carbon technologies.

Overall there has been a move to larger plants, >100 MW. Storage systems with capacities to allow full-capacity generation for at least 8 hours after sundown have become an essential part of the STE package. In terms of technology, more than 80% of existing CSP power plants use parabolic trough designs. However, solar power tower concepts are now chosen for approximately half of the projects under construction or in development. Developing a track record for reliable operation of these new larger plant designs is important to reduce finance costs. There is also scope for reduction of construction and commissioning times.

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

Concerning future market development, at global level the IEA envisages a modest role for CSP in the long-term, with installed capacity rising to 267 GW by 2040 under its sustainable development scenario The IRENA ReMAP analysis is more ambitious, with a 2050 scenario including 633 GW of CSP (contribution 3.7% of electricity generation).

In the EU, the draft National Energy and Climate Plans submitted by the Member States in early 2019 indicate 6.5 GW of new capacity by 2030, with the bulk in Spain. In the JRC-EU-TIMES scenarios, STE reaches a modest 12 GW for the diversified scenario (RES, nuclear and CCS) while with the pro-renewables scenario (no nuclear or CCS) this increases by over an order of magnitude to 134 GW.

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Annex 1 Listing of STE Plants >20 MW

The following table reports commercial STE plants with power capacity >= 20 MW.

The main source is the NREL/SolarPaces database, supplemented by JRC information. Under the column "production start", the term "tbc" indicates a date in the future (post-2019) to be confirmed.

Country	Project Name	Technology	Status	Prod. Start	Main Developer	EPC Contractor	Heat Transfer Fluid Type	Capacity MW	Cooling Method	Storage Capacity hours
AE	DEWA Noor Energy 1	Power tower	Under construction	2021	ACWA Power	Shanghai Electric	Molten Salt	100	Wet cooling	15
AE	DEWA Noor Energy 1	Parabolic trough	Under construction	2021	ACWA Power	Shanghai Electric	Thermal Oil	600	Wet cooling	15
AE	Shams 1	Parabolic trough	Operational	2013	Masdar/Total/Abengoa Solar	Abener/Teyma	Therminol VP-1	100	Dry cooling	none
AU	Aurora (Port Augusta)	Power tower	Development suspended	tbc	Solar Reserve			150		8
CL	Atacama-1	Power tower	Under construction	tbc	Abengoa Solar		Molten Salt	110	Wet cooling	17.5
CL	Copiapó	Power tower	Under development	2019	Solar Reserve			260	Dry cooling	14
CL	Likana Solar energy Project	Power tower	Under development	tbc	Solar Reserve			390	Dry cooling	13
CL	Tamarugai Solar Energy Project	Power tower	Under development	tbc	Solar Reserve			450	Wet cooling	13
CN	Chabei	Parabolic Trough	Under Development	tbc	SkyFuel		Molten Salt	64	Wet cooling	16
CN	Dacheng Dunhuang	Linear Fresnel reflector	Under Construction	tbc	Lanzhou Dacheng Technology Co., Ltd		Molten Salt	50	Wet cooling	13
CN	Delingha	Parabolic Trough	Operational	2018	CGN Delingha Solar Energy	IDOM : Thermal energy storage system engineering	Thermal oil	50	Wet cooling	9
CN	Gansu Akesai	Parabolic Trough	Under Construction	tbc	Tianjin Binhai Concentrating Solar Power Investment Co., Ltd.		Molten Salt	50	Wet cooling	15
CN	Golden Tower	Power Tower	Under Development	tbc	SunCan		Molten Salt	100	Wet cooling	8
CN	Golmud	Power tower	Under construction	2018	Qinghai CSP Electric Power Group	China Shipbuilding Industry	Molten salt	200	Wet cooling	15
CN	Gulang	Parabolic Trough	Under Development	tbc	Changzhou Royal Tech Solar Thermal Equipment Co., Ltd.		Thermal oil	100	Wet cooling	7
CN	Hami	Power Tower	Under Construction	tbc	Supcon Solar		Molten Salt	50	Wet cooling	8
CN	Huanghe Qinghai Delingha	Power Tower	Non-Operational		BrightSource Energy		Water/Steam	135	Wet cooling	3.7
CN	Luneng Haixi	Power Tower	Under Construction	tbc	Luneng Qinghai Guangheng New Energy Co., Ltd	SEPCO3	Molten Salt	50	Wet cooling	12
CN	Qinghai Delingha Solar Thermal Generation Project	Power tower	Under development	2017	BrightSource Energy and Shanghai Electric Group		Water/Steam	270	Wet cooling	3.7

CN	Qinghai Gonghe	Power Tower	Operational	2019	Supcon Solar		Molten Salt	50	Wet cooling	6
CN	Rayspower Yumen	Parabolic Trough	Under Construction	tbc	Yumen Zhongshangming de CSP Co., Ltd		Thermal oil	50	Wet cooling	7
CN	Shangyi	Power Tower	Under Development	tbc	Institute of Electrical Engineering of CAS		Water/Steam	50	Wet cooling	4
CN	Shouhang Dunhuang	Power Tower	Operational	2018	Beijing Shouhang IHW	SunCan	Molten Salt	100	Wet cooling	11
CN	Supcon Solar Project (Qinghai)	Power Tower	Operational	2018	SUPCON Solar		Molten salt	50	Wet cooling	7
CN	Urat	Linear Fresnel reflector	Non-Operational	tbc	Huaneng North United Power Co., Ltd.		Thermal oil	50	Wet cooling	6
CN	Urat Middle Banner	Parabolic Trough	Under Construction	tbc	Changzhou Royal Tech Solar Thermal Equipment Co., Ltd.		Thermal Oil	100	Wet cooling	4
CN	Yumen	Power Tower	Non-Operational	tbc	SunCan		Molten Salt	100	Wet cooling	10
CN	Yumen	Power Tower	Under Construction	tbc	Shanghai Parasol Renewable Energy Company and Jiangsu Xinchen CSP Co., Ltd		Molten Salt	50	Wet cooling	6
CN	Yumen	Parabolic Trough	Under Development	tbc	Royal Tech CSP Limited		Thermal Oil	50	Wet cooling	7
CN	Zhangbei	Linear Fresnel reflector	Non-Operational	tbc	Beijing TeraSolar Photothermal Technologies Co., Ltd		Water/Steam	50	Wet cooling	14
CN	Zhangjiakou	Linear Fresnel reflector	Under Development	tbc	Beijing TeraSolar Photothermal Technologies Co., Ltd		Water/Steam	50	Wet cooling	14
DZ	ISCC Hassi R'mel	Parabolic trough	Operational	2011	Abener	Abener	Thermal oil	20	Dry cooling	none
EG	ISCC Kuraymat	Parabolic trough	Operational	2011	NREA	Orascom/ Flagsol	Therminol VP-1	20	Wet cooling	none
EL	MINOS (Crete)	Power Tower	Under Development	tbc	NUR Energie			52	Dry cooling	5
ES	Andasol-1	Parabolic trough	Operational	2008	ACS/Cobra Group	UTE CT Andasol-1: Cobra (80%) and Sener (20%)	Dowtherm A	49.9	Wet cooling	7.5
ES	Andasol-2	Parabolic trough	Operational	2009	ACS/Cobra Group	UTE CT Andasol-2: Cobra (80%) and Sener (20%)	Dowtherm A	49.9	Wet cooling	7.5
ES	Andasol-3	Parabolic trough	Operational	2011	Ferrostaal AG	Duro Felguera Group	Thermal Oil	50	Wet cooling	7.5
ES	Arcosol 50	Parabolic trough	Operational	2011	Torresol	UTE Valle 1	Diphenyl/Diphenyl Oxide	49.9	Wet cooling	7.5
ES	Arenales	Parabolic trough	Operational	2013	RREF/OHL	Ecolaire España	Diphyl	50	Wet cooling	7.5

ES	Aste 1A	Parabolic trough	Operational	2012	Elecnor/Aries/ABM AMRO	Elecnor	Dowtherm A	50	Wet cooling	7.5
ES	Aste 1B	Parabolic trough	Operational	2012	Elecnor/Aries/ ABM AMRO	Elecnor	Dowtherm A	50	Wet cooling	7.5
ES	Aste 1B	Parabolic trough	Operational	2012	Elecnor/Aries/ABM AMRO	Sener	Thermal Oil	49.9	Wet cooling	7.5
ES	Astexol II	Parabolic trough	Operational	2012	Elecnor/Aries/ABM AMRO	Elecnor	Thermal Oil	50	Wet cooling	7.5
ES	Borges Termosolar	Parabolic trough	Operational	2012	Abantia	Abantia & Comsa EMTE	Thermal Oil	22.5	Wet cooling	none
ES	Casablanca	Parabolic trough	Operational	2013	ACS - COBRA group	Cobra Instalaciones y Servicios		50	Wet cooling	7.5
ES	Enerstar	Parabolic trough	Operational	2013	FCC Energy	FCC, SerIDOM (IDOM Group)	Thermal Oil	50	Wet cooling	none
ES	Extresol-2	Parabolic trough	Operational	2010	ACS/Cobra Group	Cobra Instalaciones y Servicios	Diphenyl/Biphenyl oxide	49.9	Wet cooling	7.5
ES	Extresol-2	Parabolic trough	Operational	2010	ACS/Cobra Group	Cobra Instalaciones y Servicios	Diphenyl/Biphenyl oxide	49.9	Wet cooling	7.5
ES	Extresol-3	Parabolic trough	Operational	2012	ACS/Cobra Group	Cobra Instalaciones y Servicios	Diphenyl/Biphenyl oxide	50	Wet cooling	7.5
ES	Gemasolar Thermosolar Plant	Power tower	Operational	2011	Torresol Energy	UTE C.T. Solar Tres	Molten salts (sodium and potassium nitrates)	19.9	Wet cooling	7.5
ES	Guzmán	Parabolic trough	Operational	2012	FCC Energy	FCC, Abantia, SerIDOM (IDOM Group)	Dowtherm A	50	Wet cooling	none
ES	Helioenergy 1	Parabolic trough	Operational	2011	Abengoa Solar	Abener/Teyma	Thermal Oil	50	Wet cooling	none
ES	Helioenergy 2	Parabolic trough	Operational	2012	Abengoa Solar	Abener/Teyma	Thermal Oil	50	Wet cooling	none
ES	Helios I	Parabolic trough	Operational	2012	Helios I HYPERION Energy Investments, S.L.	Abener/Teyma	Thermal Oil	50	Wet cooling	none
ES	Helios II	Parabolic trough	Operational	2012	Helios II HYPERION Energy Investments, S.L.	Abener/Teyma	Xceltherm® MK1	50	Wet cooling	none
ES	Ibersol Ciudad Real (Puertollano)	Parabolic trough	Operational	2009	IBERCAM (Iberdrola Renovables Castilla-La Mancha)		Dowtherm A	50	Wet cooling	none
ES	La Africana	Parabolic trough	Operational	2012	Ortiz/TSK/Magtel	Sener		50	Wet cooling	7.5
ES	La Dehesa	Parabolic trough	Operational	2011	Renovables SAMCA	Not applicable (several contractors)	Diphenyl/Biphenyl oxide	49.9	Wet cooling	7.5
ES	La Florida	Parabolic trough	Operational	2010	Renovables SAMCA	Not applicable (several contracto	Biphenyl/Diphenyl oxide	50	Wet cooling	7.5

						rs)				
ES	La Risca	Parabolic trough	Operational	2009	Acciona Energía	Acciona Energía, SerIDOM (IDOM Group)	Biphenyl/ Diphenyl oxide	50	Wet cooling	none
ES	Lebrija 1	Parabolic trough	Operational	2011	Solucia Renovables 1, S.L.	Soleval Renovables, S.L.	Therminol VP1	50	Wet cooling	none
ES	Majadas I	Parabolic trough	Operational	2010	Acciona Energía	Acciona Energía, SerIDOM (IDOM Group)	Biphenyl/Diphenyl oxide	50	Wet cooling	none
ES	Manchasol-1	Parabolic trough	Operational	2011	ACS/Cobra Group	Cobra Instalaciones y Servicios	Diphenyl/Diphenyl oxide	49.9	Wet cooling	7.5
ES	Manchasol-2	Parabolic trough	Operational	2011	ACS/Cobra Group	Cobra Instalaciones y Servicios	Diphenyl/Diphenyl oxide	50	Wet cooling	7.5
ES	Morón	Parabolic trough	Operational	2012	Ibereólica Solar	Acciona/Seridom	Thermal Oil	50	Wet cooling	none
ES	Olivenza 1	Parabolic trough	Operational	2012	Ibereólica Solar	Acciona/Seridom	Thermal Oil	50	Wet cooling	none
ES	Orellana	Parabolic trough	Operational	2012	Acciona	Sener	Thermal Oil	50	Wet cooling	none
ES	Palma del Río I	Parabolic trough	Operational	2011	Acciona Energía	Acciona Energía	Biphenyl/Diphenyl oxide	50	Wet cooling	none
ES	Palma del Río II	Parabolic trough	Operational	2010	Acciona Energía	Acciona Energía	Biphenyl/ Diphenyl oxide	50	Wet cooling	none
ES	Planta Solar 20	Power tower	Operational	2009	Abengoa Solar	Abener Energía	Water	20	Wet cooling	1
ES	Puerto Errado 2 Thermosolar Power Plant	Linear Fresnel reflector	Operational	2012	Novatec Biosol AG	Novatec GmbH & Co. KG	Water	30	Dry cooling	0.5
ES	Solaben 1	Parabolic trough	Operational	2013	Abengoa	Abener/Teyma	Thermal Oil	50	Wet cooling	none
ES	Solaben 2	Parabolic trough	Operational	2012	Abengoa	Abener/Teyma	Thermal Oil	50	Wet cooling	none
ES	Solaben 3	Parabolic trough	Operational	2012	Abengoa	Abener/Teyma	Thermal Oil	50	Wet cooling	none
ES	Solaben 6	Parabolic trough	Operational	2013	Abengoa	Abener/Teyma	Thermal Oil	50	Wet cooling	none
ES	Solacor 1	Parabolic trough	Operational	2012	Abengoa Solar	Abener/Teyma	Thermal Oil	50	Wet cooling	none
ES	Solacor 2	Parabolic trough	Operational	2012	Abengoa Solar	Abener/Teyma	Thermal Oil	50	Wet cooling	none
ES	Solnova 1	Parabolic trough	Operational	2009	Abengoa Solar	Abener Energia	Thermal oil	50	Wet cooling	none
ES	Solnova 3	Parabolic trough	Operational	2009	Abengoa Solar	Abener Energia	Thermal oil	50	Wet cooling	none
ES	Solnova 4	Parabolic trough	Operational	2009	Abengoa Solar	Abener Energia	Thermal oil	50	Wet cooling	none

ES	Termesol 50	Parabolic trough	Operational	2011	Torresol	UTE Valle 2	Diphenyl/Diphenyl Oxide	49.9	Wet cooling	7.5
ES	Termosol 1	Parabolic trough	Operational	2013	NextEra, FPL	Sener	Thermal Oil	50	Wet cooling	9
ES	Termosol 2	Parabolic trough	Operational	2013	NextEra, FPL	Sener	Thermal Oil	50	Wet cooling	9
IL	Ashalim	Parabolic trough	Operational	2019	Negev Energy Ltd. (Abengoa and Shikun & Binui)			110	Wet cooling	4.5
IL	Ashalim Plot B (Magalim)	Power Tower	Under construction	tbc	Megalim Solar Power Ltd			121	Wet cooling	none
IN	Abhijeet Solar Project	Parabolic trough	Under construction	tbc	Corporate Ispat Alloys Ltd.	Shriram EPC Ltd Chennai	Therminol VP-1	50	Wet cooling	none
IN	Dhursar	Linear Fresnel reflector	Operational	2014	Rajasthan Sun Technique Energy	Areva		125	Wet cooling	none
IN	Diwakar	Parabolic trough	Under construction	tbc	Lanco Solar	Lanco Solar	Synthetic Oil	100	Wet cooling	4
IN	Godawari Solar Project	Parabolic trough	Operational	2013	Godawari Green Energy Limited	Lauren-Jyoti	Dowtherm A	50	Wet cooling	none
IN	Gujarat Solar One	Parabolic trough	Under construction	tbc	Cargo Solar Power	Lauren CCL	Diphyl	25	Wet cooling	9
IN	KVK Energy Solar Project	Parabolic trough	Under construction	tbc	KVK Energy Ventures Ltd	Lanco Solar	Synthetic Oil	100	Wet cooling	4
IN	Megha Solar Plant	Parabolic trough	Operational	2014	Megha Engineering and Infrastructure	MEIL Green Power	Xceltherm® MK1	50	Wet cooling	none
KW	Shagaya CSP Project	Parabolic trough	Operational	2019	Kuwait Institute for Scientific Research (KISR)	TSK		50	Wet cooling	9
MA	ISCC Ain Beni Mathar	Parabolic trough	Operational	2010	Abener	Abener	Therminol VP-1	20	Wet cooling	none
MA	NOOR I (Ouarzazate)	Parabolic trough	Operational	2015	ACWA Power, Aries and TSK	Acciona, Sener and TSK	Dowtherm A	160	Wet cooling	3
MA	NOOR II	Parabolic trough	Operational	2017	ACWA	Sener	Thermal oil	200	Wet cooling	7
MA	NOOR III	Power tower	Under construction	tbc	ACWA	Sener	Molten salt	150	Wet cooling	7
SA	ISCC Duba 1	Parabolic trough	Under construction	tbc	Saudi Electricity Co.	Initec Energia		43	Wet cooling	none
SA	Waad Al Shamal ISCC Plant	Parabolic trough	Under Development	tbc				50		
US	Crescent Dunes Solar Energy Project	Power tower	Operational	2015	SolarReserve, LLC	ACS Cobra	Molten salt	110	Hybrid	10
US	Genesis Solar Energy Project	Parabolic trough	Operational	2014	Genesis Solar, LLC		Therminol VP-1	250	Dry cooling	none
US	Ivanpah Solar Electric Generating System	Power tower	Operational	2014	BrightSource Energy	Bechtel Engineering	Water	377	Dry cooling	none
US	Martin Next (ISCC plant)	Parabolic trough	Operational	2010	Florida Power & Light Co.	Lauren Engineers & Construct	Thermal Oil	75	Wet cooling	none

						ors				
US	Mojave Solar Project	Parabolic trough	Operational	2014	Mojave Solar, LLC	Abener - Teyma	Therminol VP-1	250	Wet cooling	none
US	Nevada Solar One	Parabolic trough	Operational	2007	Acciona Solar Power	Lauren Engineeri ng	DOWTHER M A	72	Wet cooling	0.5
US	Solana Generating Station	Parabolic trough	Operational	2013	Abengoa Solar	Abener-Teyma	Therminol VP-1 --- Xceltherm MK1	250	Wet cooling	6
US	SEGS-2- II	Parabolic trough	Non-operational	1985	Luz			30	Wet cooling	none
US	SEGS-3- III	Parabolic trough	Operational	1985	Luz		Therminol	30	Wet cooling	none
US	SEGS-4- IV	Parabolic trough	Operational	1989	Luz		Therminol	30	Wet cooling	none
US	SEGS-5- V	Parabolic trough	Operational	1989	Luz		Therminol	30	Wet cooling	none
US	SEGS-6- VI	Parabolic trough	Operational	1989	Luz		Therminol	30	Wet cooling	none
US	SEGS-7- VII	Parabolic trough	Operational	1989	Luz		Therminol	30	Wet cooling	none
US	SEGS-8- VIII	Parabolic trough	Operational	1989	Luz		Therminol	80	Wet cooling	none
US	SEGS-9- IX	Parabolic trough	Operational	1990	Luz		Therminol	80	Wet cooling	none
ZA	Bokpoort	Parabolic trough	Operational	2016	ACWA Power	Acciona, Sener and TSK	Dowtherm A	50	Dry cooling	9.3
ZA	Ilanga I	Parabolic trough	Operational	2018	Emvelo and Cobra	Cobra	Thermal oil	100	Wet cooling	5
ZA	Kathu Solar Park	Parabolic trough	Under construction	2019	Engie	Acciona and Sener	Thermal oil	100	Wet cooling	4.5
ZA	KaXu Solar One	Parabolic trough	Operational	2015	Abengoa Solar - IDC	Abener - Teyma	Thermal oil	100	Dry cooling	2.5
ZA	Khi Solar One	Power tower	Operational	2016	Abengoa Solar - IDC	Abener - Teyma	Water/Stea m	50	Dry cooling	2
ZA	Redstone Solar Thermal Power Plant	Power tower	Under development	tbc	ACWA	Tecnicas Reunidas and TSK	Molten salt	100	Dry cooling	12
ZA	Xina solar One	Parabolic trough	Operational	2018	Abengoa		Thermal Oil	100	Wet cooling	5

Annex 2 Major Companies involved in STE

The following list includes a selection of the major companies involved in the STE sector.

Abengoa (ES)
Abengoa developed as an integrated company offering "turn-key" projects and operating energy assets such as solar-thermal plants, transmission lines, biofuel production plants, cogeneration plants. Abengoa designs, constructs and operates parabolic trough and central receiver concentrating solar power plants.

Acciona Energy (ES)
Acciona Energy is the energy division of the Acciona Group and a world leader in the field of renewable energies, in particular wind and PV, but also hydropower, CSP and biomass. It developed Nevada Solar One in the US in 2007 and installed five utility-scale plants with solar trough technology in Spain.

ACWA Power (Saudi Arabia)
ACWA Power is a developer, investor, co-owner and operator of a portfolio of power generation and desalinated water production plants in the Middle East and North Africa, Southern Africa and South East Asia regions. In 2013 it acquired Flabeg FE GmbH, a developer and manufacturer of solar mirrors (see below). It is the developer of the DEWA project in the UAE.

Brightsource Energy (US)
BrightSource Energy designs, develops and deploys concentrating solar thermal technology to produce high-value steams for electric power, petroleum and industrial-process markets worldwide. It began as Luz International, the company that developed and operated the SEGS plants in the 1980s/1990s. It now has operations in the United States, China, Europe, Israel and South Africa. Its focus is on central receiver technology, with direct heating of pressurised steam in a tower-top boiler. The steam is used either in a conventional turbine to produce electricity, for molten salt storage or potentially for industrial process applications, such as thermal enhanced oil recovery. Brightsource provides the technology for the world largest STE plant (377 MW) at Ivanpah in the US.

Ener-T International (Israel)
Ener-T is a technology developer and an engineering, procurement and construction (EPC) contractor for large scale solar thermal power projects. Some of its staff were previously at solar thermal pioneers Luz. The company has developed what's claimed as a next generation of CSP parabolic trough technology. The company's innovations include thermal storage systems, as well as a patented hybrid solution with biomass, gas or any other type of fossil fuel, which enables plants to generate power 24/7. Ener-T is involved in projects in India and China.

Flabeg FE GmbH (DE)
Flabeg is a leading developer and manufacturer of mirrors for CSP, and is owned by **ACWA** (Saudi Arabia). Its mirrors were used in the first commercially operated power stations in the early 80s, and are still in daily operation today. The company has been expanding its skills in the area of engineering services and project development support in parabolic trough technology. Its new collector design – the Ultimate Trough Collector – offers higher cost efficiency compared to currently available technology. Its currently supplies projects being developed in Saudi Arabia and Morocco.

Grupo Ibereolica (ES)
Grupo Ibereolica's business areas include water, wind, biomass and the sun. It develops solar thermal power plants with cylinder-parabolic collector technology.

Ingeteam Power Technology (ES)
Ingeteam specialises in the development of electrical equipment, motors, generators, frequency converters, electrical engineering and generation plants. In 2015 the company won a contract to supply basic engineering for a CSP parabolic trough power plant in China.

Rioglass Solar (BE)
Rioglass Solar is a multinational solar power and renewable energy technology manufacturer set up in 2007. It supplies two of the main components of the parabolic trough technology, mirrors and receivers, as well as reflectors for CSP towers, Fresnel and Stirling technologies .Rioglass Solar is reportedly now the largest provider of heat collector tubes and tempered glass mirrors in the world. Acquisitions have played a significant role: in 2013 it took over the receiver technology and related manufacturing assets of Siemens CSP, and in 2015 it also acquired Schott Solar's receiver business, including the company in Spain and the assets in Germany.[16]

Sener (ES)
SENER is a private engineering and technology group founded in 1956. It provides EPC for projects in the fields of aeronautics, energy and the environment. For STE it exploits both parabolic trough and central tower CSP technologies.

Shandong Beaconergy Associated Equipment Corp. Ltd., (PRC)
Beaconergy provides solutions and advanced equipment in the field of thermal systems. The business activities are:

1. R&D, production and sales of high temperature molten salt receivers
2. R&D, production and sales of high temperature solar heating and refrigeration technology
3. R&D, production and sales of concentrator tracking systems
4. Exploration of industrial waste heat utilization
5. Thermal engineering projects

Shanghai Electric Group Co.,Ltd. (PRC)
SEG is one of the largest mechanical and electrical equipment manufacturers in China. Its products cover more than ten industrial sectors and range over power generation equipment, power transmission and distribution equipment, electromechanical integration equipment, transport equipment, environmental protection.

Siemens (DE)
Siemens is the market leader in steam turbines for CSP plants, and has more than 20 years of experience with steam turbines for daily cycling. In 2013 Rioglass took over the Siemens receiver technology and the related manufacturing assets of the then-subsidiary Siemens CSP.

SolarReserve (US)
SolarReserve is a leading global developer of utility-scale solar power projects, which include electricity generation by solar thermal energy and photovoltaic panels. It has commercialized a proprietary solar thermal technology with integrated energy storage, using a power tower CSP system with direct molten salt heat transfer and storage. It has managed the design, engineering, fabrication and erection of the world’s largest capacity molten salt tower receiver at the Crescent Dunes Solar Energy Project in the United States. It has acquired Aerojet Rocketdyne’s intellectual property rights related to molten salt technology for concentrating solar-thermal power and electricity storage applications.

Soltigua SpA. (Italy)
Soltigua is an Italian SME that provides solar concentrating collectors and systems. The company produces solar troughs and Fresnel collectors (FLT series). IRESEN’s Green Energy Park has chosen the FLT10v linear Fresnel collectors for constructing a 1MW CSP system in Benguerir, Morocco.

Torresol Energy
Torresol Energy was founded in 2008 through an alliance between SENER Grupo de Ingeniería, S.A.,a Spanish multinational technology leader (owner of 60% of the company), and MASDAR, an alternative power company in Abu Dhabi (owner of 40%). Torresol Energy operates three plants in Spain and is involved in the development of a thermosolar plant in Abu Dhabi.

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[16] Schott continue to offer after sales support for the CSP receivers it sold in the past, and SCHOTT Solar CSP GmbH continues trading for this purpose.

TSK (ES)/ TSK Flagsol (DE)

TSK is a leading technology company. In 2015 it had a turnover of 740 million Euros, with 97% of its activity outside of Spain. It has worked in PV since 2006 and since 2008 in STE.

In 2013, TSK acquired the German engineering company Flagsol, with extensive experience in parabolic trough plants. The TSK group also has projects on linear Fresnel collectors and development work on solar tower systems.

KJ-BK-19-012-EN-N

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Publications Office of the European Union

doi:10.2760/975583

ISBN 978-92-76-12564-8