International Renewable Energy Agency

RENEWABLE ENERGY BENEFITS

LEVERAGING LOCAL CAPACITY FOR CONCENTRATED SOLAR POWER

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ABBREVIATIONS

CSP	concentrated solar power
CST	concentrated solar thermal
DNI	direct normal irradiance
EPC	engineering, procurement and construction
FiT	feed-in tariff
GW	gigawatt
HTF	heat transfer fluid
IRENA	International Renewable Energy Agency
kWh	kilowatt hour
LCOE	levelised cost of energy
m^2	square metre
MW	megawatt
O&M	operation and maintenance
PSA	Plataforma Solar de Almería
PV	photovoltaic
R&D	research and development
SEGS	solar energy generating systems
SHIP	solar heat for industrial processes
STEM	science, technology, engineering and mathematics
SWOT	strengths, weaknesses, opportunities and threats
TES	thermal energy storage

ABOUT THE IRENA LEVERAGING LOCAL CAPACITY SERIES

Renewable energy development can drive economic growth, create new jobs and enhance human health and welfare. The leveraging local capacity series examines the kinds of jobs created and suggests ways to build on existing capacity to maximise the benefits of renewable energy development. Each study, focused on a technology, outlines the requirements along the entire value chain, particularly in terms of human labour and skills, to produce, install and operate plants or facilities. It intends to support assessment of potential for local value creation and leveraging domestic capabilities.

To date, studies have focused on both utility-scale and decentralised renewable energy solutions. The utility-scale solutions considered to date include solar photovoltaic (2016), on-shore wind (2017), off-shore wind (2018) and now concentrated solar power (2025). Decentralised solutions include solar water heaters (2021) and small-scale hydropower (2023). Analysis updates are under preparation.

The series may be used to assess the feasibility of procuring needed components and services domestically by leveraging local capabilities and capacities. The studies can help decision makers identify ways to maximise domestic value creation opportunities for various energy transition solutions and reap socio-economic benefits.

The series is part of IRENA's extensive analytical work since 2011 assessing the socio-economic impacts of a renewables-based energy transition. An initial focus on employment creation and skills was subsequently extended to cover other socio-economic elements such as gross domestic product, broader measures of welfare, local economic value creation, improved livelihoods and gender-differentiated impacts.

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HIGHLIGHTS

- Global concentrated solar power (CSP) capacity increased by five-fold over the past decade, from 1.2 gigawatts (GW) in 2010 to approximately 6.4 GW by 2020. But the growth trajectory has levelled off in subsequent years.
- Through energy storage and grid stabilisation, CSP can play a crucial role in helping import-dependent nations achieve greater energy security.
- In a scenario aligned with the Paris Agreement, global installed CSP capacity will need to reach 196.7 GW by 2030 and 872.6 GW by 2050. Such an expansion would entail cumulative investments of approximately USD 657 billion by 2030, followed by an additional USD 1.83 trillion in investments from 2030 to 2050. CSP could employ up to 767 000 people in this scenario, up from 80 000.
- CSP offers the potential for substantial job growth. An evaluation of job distribution across the value chain's primary segments reveals that establishing a 100 megawatt CSP plant with a ten-hour thermal energy storage capacity requires about 1.16 million person-days.
- Labour is distributed unevenly across the value chain clustered in the engineering, procurement and construction (EPC) (46%), and operation and maintenance (O&M) (42%) sectors, and, to a lesser extent, in the manufacturing of essential components (9%).
- A substantial portion of the CSP workforce (79%) has low- to medium-level technical skills, which are typically available within any national labour pool or can be developed through certification programmes or vocational training centres.
- Many of these skillsets are already available in fossil-fired power plants, offering a valuable opportunity for workforce transition as the energy industry shifts towards renewable technologies. This transition not only leverages existing expertise but also facilitates the reskilling and upskilling of workers to meet the evolving demands of CSP.
- Countries lacking domestic equipment manufacturing can still generate employment in other value chain segments, especially in the EPC and O&M sectors.
- The deployment of CSP technology holds significant potential for local value creation. However, this potential can only be realised with policies that nurture local industry growth, foster innovation and engage communities. Strategic policy making can ensure that the socio-economic benefits of CSP projects are widely distributed and support the long-term sustainability of renewable energy initiatives.

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INTRODUCTION

The urgency of addressing the climate crisis necessitates a swift transition towards a global energy paradigm anchored in renewable energy sources and technologies. While this transition is imperative for environmental stewardship and the continued existence of humanity, it also presents significant opportunities to augment human health and welfare.

Indeed, the socio-economic advantages afforded by renewable energy systems are increasingly instrumental in catalysing their deployment. Recent studies by the International Renewable Energy Agency (IRENA) estimate that about 16.2 million people had jobs in renewable energy in 2023, across the entire value chain (IRENA and ILO, 2024). Beyond job creation, socio-economic benefits include the generation of new avenues for economic expansion at both local and national levels, the enrichment of a country's skill portfolio, enhancement of industrial development, and the mitigation of health and environmental externalities linked to energy consumption (IRENA, 2017).

Access to diverse renewable energy sources varies significantly from one nation to another, and within nations, from one region to another. The technologies available to harness these energies have disparate advantages and limitations, and their value propositions are, by and large, distinct. In regions with abundant direct solar irradiance, concentrated solar thermal (CST)[1] presents a particularly compelling value proposition because (1) it can be easily and efficiently integrated with thermal energy storage (TES) across an array operational temperatures; (2) it shows versatility in applications beyond electricity generation, including process heat production and various thermal and photochemical processes; (3) it has potential for high-temperature operations conducive to driving chemical reactions and generating solar fuels; (4) it involves minimal reliance on critical, hazardous or environmentally detrimental materials and (5) countries can achieve substantial local content with moderate technical expertise and industrial capabilities.

Until the recent past, the principal commercial application of CST technologies was in generating electricity at utility-scale power plants, traditionally termed concentrated or concentrating solar power (CSP). Such technologies employed approximately 80 000 individuals in 2022 (IRENA *et al.*, 2023); however, policies that advance progress in meeting the 1.5°C target by 2050 (as set out in IRENA's *World Energy Transitions Outlook*, in line with the objectives of the Paris Agreement) might call for the employment of upwards of 449 000 individuals by 2030, increasing to 767 000 by 2050 (IRENA, 2023).

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[1] *CST systems collect and concentrate direct solar radiation on the active surfaces of one or multiple receivers. The concentrated radiant solar energy on those active surfaces is transformed into high-temperature heat, which is then transformed into any convenient form of useful energy, such as electricity or process heat.*

This report maps the array of job roles created throughout the value chain of CSP plants. It provides policy makers with an understanding of the personnel and skill sets required for constructing, operating and decommissioning such facilities. The report also examines the material and equipment requirements across each segment of the value chain. It focuses on CSP plants producing electricity and does not analyse the emerging commercial applications of CST systems for producing heat.

The data presented in this report have been derived from surveys and interviews of globally recognised experts, complemented by desktop research, which helped collate information disseminated by pre-eminent CSP industry firms and specialist institutions. The information collected was reviewed and refined through consultations with a range of international companies that provide engineering, procurement and construction (EPC) services, and those that supply key technological components in the CSP sector.

The scope of this study is global, but the analytical estimations focus on two countries, Spain and South Africa, which are representative of the spectrum of countries - from developed, highly industrialised to developing and less industrialised - for which CSP plants are particularly suitable.

The first chapter discusses sector trends and drivers, particularly in terms of deployment, investment and cost. The second chapter evaluates the socio-economic benefits of CSP deployment. The third chapter analyses the requirements (in terms of skills, materials and equipment) to develop CSP projects along each segment of the value chain. The fourth chapter discusses the factors driving the development of a local CSP industry in South Africa and Spain. The last chapter presents recommendations on how to maximise value creation from the development of a domestic CSP industry while leveraging existing industries.


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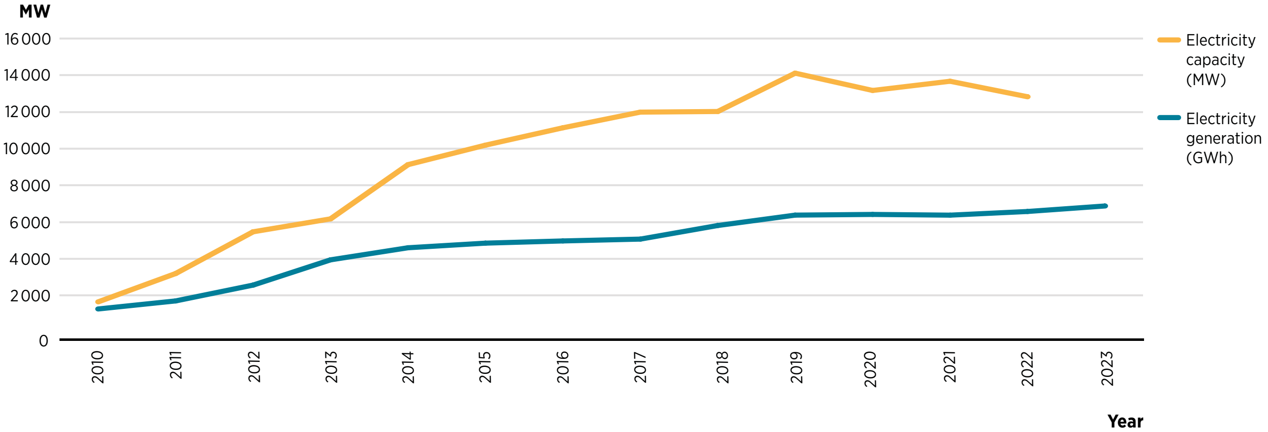
1. TRENDS IN THE CONCENTRATED SOLAR POWER SECTOR

The evolution of the CSP sector since 1990 has been marked by steady advancements and diversification. Global CSP capacity increased substantially over the past decade, nearly five-fold, from 1.2 gigawatts (GW) in 2010 to approximately 6.4 GW by 2020, as illustrated in Figure 1, but has levelled off in more recent years.

Figure 1 ■ **Estimated cumulative CSP capacity (2000-2023) and electricity generation (2000-2022)**

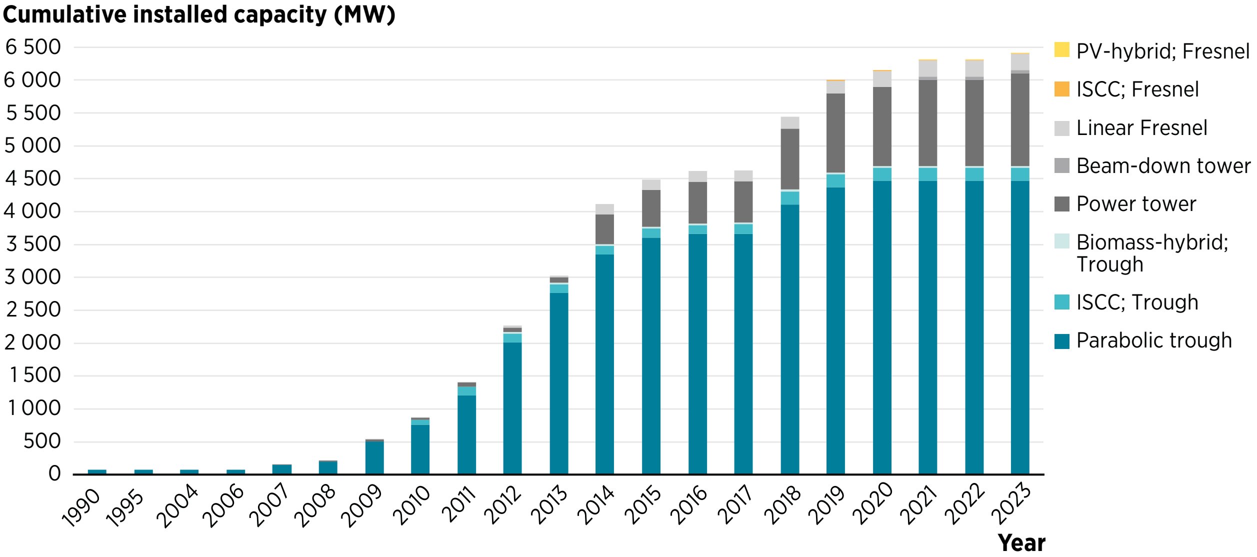


Source: (IRENA 2024a).

Notes: CSP = concentrated solar power; GWh = gigawatt hour; MW = megawatt.

The sector's growth was gradual initially. Pioneering efforts were concentrated in the United States and Spain, which were the early trailblazers, mainly harnessing parabolic trough (PT) and power tower technologies. These early endeavours laid the groundwork for what would become a significant evolution in both total installed capacity and efficiency through technological advancements and economies of scale, as depicted in Figure 2.

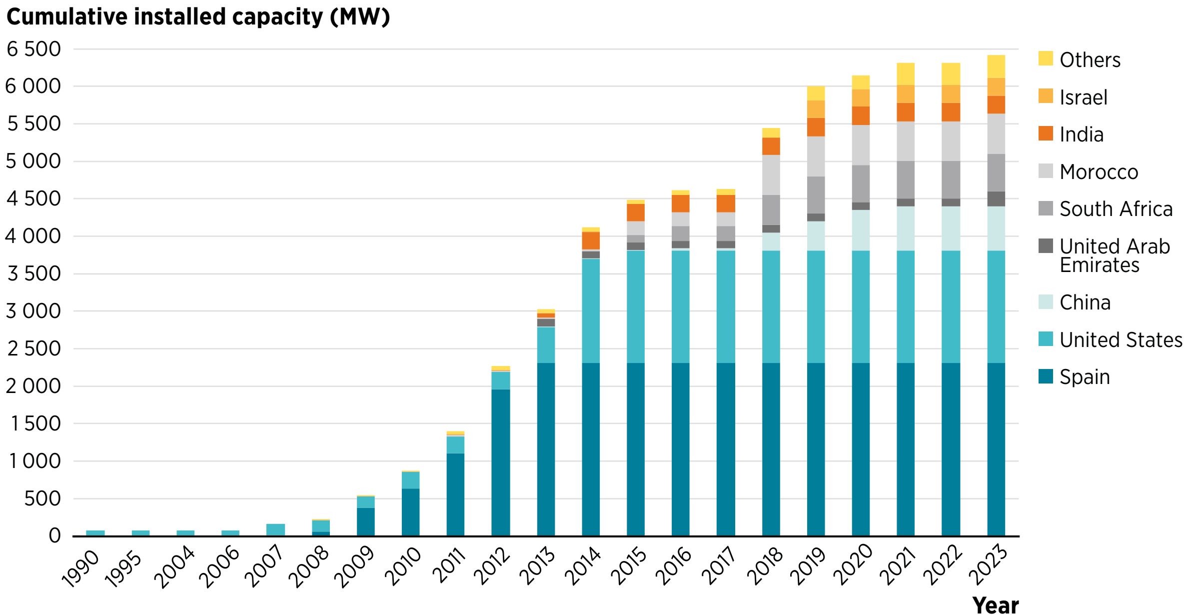
Figure 2 ■ **Evolution of operational CSP capacity by technology**



Source: (Thonig, Gilmanova and Lilliestam, 2023).

Notes: No plant entered into operation in 2022. CSP = concentrated solar power; ISCC = integrated solar combined cycle; MW = megawatt; PV = photovoltaic.

Figure 3 ■ **Evolution of operational CSP capacity by country**



Source: CSP.guru 2023-07-01 [Data set] (Thonig, Gilmanova and Lilliestam, 2023).

Notes: CSP = concentrated solar power; MW = megawatt.


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Table 1 ■ **Commercial CSP projects under construction worldwide**

Country	Power station	Capacity (MW)	Technology	Comments	Started/ expected end
China	CEIC Dunhuang 100 MW Fresnel + 600 MW PV	100	V-hybrid; Fresnel	Co-located with 600 MW of PV	2021/2024
China	Jinta Zhongguang Solar 100 MW Tower + 600 MW PV	100	PV-hybrid; tower	Co-located with 600 MW of PV	2022/2023
China	Huidong New Energy Akesai 110 MW Tower+ 640 MW PV	110	PV-hybrid; tower	Co-located with 640 MW of PV	2022/2023
China	Three Gorges CTGR Henderson Energy Guazhou 2x50 MW Tower + 200 MW PV + 400 MW Wind	100	Wind-PV-hybrid; tower	2x50 MW tower with one turbine; co-located with 200 MW of PV and 400 MW of wind	2022/2024
China	CNNC Yumen 100 MW Fresnel + 400 MW PV + 200 MW Wind	100	Wind-PV-hybrid; Fresnel	Co-located with 200 MW of PV + 400 MW of wind	2022/2023
China	Power China Ruoqiang 100 MW Tower + 900 MW PV	100	PV-hybrid; tower	Co-located with 900 MW of PV	2022/2024
China	Power China Toksun 100 MW Tower + 900 MW PV	100	PV-hybrid; tower	Co-located with 900 MW of PV	2023/2025
China	SIDC Ruoqiang 100 MW Tower + 900 MW PV	100	PV-hybrid; tower	Co-located with 900 MW of PV	2023/2025
China	CTGR Qinghai Golmud100 MW Tower + 1 000 MW PV	100	PV-hybrid; tower	Co-located with 1 000 MW of PV	2023/2024
China	CTGR Qinghai Quingyu DC 100 MW Tower + 900 MW PV	100	PV-hybrid; tower	Co-located with 900 MW of PV	2023/2024
Italy	CSP2 SOLINPAR Sicily Stromboli MS-LFR	4	PV-hybrid; Fresnel	Co-located with PV	2020/2021
Italy	CSP3 BILANCIA Sicily MS-LFR	4	PV-hybrid; Fresnel	Co-located with PV	2022
Saudi Arabia	ISCC Green Duba 1	43	ISCC; trough	ISCC	2016/2023
South Africa	Redstone	100	Power tower	Co-located with the 75 MW Jasper and 96 MW Lesedi PV projects	2021/2023
United Arab Emirates	Noor Energy 1 / DEWA IV 3x 200 MW trough segment	600	Parabolic trough	Co-located with 250 MW of PV and a 100 MW CSP tower for a total of 950 MW; project-level hybridisation	2023
United Arab Emirates	CSP-PV hybrid project Noor Energy 1 / DEWA IV 700 MW CSP + 250 MW PV	700	PV-hybrid; trough; tower	Project-level hybridisation of PV and CSP	2023

Source: (Thonig, Gilmanova and Lilliestam, 2023).

Notes: CSP = concentrated solar power; ISCC = integrated solar combined cycle; MW = megawatt; PV = photovoltaic.

While auctions are instrumental in driving CSP costs down, it is noteworthy that the resurgence of CSP since the 1980s was significantly due to Spain's feed-in tariff (FiT) (Martín *et al.*, 2015). This initiative, later emulated in India (Shankar *et al.*, 2024) and China (Ling-zhi *et al.*, 2018) to varying degrees, has positioned Spain as the current leader in global CSP deployment,[2] especially in PT.

Unlike photovoltaic (PV) technology, which improves primarily through advancements in manufacturing processes, CSP relies on operational power plants to refine the technology through practical experience ("learning by doing"). PT technology has seen significant advancements in Spain, where 44 operational power plants have been built since 2008. However, the trend has recently shifted to the emerging solar tower (ST) technology, for which China leads in total installed capacity, with 321 megawatts (MW) (eight power plants) operational and two more plants (200 MW combined) under construction. By contrast, Spain has only four ST plants, each with less than 50 MW capacity. This demonstrates China's ability to capitalise on emerging technological niches (Gosens *et al.*, 2021).

The push towards hybrid systems integrating CSP with PV or wind technologies is a response to the market's demand for more flexible and reliable energy solutions. These hybrid configurations support the integration of renewable energy into the grid by delivering a balanced energy output, which counters the variability of solar and wind resources. Hybridisation can significantly reduce the overall costs of power plants as the required size of the solar field (often the most expensive component) is reduced.

While traditionally CSP systems are considered optimally effective in regions with direct normal irradiance (DNI) exceeding 1 900 kilowatt hours per square metre per year (kWh/m^2/year), they could also be of interest in areas with much lower DNI levels.

CSP's adoption has been uneven; certain regions have lagged due to insufficient government incentives or limited finance. In countries where CSP has been deployed, auctions combined with financing mechanisms have reduced costs while aiding in the achievement of other objectives.

The levelised cost of energy (LCOE) for CSP decreased by 69% between 2010 and 2020 globally but remains higher than that of other technologies, for example, solar and wind, which do not have storage. Even if costs are higher, CSP brings many opportunities for value creation, given its potential for storage and system balancing, and for localising supply chains and socio-economic benefits (IRENA, 2023). The inherently low environmental impact and reduced reliance on strategic, hazardous or environmentally detrimental materials, relative to other renewable energy alternatives, are additional factors expected to advance the market penetration of these technologies at a global scale.

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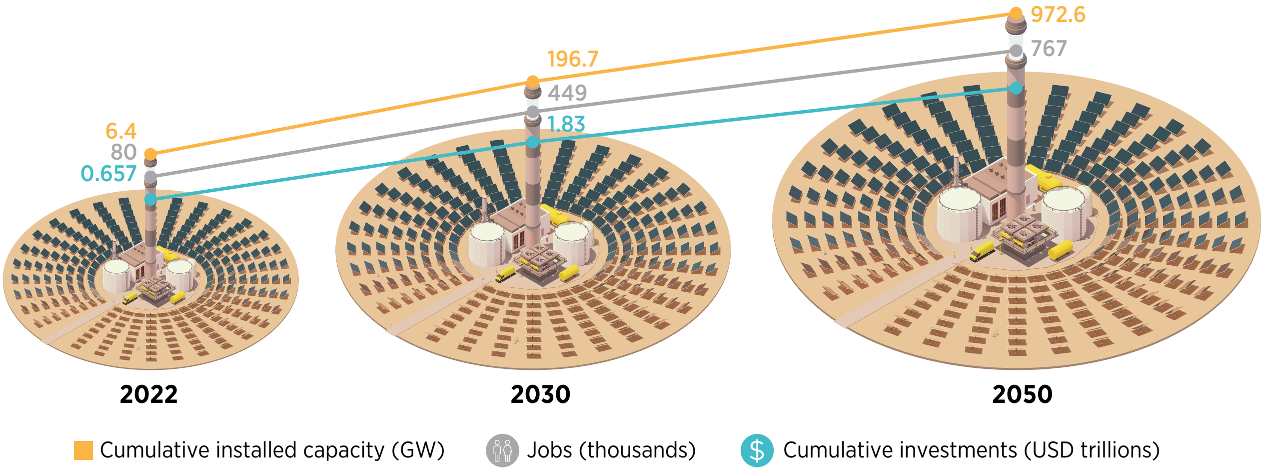
[2] *www.solarpaces.org/worldwide-csp/csp-projects-around-the-world.*

2. OPPORTUNITIES FOR VALUE CREATION IN THE CONCENTRATED SOLAR POWER SECTOR

IRENA projects that, in a scenario aligned with the objectives of the Paris Agreement, global installed CSP capacity will need to reach 196.7 GW by 2030 and 872.6 GW by 2050 (IRENA, 2023). Such an expansion would entail cumulative investments of approximately USD 657 billion by 2030, followed by an additional USD 1.83 trillion in investments from 2030 to 2050 (IRENA, 2023). Among other benefits, these financial inputs could fortify energy security for import-dependent nations and catalyse value by creating jobs (up to 767 000 jobs by 2050) (see Figure 4). In addition, CSP brings value to power systems, by enabling storage and helping stabilise grids.

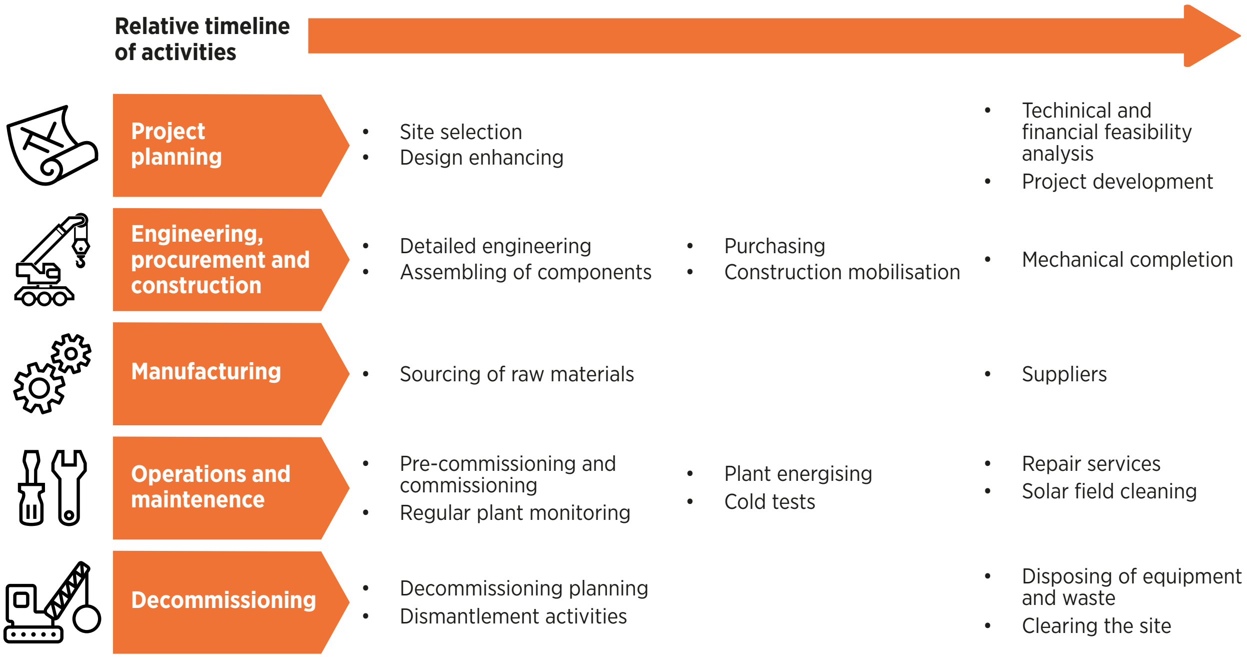
Figure 4 **Estimated cumulative CSP capacity, investments and employment in 2023 and those needed in 2030 and 2050 to achieve the energy transition objectives of the Paris Agreement**



Based on: (IRENA, 2023) and (IRENA and ILO, 2023).
Notes: CSP = concentrated solar power; GW = gigawatt.

CSP technologies, like other renewable technologies, have high potential for local value generation. Despite some countries' inability to manufacture critical plant components, substantial job creation opportunities exist within various other segments of the value chain, notably in EPC and in the operation and maintenance (O&M), and decommissioning phases. Section 2.1 presents the potential for job creation, and Chapter 3 explores the opportunities and requirements in each segment of the value chain. Figure 5 delineates the standard value chain for a CSP plant, highlighting key activities in each segment. The order of operations and activities may differ slightly from one country or project to another, influenced by various factors.

Figure 5 ■ **Value chain for a CSP plant**



Note: CSP = concentrated solar power.

Assessing CSP deployment's potential to generate local value can help to determine the extent of socio-economic advantages such as income generation and job creation in host countries, compared with reliance on imported goods and/or services. The potential for domestic value creation is largely contingent upon the scale of a country's renewable energy market, the maturity of its renewable energy and industrial sectors, the presence of related industries, the dynamics of the regional and global markets for the requisite components and services, availability of skills and the overarching business climate.

In addition, CSP technologies can bring significant value to the power system, by enabling grid stability and storage to match supply with demand.

2.1 System balancing and storage

CSP's expansion into new markets is also driven by its ability to provide stable and dispatchable power – a valuable complement to the variable nature of solar PV and wind energy. Hybrid systems integrating CSP with PV or wind technologies can be a response to the market's demand for more flexible and reliable energy solutions. These hybrid configurations support the integration of renewable energy into the grid by delivering a balanced energy output that mitigates the variability of solar and wind resources. Examples of hybrid configurations include hybrid solar complexes (solar PV and CSP) in Morocco and the United Arab Emirates that were awarded through competitive procurement (auctions). Box 1 provides some of the highlights of the results and design of CSP auctions to achieve objectives beyond price.

The integration of thermal storage in CSP, typically via two-tank molten salt systems, among other methods, represents a significant advantage (Zhang *et al.*, 2024). Modern CSP facilities have adopted thermal storage solutions; this has improved their operational flexibility and allowed them to supply energy during periods of peak electricity market prices (Li *et al.*, 2022; Zurita *et al.*, 2020).

Box 1 ■ Auctions as a policy instrument to support CSP while maximising value creation

Various countries have held auctions for concentrated solar power (CSP). The following are some examples (World Bank, 2021):

- **South Africa**. A 2011 renewable energy auction led to the commissioning of CSP plants totalling 500 MW by 2019.[3]
- **Morocco**. Since its first operational CSP plant in 2016, Morocco has conducted several CSP-focused auctions, including one for a 160 MW project in 2018. The Noor Power Station in Ouarzazate was auctioned in four rounds: the first three rounds for CSP totalled 510 MW. The 160 MW Noor I and 200 MW Noor II projects use parabolic trough technology with storage capacity of three and seven hours, respectively, and Noor III, a 150 MW solar tower has seven hours of storage capacity. They were followed by a fourth round for 72 MW of PV. In May 2019, Morocco auctioned the world's first advanced CSP and PV hybrid. The 800 MW CSP-PV Noor Midelt hybrid is designed to provide dispatchable solar energy during the day and until five hours after sunset.
- **Chile.** A 2017 renewable energy auction in Chile resulted in several CSP contracts, cumulatively amounting to 250 MW by 2020.
- **United Arab Emirates.** The fourth phase of the Mohammed bin Rashid Al Maktoum Solar Park auction in Dubai- a 700 MW CSP project consisting of 600 MW from a parabolic basin complex and 100 MW from a concentrated solar tower, with thermal storage capacity of 15 hours.

For auctions specifically for the deployment of CSP or any other renewable technology, it is essential to craft conditions that emphasise local community advantages and sustainable economic development. The following are some key considerations for auction design to optimise socio-economic returns (IRENA, 2019) and (Del Río and Mir-Artigues, 2019):

- **Inclusion of small and new players.** The following design elements can enable the inclusion of small and new players:
  - setting a predetermined volume for local, small and new players;
  - technology-specific auctions and limited project size;
  - preferential treatment (*e.g.* discounted bid bond) and less stringent qualification requirements;
  - less stringent compliance rules.
- **Development of local industries and job creation.** The following design elements can enable the development of local industries and job creation:
  - local content requirements and commitments for local job creation;
  - criteria for selecting winners;
  - regularity of auctions that support local industries.
- **Subnational development and community benefits.** The following design elements can enable subnational development and the generation of community benefits:
  - zone-, site- or project-specific auctions, can pre-select sites and regions that best suit policy objectives;
  - proof of land-use rights, grounded in solid documentation, which is binding on auction participants.

In addition to auctions, various incentives can promote the adoption of CSP technology. Examples include South Africa's Renewable Energy Independent Power Producer Procurement Programme and Chinese regulations that mandate storage integration for large-scale solar PV and wind power plants and can result in hybrid facilities. The right set of policies can support CSP while maximising local benefits.

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[3] *In addition to 500 MW of commissioned CSP projects, South Africa has an 100 MW CSP project, the Redstone Solar Plant, expected to enter into operation in 2024. This project was awarded to ACWA Power and SolarReserve in 2015 within the framework of South Africa's Renewable Energy Independent Power Producer Programme.*

2.2 Opportunities for job creation along the value chain

An evaluation of job distribution across the value chain's primary segments reveals that establishing a 100 MW CSP plant with a ten-hour TES capacity requires an estimated approximately 1.16 million person-days (see Box 2). This figure includes direct[4] jobs only and does not include indirect[5] or induced[6] jobs, derived from the economic activity of a CSP plant.

Box 2 ■ Selection of parameters for a representative CSP plant and methodology to estimate its labour requirements

To illustrate the workforce, and the material and equipment requirements of concentrated solar power (CSP) projects, the case of a 100 MW CSP plant with ten hours of thermal energy storage (TES) capacity is utilised throughout this report. The reference plant's configurations, based on the two predominant CSP technologies, parabolic trough and solar towers, were optimised and analysed for two geographic case studies: Spain and South Africa.

The choice of nominal power and TES capacity for the reference CSP plant is grounded in a detailed examination of the prevailing trends in CSP plant deployments globally. This examination goes beyond just the historical data for nominal power and TES capacities; it also considers the changing preferences of developers and the evolving objectives for the energy transition. In terms of size, the chosen nominal power is well within the range of what is currently being deployed. While some parabolic trough plants have exceeded 100 MW, power tower plants, which are becoming more common, tend to have lower nominal power. Selecting 100 MW capacity is therefore representative of both technologies.

The integration of intermittent renewable energy sources into power systems is increasingly highlighting the value of energy storage. CSP plants are particularly effective at incorporating substantial thermal storage, reflecting the industry's move towards larger TES systems. With the current average TES capacity of CSP plants at 7.5 hours of nominal power and a clear trend towards larger capacities, TES capacity of ten hours is a prudent and reasonable decision that aligns with the latest industry developments.

As explicit data and industry support were unavailable when this report was being drafted, the labour effort estimates in person-days in the report are based on the informed judgements of the core experts involved, derived from a thorough assessment of relevant information from numerous CSP projects with which they have collaborated, and tailored adaptation of field data to the specific characteristics of the reference CSP plant considered. After formulating these estimates, they were shared with industry professionals, whose feedback was subsequently used to refine the estimates.

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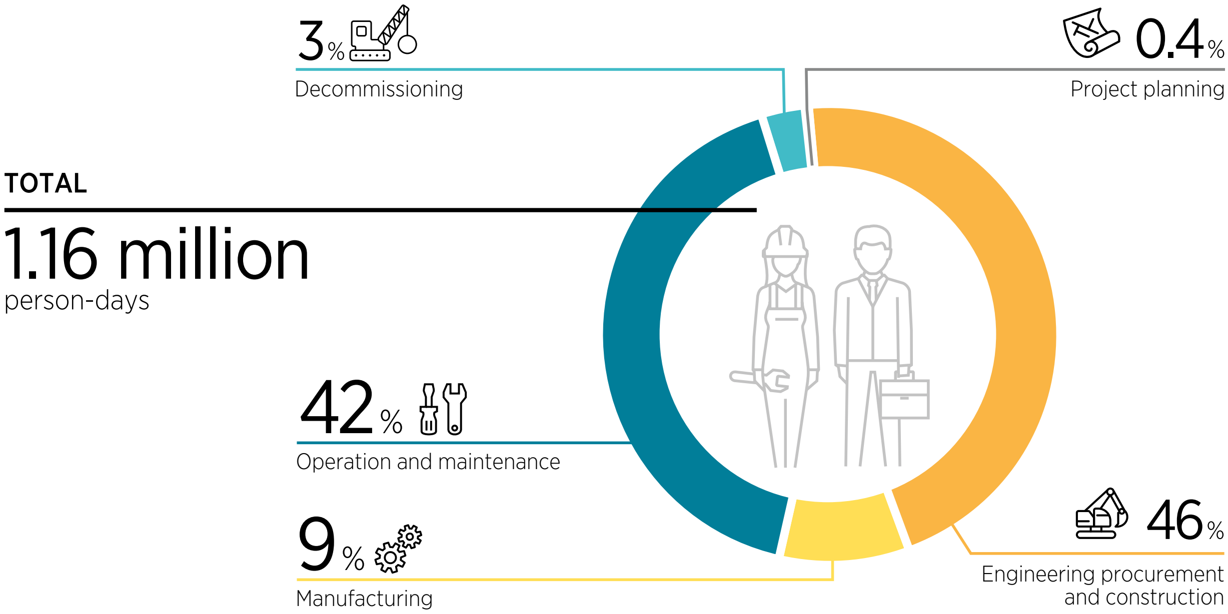
[4] *Direct employment refers to employment generated directly due to core activities, without considering the intermediate inputs necessary to manufacture renewable energy equipment or construct and operate facilities. These directly involved industries are also called renewable energy industries (sectors). Data on direct employment may be computed based on industry surveys or data derived from representative projects and facilities for the industry in question, or they may be computed using economic data, such as labour input coefficients (employment factors) for the selected industries.*

[5] *Indirect employment includes the employment in the upstream industries supplying and supporting the core activities of renewable energy deployment. Workers in such positions may be involved in the production of steel, plastics or other materials, or they provide financial and other services. These industries are not directly involved in renewable energy activities but produce intermediate inputs along the value chain of each renewable energy technology. A literature review indicates that including indirect jobs typically increases the overall job numbers by anywhere from 50% to 100%.*

[6] *Induced employment includes jobs beyond the renewable energy industry and its upstream industries; it includes, for example, jobs in the consumer goods industry. When individuals who are employed directly or indirectly spend their incomes on a variety of items in the wider economy (e.g. food, clothing, transportation and entertainment), that expenditure generates induced employment effects.*

As Figure 6 illustrates, labour is distributed unevenly across the value chain; significant clustering may be seen in the EPC (46%) and O&M (42%) sectors, and, to a lesser extent, in the manufacturing of essential components (9%).

Figure 6 ■ **Distribution of labour across the value chain for the development of a 100 MW CSP plant with ten-hour TES capacity**

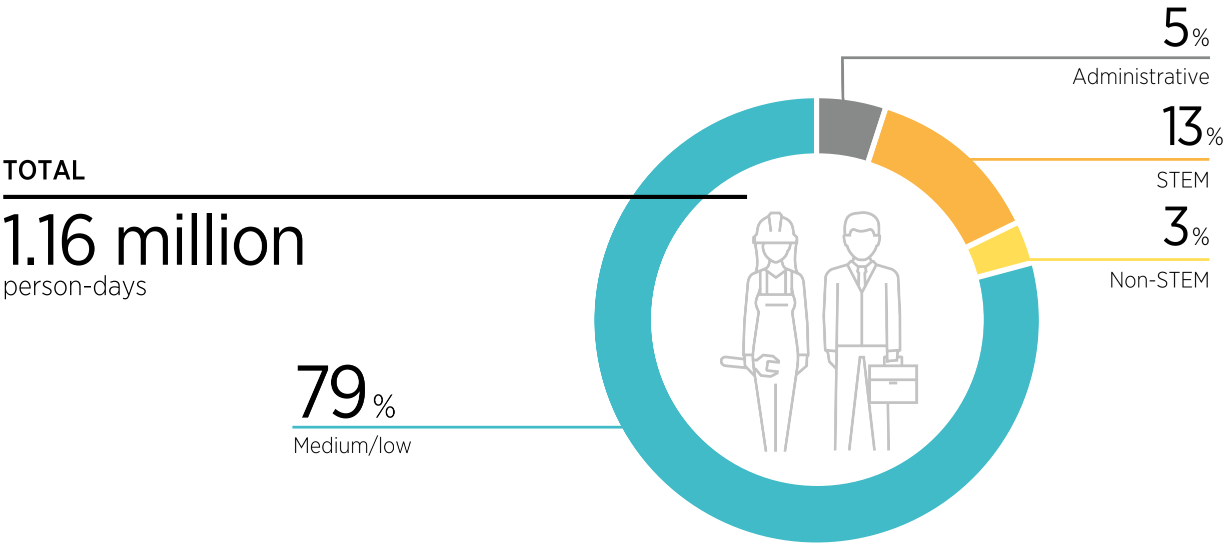


Notes: Solar thermal plants' operational efficiency improves significantly in the first two or three years, while registering negligible additional gains in subsequent years. Therefore, for cumulative requirements over 25 years, average productivity improvements are estimated at 0.5% per year.
CSP = concentrated solar power; EPC = engineering, procurement and construction; MW = megawatt; O&M = operation and maintenance;
TES = thermal energy storage.

Countries lacking domestic equipment manufacturing can still generate employment in other value chain segments, especially within the EPC and O&M sectors. A substantial portion of the required workforce (79%) necessitates low- to medium-level technical skills, which are generally accessible within any national labour pool or can be developed through certification programmes or vocational training centres (Figure 7). Many of these skill sets are already well established within the fossil-fired power plants sector. There is thus a valuable opportunity for workforce transition as the energy industry shifts towards renewable technologies. This transition not only leverages existing expertise but also facilitates the re-skilling and upskilling of workers to meet the evolving demands of the CSP sector.

The discussion below highlights the labour and equipment requirements for different segments of the small hydro implementation value chain, from project feasibility studies all the way to the decommissioning of projects that have reached the end of their useful life.

Figure 7 ■ **Distribution of the skills required for developing a 100 MW CSP plant with ten-hour TES capacity**



Notes: CSP = concentrated solar power; MW = megawatt; STEM = science, technology, engineering and mathematics; TES = thermal energy storage.

Chapter 3 details the labour and equipment requisites for the CSP value chain, from project feasibility studies through to the decommissioning of facilities that have reached their operational end. It explores the job types created and the prospects for value generation across individual value chain segments. The chapter equips policy makers with insights into the labour and skills needed for the construction, operation and eventual decommissioning of CSP installations.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3. REQUIREMENTS FOR DEVELOPING CSP

Optimising local advantages from CSP plants' deployment necessitates policy frameworks that consider job distribution across the industry's value chain. This section examines job concentration in the CSP sector and the sector's capacity to integrate workers affected by the energy transition. Beyond job generation, economic value stems from sectoral activities, including material procurement, equipment installation and ongoing O&M.

Subsequent subsections articulate the objectives of each step in the value chain. They detail the associated primary activities, job creation potential and material requirements.

3.1 Project planning

The initial phase of the value chain encompasses a suite of critical activities: site selection, technical and financial feasibility studies, design engineering and project development.

An optimal site for a CSP facility is selected based on an assessment of a site's potential and an examination of possible environmental and social ramifications. This evaluation is followed by a thorough technical feasibility analysis, which is complemented by an economic feasibility study to ascertain the investment's profitability. This is followed by design engineering, which addresses the electrical and mechanical systems of the solar plant and civil works planning, infrastructure installation and the prospective O&M for it. The project development stage is dedicated to administrative tasks, including the acquisition of permits and licenses, negotiation of financing and contracts, land procurement or leasing, and managing regulatory and procurement processes.

An assessment of a location's long-term climatic conditions is imperative at this stage, as it informs the estimation of the available solar resource and its attributes and underpins the technical and economic analyses. This climatic appraisal also aids in recognising meteorological events that may impact the plant's operation and the integrity of critical components, such as the solar collectors. Soil characteristics, which can influence the installation of structures and foundations, must also be considered.

This planning phase necessitates the installation of instruments at the proposed plant site to measure pertinent meteorological variables, including solar DNI, wind direction and speed, ambient temperature and relative humidity. The data collected on site should be juxtaposed with data from regional meteorological stations or satellite measurements to identify potential micro-climatic concerns and aid in the detailed characterisation of the DNI. Simulations by means of computational programmes are pivotal for conducting technical and financial analyses based on the solar resource assessment for a site.

In this phase, designers determine which components to import, and which are available locally. This decision is based on factors such as the cost of technology, import taxes, local product subsidies, transport expenses, local supply mandates and other considerations.

Planning a 100 MW CSP plant with ten hours of TES requires an estimated 4 195 person-days of labour. As detailed in Table 2, the labour distribution for project planning is as follows: project development (47%, 1 961 person-days), engineering design (23%, 977 person-days), feasibility analysis (18%, 741 person-days) and site selection (12%, 516 person-days).

Table 2 ■ **Labour required for planning a 100 MW CSP plant with ten-hour TES capacity (person-days) and breakdown by activity**

Type of labour	Site selection	Feasibility analysis	Engineering design	Project development	Total (person-days)
Engineers and other technical personnel	234	469	703	-	**1 476**
Legal, energy regulation, real estate and taxation experts	129	83	138	648	**998**
Financial analysts	-	54	-	630	**684**
Logistics experts	-	-	-	450	**450**
Administrative personnel	20	26	26	233	**305**
Environmental experts	72	86	-	-	**158**
Health and safety experts	-	-	75	-	**75**
Management	12	23	35	-	**70**
Geotechnical experts	49	-	-	-	**49**
TOTAL	**516**	**741**	**977**	**1 961**	**4 195**
(as %)	**12%**	**18%**	**23%**	**47%**	

Notes: CSP = concentrated solar power; MW = megawatt; TES = thermal energy storage.

The skills in greatest demand include those in the STEM (science, technology, engineering and mathematics) fields, for example, energy regulation, engineering, and environmental health and safety, as well as geo-technical expertise. Non-STEM professions are also crucial, including legal, real estate, taxation, financial analysis and logistics experts. Engineers are the most sought after, constituting 34% of the total labour (1 406 person-days), followed by legal, energy regulation, real estate and taxation experts, who account for 24% (996 person-days). These positions can typically be filled by both foreign and local experts. Figure 8 details the occupations and skill sets of the labour required to plan a project for a 100 MW CSP plant with a ten-hour TES capacity.

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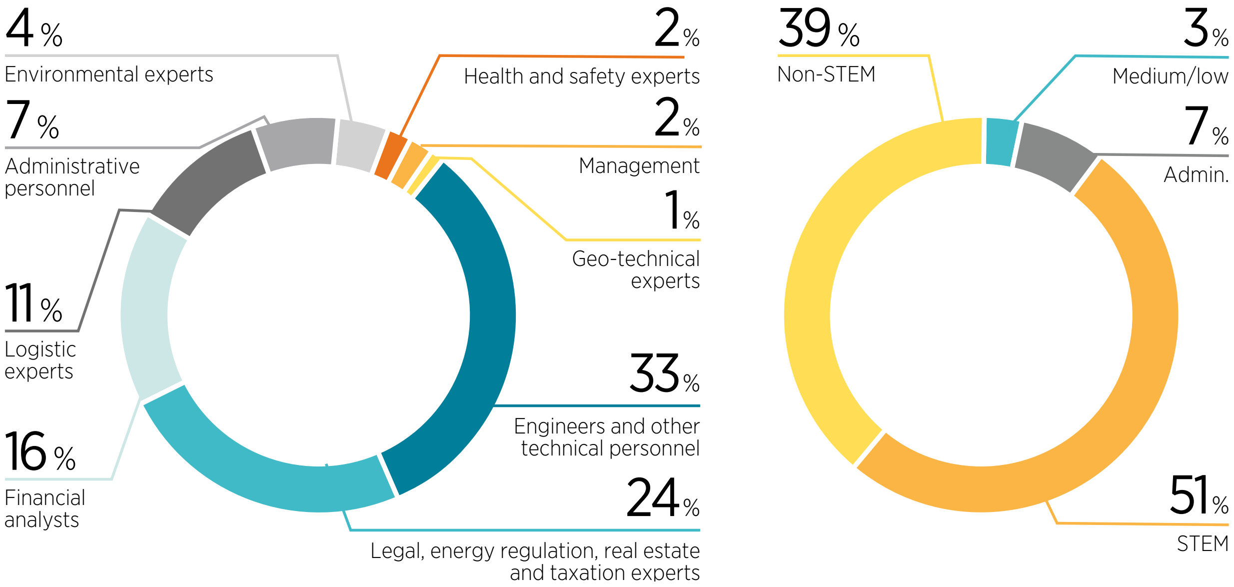
Figure 8 ■ **Distribution of the labour required to plan a 100 MW CSP plant with ten-hour TES capacity, by occupation and skill set**



Notes: Admin. = administrative; CSP = concentrated solar power; MW = megawatt; STEM = science, technology, engineering and mathematics; TES = thermal energy storage.

The following subsections describe in greater detail each of the main project planning activities.

3.1.1 Site selection

The selection of a suitable site for a CSP facility may fall under the purview of the public sector or the project developer. The chosen site must be rigorously evaluated based on the following criteria:

- **Long-term solar resource.** This entails the amount of direct solar radiation a location receives, the temporal distribution of solar radiation and the influence of meteorological conditions, ascertained by means of on-site measurements and/or satellite data.
- **Available land area and topography.** Utility-scale CSP installations typically require a substantial expanse of unobstructed land.
- **Local water resources.** CSP installations may use water, if the resource is abundant, as a cooling medium for the steam turbine condenser. They use water as a working fluid in the steam turbine and for cleaning the mirrors of the solar concentrators.
- **Grid connections**. Effective delivery of the electricity generated by a CSP plant to consumers is critical. Access to high-voltage power lines is a necessity.
- **Transport and communications infrastructure.** Adequate roads and proximity to airports and to other facilities are essential for the transport of personnel, materials and equipment to the site.
- **Environmental and ecological impact.** The potential environmental and ecological impacts of the CSP installation must be evaluated thoroughly. This includes assessing impacts on local wildlife, vegetation and ecosystems. Comprehensive risk mitigation strategies should be developed and quantified.

The growing trend of hybridising CSP with other renewable energy technologies underscores the importance of evaluating not just the suitability of a location for CSP but also for PV and wind power. This comprehensive assessment should consider current and future plans for deploying these technologies in proximity to potential CSP plant locations. As hybrid energy solutions become more prevalent, integrating site selection criteria that encompass multiple renewable energy sources is critical to maximising the efficiency and economic viability of projects.

The labour vital for site selection includes local weather data analysts; geo-technical specialists to assess land specifications; environmental experts to appraise impacts, risks and potential conflicts; as well as legal and real estate professionals to navigate regulatory issues such as energy policy, land use and grid access. The extent of effort required is contingent upon the prevailing legal and regulatory frameworks in the energy sector, location characteristics, accessibility, grid connection requirements and a project's magnitude (refer to Table 2). This activity may utilise local expertise where accessible.

The principal equipment needed for site selection pertains to the assessment of a site's solar resource. Profound knowledge of the DNI at a site is imperative for conducting an economic feasibility analysis for a CSP plant, given that DNI is a critical determinant of a plant's energy output. Feasibility analysis for a CSP plant is customarily performed by simulating the plant's performance using a Typical Meteorological Year dataset, which contains hourly values of the DNI and other meteorological parameters.

The information needed to undertake these activities includes the stipulations of relevant policies and regulations on land use and the restrictions for the development of CSP projects, in addition to data relating to resource availability.

3.1.2 Technical and financial feasibility studies

Once site selection is complete, a comprehensive analysis is conducted to ascertain the viability of a CSP project at the chosen location. This analysis rigorously examines technical performance, financial viability and the potential to secure the necessary financing – often referred to as 'bankability'. A critical component of this activity is the assessment of the DNI. The assessment necessitates installing and operating a temporary meteorological station on site for 12-24 months.

Moreover, a detailed evaluation of the investment is necessary, considering the long-term demand for solar energy. This evaluation must consider the specific country's conditions, including political stability, regulatory frameworks and legal certainties. Additional considerations include the ease of grid access, proximity to equipment suppliers, and the status or development of the infrastructure necessary for accessing the site. The capabilities and performance of the principal components and subsystems are derived from suppliers' quotations and the conceptual design. Multiple configurations are analysed to economically optimise the solar plant's configuration.

Parallel analyses of different operating strategies for the same plant are also essential. These analyses assess the advantages of distinct electricity contracts, which may influence decisions regarding storage capacity, the use of fossil fuels as backup and cooling technology.

Typically, the project developer is responsible for conducting the study. The necessary labour for this phase includes environmental specialists; energy engineers with expertise in solar technology; electrical and mechanical engineers; financial analysts; and professionals well-versed in energy regulation, legal matters and taxation. This task leverages expertise that can be sourced both locally and internationally.

3.1.3 Engineering design

The engineering design process is initiated after the investment decision and alongside the administrative tasks of project development. During this critical stage, a plant's configuration is established. While suppliers' offerings are leveraged for the engineering of primary components, ancillary components are engineered in accordance with established engineering practices.

Project developers may undertake the engineering design provided they possess the requisite expertise and capabilities. Alternatively, these tasks may be delegated to external specialists and organisations. The expertise required spans multiple disciplines. The necessary labour includes legal professionals adept in regulatory matters; process, mechanical, electrical and civil engineers specifically for instrumentation and control; as well as health and safety experts to address the multi-faceted needs of a project.

3.1.4 Project development

This phase involves the execution of all necessary legal and administrative actions to obtain permits and financing. The critical tasks include assessing the solar resource and energy yield; conducting environmental and ecological impact studies; conducting geo-technical and topographical surveys; securing permits and authorisations; engaging in contract negotiations; acquiring equipment price quotations; and establishing agreements for construction, equity and debt. As detailed in Table 2, this extensive process demands the collaboration of a team of professionals, including legal experts, authorities on energy regulation, real estate and taxation specialists, financial analysts and logistics experts.

3.2 Engineering, procurement and construction

The engineering, procurement and construction (EPC) phase is a critical component in the value chain of a CSP project. It typically extends over a period of 24 months and mobilises a substantial array of resources. Specialised expertise is required for developing and assembling the solar thermal collection system, including the reflective mirror arrays and thermal receivers, and integrating it into the thermodynamic cycle. At present, a limited number of corporations globally hold the requisite qualifications to function as the principal contractor for these complex projects.

EPC contractors are adept at orchestrating the intricate logistics for the delivery of custom equipment and materials. They ensure the timely arrival and integration of custom equipment and materials into the overarching CSP system. Given the necessity to control equipment and system costs, EPC contractors must possess advanced system design capabilities and the corresponding national design qualifications. This ensures that the design and implementation are not only efficient but also adhere to the specific regulatory standards, in turn minimising risks and cost overruns.

Moreover, EPC contractors bring specialised expertise to critical project components. They oversee the design and implementation of subsystems, precision machinery, high-performance components, inter-connections, as well as conductive elements and fluid transport infrastructure. Further, the quality of a solar field's optical elements, for example, heliostats or parabolic troughs (PTs), is directly linked to the plant's electrical output and its economic success. To ensure the highest standards, specialist firms employ cutting-edge metrological technologies for meticulous quality assurance and oversight during construction.

A significant portion of the inputs required for the EPC phase can be sourced locally, leveraging synergies with industries such as the local automotive manufacturing sector. Local employment potential can be augmented if these sectors adapt to support CSP production, particularly if local manufacturers possess expertise in the design and construction of large-scale energy plants.

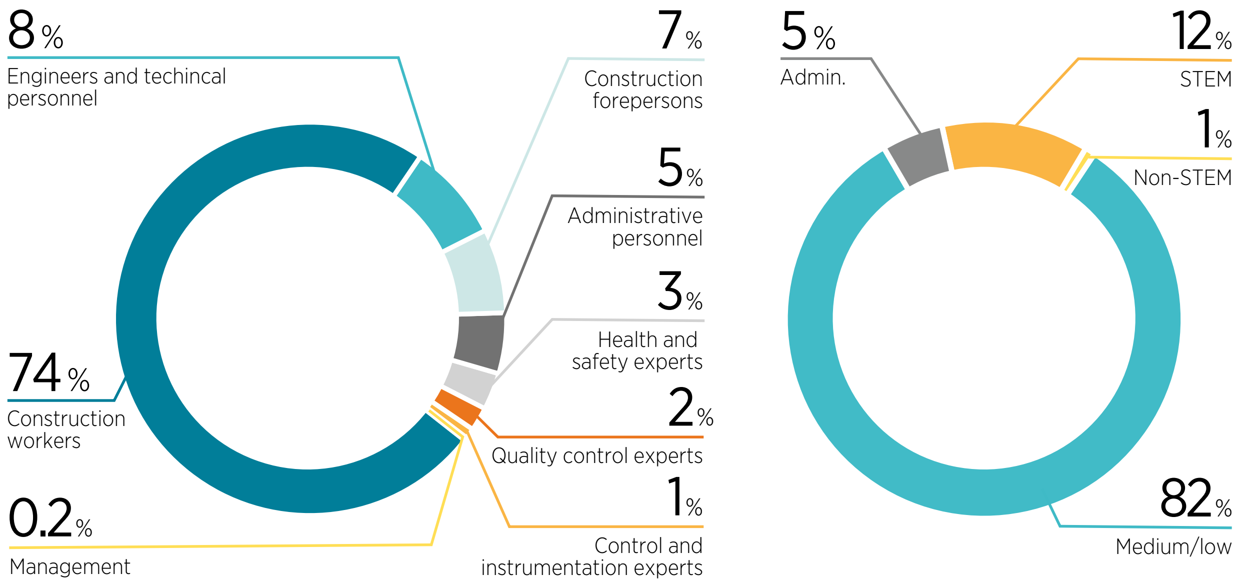
Table 3 details the human resource allocation for the EPC of a 100 MW CSP plant with a ten-hour TES capacity, broken down by activity. Additionally, Figure 9 illustrates a comprehensive distribution of the required labour, segmented by occupation and expertise.

Table 3 ■ **Labour required for the EPC of a 100 MW CSP plant with ten-hour TES capacity (person-days) and breakdown by activity**

Type of labour	Management	Engineering	Civil works	Installation of mechanical equipment	Installation of electrical equipment	Instrumentation and control	Commissioning	Total
Construction workers	17 275	2 249	191 651	149 798	26 437	5 131	6 311	**398 852**
Engineers and other technical personnel	16 764	2 184	-	18 891	4 667	1 466	838	**44 810**
Construction forepersons	6 911	900	11 070	12 231	3 047	1 246	588	**35 993**
Administrative personnel	1 919	267	22 690	153	-	750	1 585	**27 364**
Health and safety experts	5 119	668	6 084	4 146	734	289	147	**17 187**
Quality control experts	2 559	317	33 135	2 898	-	319	140	**9 368**
Instrumentation and control experts	5 119	667	-	-	-	426	148	**6 360**
Management	640	83	157	119	91	16	44	**1 149**
TOTAL	**56 306**	**7 335**	**234 787**	**188 235**	**34 976**	**9 643**	**9 800**	**541 082**
(as %)	**10.4%**	**1.4%**	**43.4%**	**34.8%**	**6.5%**	**1.8%**	**1.8%**	

Notes: CSP = concentrated solar power; EPC = engineering, procurement and construction; MW = megawatt; TES = thermal energy storage.

Figure 9 ■ **Distribution of the labour required for the EPC of a 100 MW CSP plant with ten-hour TES capacity, by occupation and skill set**



Notes: Admin. = administrative; CSP = concentrated solar power; EPC = engineering, procurement and construction; MW = megawatt; STEM = science, technology, engineering and mathematics; TES = thermal energy storage.

The following subsections offer detailed findings on engineering and construction, procurement and manufacturing.

3.2.1 Engineering and construction

In the engineering and construction phase, construction labour represents the bulk of the workforce, comprising 74% of the total effort, or 398 852 person-days. Engineers and other highly skilled technical staff follow at 8% of the total effort, amounting to 44 810 person-days. Predominantly, medium- and low-level STEM-related skills are in demand, especially during the construction phase, constituting 82% of the total work, or 444 295 person-days. This is primarily due to the labour-intensive nature of construction activities and the leadership role of construction forepersons.

Civil engineering tasks and the installation of mechanical equipment are the most labour-intensive activities, accounting for 43% and 35% of the total human resource requirements, respectively.

Local participation is emphasised in the construction stage. In regions like Spain, where numerous EPC companies originate, the workforce predominantly consists of nationals, who often account for more than 90%. A considerable proportion of the workforce is, for example, staff residing within 100 kilometres of plants, thus contributing to local content. For countries with less specialised personnel and marginalised communities, the inclusion of citizens remains substantial. For instance, in South Africa, more than 70% of the workforce are citizens, with 36% belonging to local communities, as detailed in the South African case study (see section 4).

3.2.2 Procurement

Procuring raw materials and manufactured products is essential for constructing the CSP plant. Local sourcing of these materials adds value to regional industries. The standardisation of certain components has widened the scope for local industries to participate in the production of CSP components, including structural elements, mirrors, trackers and pipes. To outline the material requirements for parabolic trough (PT) and solar tower (ST) technologies, two separate tables detail the quantities needed (expressed in tonnes) for manufacturing and constructing plant subsystems.

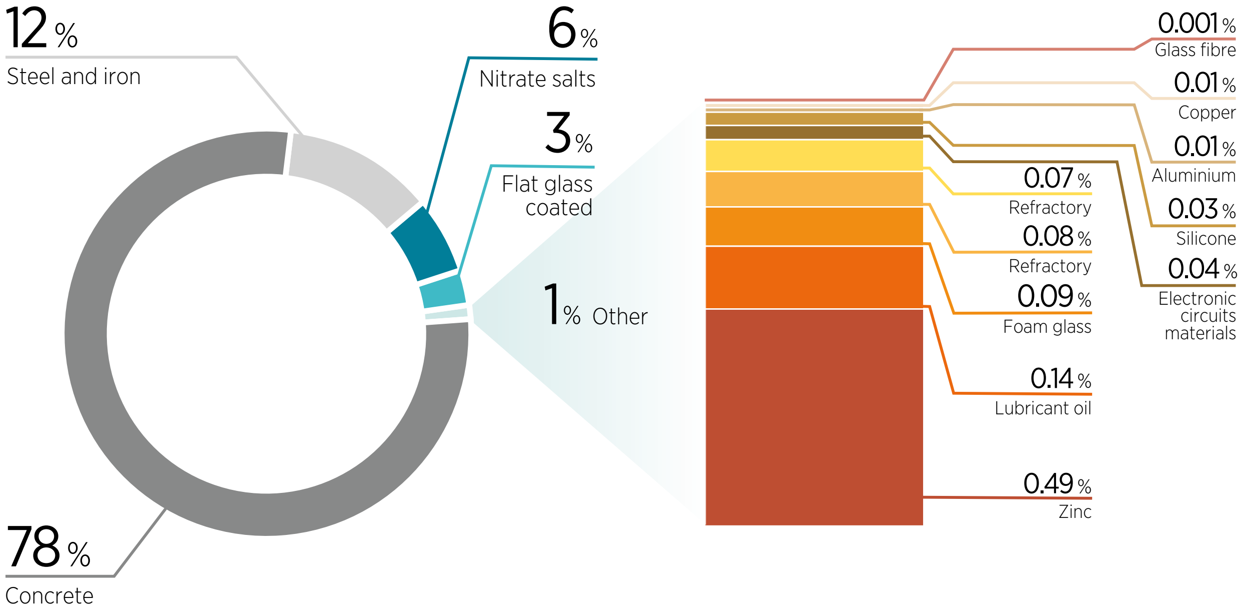
Table 4 details the material requirements for the construction of a 100 MW power plant with ten hours of TES that utilises ST technology. The proportional utilisation of the materials is depicted in Figure 10. Concrete is the predominant material; it is especially utilised in the construction of the solar field and ST. The total concrete requirement is 255 836 tonnes (77% of the overall material requirement for the plant's construction). Concrete is followed by steel and iron, whose requirement is at 41 570 tonnes (13%); they are mainly utilised for the solar field. Molten salts are next. They serve dual functions, as thermal storage and a heat transfer fluid (HTF), with a total material requirement of 20 991 tonnes (6%).

Table 4 ■ **Materials required for a 100 MW ST plant with ten-hour TES capacity (tonnes)**

Material	Solar field	Receiver system	Tower	Steam generator	Power block	TES and HTF	Foundation and auxiliary buildings	Wiring and piping	Total
Concrete	193 699	-	38 165	-	-	17 133	19 272	**-**	**251 136**
Steel and iron	33 218	2 047	3 013	440	1 019	972	662	**199**	**41 570**
Nitrate salts	-	-	-	-	-	20 991	-	**-**	**20 991**
Coated flat glass	9 345	-	-	-	-	-	-	**-**	**9 345**
Zinc coat, pieces	1 638	-	-	-	35	-	-	**-**	**1 673**
Lubricant oil	484	-	-	-	-	-	-	**-**	**484**
Foam glass	-	-	-	-	-	303	-	-	**303**
Refractory, basic	-	273	-	-	-	-	-	-	**273**
Stone wool	-	26	-	0.07	1.6	217	-	-	**245**
Electronics for control units	127	-	-	-	-	-	-		**127**
Silicone	93	0.73	-	-	-	-	-	-	**94**
Aluminium	-	-	-	-	50	-	-	-	**50**
Copper	-	-	-	-	14	-	-	35	**49**
Glass fibre	-	-	-	1.9	-	-	-	-	**1.9**

Notes: HTF = heat transfer fluid; MW = megawatt; ST = solar tower; TES = thermal energy storage.

Figure 10 ■ **Distribution of the materials required to construct a 100 MW ST plant with ten-hour TES capacity**



Based on: (Gamarra et al., 2023; Kis et al., 2018; Pihl et al., 2012 and Gereffi and Dubay, 2008).
Notes: MW = megawatt; ST = solar tower; TES = thermal energy storage.

The material distribution of a PT plant of equivalent capacity is outlined in Table 5. Although concrete remains the primary construction material, with a requirement of 185 784 tonnes (48% of the total material requirement), the volume required is less than that for ST projects, because material requirements are lower for the solar field and there is no tower structure. Steel and iron consumption is approximately double that for ST projects, at 98 700 tonnes (26%), because PT technology operates at lower temperatures and necessitates an extensive solar field, with substantial metal content in receivers, collectors and piping systems. The PT technology requires nearly four times as much molten salt volume as the ST technology, at 76 516 tonnes (20%), because the storage temperature in the PT technology is lower (391°C, compared with 565°C in the ST technology), and a larger mass of salts is required to store equivalent energy levels. Notably, PT technology utilises thermal oil as the HTF in the solar field; the material requirement is 7 328 tonnes (2%).


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Table 5 ■ **Materials required for a 100 MW PT plant with ten-hour TES capacity (tonnes)**

Material	Solar field	Steam generator	Power block	TES and HTF	Foundation and auxiliary buildings	Wiring and piping	Total
Concrete	149 231	-	-	17 133	19 420	-	**185 784**
Steel and iron	24 245	900	1 026	6 773	662	65 093	**98 699**
Nitrate salts	-	-	-	76 516	-	-	**76 516**
Glass	13 905	-	-	-	-	-	**13 905**
HTF oil	-	-	-	7 328	-	-	**7 328**
Zinc coat, pieces	1 492	-	35	-	-	-	**1 527**
Stone wool	-	0.07	1.6	943	-	-	**945**
Foam glass	-	-	-	303	-	-	**303**
Electronics for control units	116	-	-	-	-	-	**116**
Silicone	85	-	-	-	-	-	**85**
Lubricant oil	80	-	-	-	-	-	**80**
Aluminium	-	-	50	-	-	-	**50**
Copper	-	-	14	-	-	35	**49**
Glass fibre	-	3	-	-	-	-	**3**

Notes: HTF = heat transfer fluid; MW = megawatt; PT = parabolic trough; TES = thermal energy storage.

Figure 11 illustrates the percentages of the main materials required for constructing and the initial operation of a PT plant. A portion of these materials are derived from intermediate products, which must be chosen based on the specifications of the equipment. Before the products are acquired, their local availability is assessed. Additionally, considerations of sustainability and a just energy transition can be taken into account to guide the selection of the material's geographical source (see Box 3).


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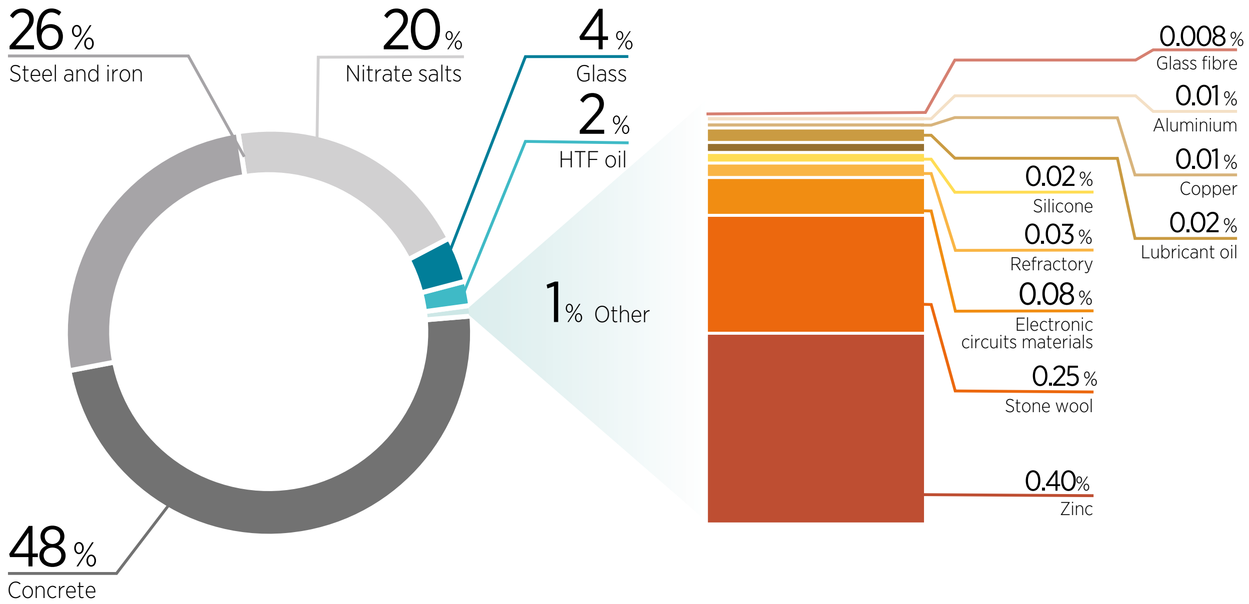
Figure 11 ■ **Distribution of the materials required to construct a 100 MW PT plant with ten-hour TES capacity**



Based on: (Gamarra et al., 2023; Kis et al., 2018; Pihl et al., 2012 and Gereffi and Dubay, 2008).
Notes: MW = megawatt; ST = solar tower; TES = thermal energy storage.

Box 3 ■ Materials for a just transition

The extraction and refining of minerals and metals crucial for energy transition technologies have raised several concerns, including the challenge of overcoming deep-rooted historical dependencies within the global economic order. Notably, certain countries possess concentrated resources of these materials. While rising demand could potentially boost income and employment, realising the full spectrum of benefits requires these countries to advance their material processing capabilities. This involves moving beyond the role of mere commodity producers and striving for enhanced value-added generation.

There are also important issues regarding environmental and labour standards, as well as the consequences of mining and refining for local communities. Industry practices have long been scrutinised for deficiencies in job quality, occupational health and safety standards, and workers' rights. The sector's prevalence of informal work arrangements that might not comply with national laws and regulations. Increased awareness of exploitative conditions, such as child labour in cobalt mining, is prompting a demand for change. The enforcement of applicable labour standards could influence where supply chain investments are made and, consequently, impact the geographical distribution of job creation. Notably, athese growing concerns have triggered a push for greater transparency in supply chains; this has prompted some companies to re-evaluate their sourcing strategies for this critical material.

Moreover, it is essential to recognise that raw material mining and processing entail significant environmental costs. These activities pose risks to air and water, causing pollution, and, if not executed responsibly, can jeopardise biodiversity, leading to deforestation and flooding. Creating a more sustainable future energy system necessitates mitigating these environmental impacts. Emphasis must be on the use of secondary and recycled materials, as well as on minimising the energy and emission intensity associated with primary production processes. A transition towards a more sustainable approach is pivotal for mitigating the ecological footprint of the renewable energy supply chain.

3.3 Manufacturing

In the project planning phase, critical decisions are made regarding the procurement of components, which may be sourced locally or imported from international suppliers (see Box 3). Europe is home to prominent manufacturers of receivers, while the leading supplier of molten salts operates in Chile (as detailed in Box 4). To strengthen local manufacturing capabilities for CSP, key component suppliers might be encouraged to form partnerships with local enterprises.

Box 4 ■ Distribution of relevant suppliers

In the domain of concentrated solar power (CSP) technologies, the supply chain for receivers is dominated by a select group of companies. For central receivers, notable engineering firms and manufacturers include Cockerill Maintenance & Ingénierie (Belgium), Brightsource (Israel), Sener (Spain) and Aalborg CSP (Denmark). For receiver tubes, Rioglass (Spain), along with Royaltech, Lanzhou Dacheng Technology Co., Ltd and TRX Solar Technology (China), are the leading suppliers.

The market for molten-salt-based thermal energy storage is geographically diverse. Prominent suppliers in this segment are SQM (Chile), BASF (Germany), Yara International ASA (Norway) and China's Enesoon. As for thermal oil, a crucial fluid in CSP operations, the United States leads with manufacturers such as Dow Chemical, Eastman Chemical, Radco Industries and Paratherm. Other important suppliers in this category are Thermax (India), Wacker (Europe) and various enterprises across China.

Regarding essential components such as ball joints and metal hoses, Germany's Senior Flexonics, and the United States' ATS and Hyspan stand out as the principal suppliers.

The procurement of commodities like steel and concrete is standard for the construction of CSP plants, and the fabrication of non-proprietary components is typically outsourced. Decisions on sourcing are influenced by technological costs, national policies, including import taxes and local content requirements, which incentivise local production through subsidies (see Box 5), transport expenses, and the availability of maintenance services and warranties. Governments should design policies to augment the local economic benefits from CSP projects.

Box 5 ■ Local content requirements for material sourcing

The engineering team is entrusted with the critical task of evaluating the local availability of materials and identifying components that are viable for local procurement versus components that require importation. A fundamental aspect of this process is adherence to national policies and prevailing regulations that mandate local content requirements.

A case in point is South Africa's Renewable Energy Independent Power Producer Procurement Programme, which stipulates allocating a specified proportion of the total project expenditure to local content. For the concentrated solar power projects under this programme, 40% of the overall project value is set aside for purchases from South African suppliers.

Although local content requirements may initially inflate the costs of renewable energy initiatives and pose challenges in sourcing specific materials and components, such mandates are also recognised for their potential to strengthen local industry, foster job creation and enable a more equitable distribution of the economic advantages of renewable energy developments (Montmasson-Clair and Ryan, 2014).

Manufacturers must weigh the economic advantages of establishing a factory within a target country against shipping products from an existing plant abroad. Considerations include the demand for CSP components, the legal framework, labour and transportation costs, market competition, availability of raw materials and intermediate products, and government incentives for local manufacturing.

Components that can be easily transported are generally procured through networks associated with manufacturers. In the context of a solar field, which includes either PT collectors or heliostats, on-site workshops facilitate design, assembly and quality control. For commercial CSP operations, the steam generation equipment, which commonly includes super heaters, re-heaters, evaporators, steam drums and economisers, is sourced from suppliers that typically serve conventional power plants – a practice consistent across both PT and ST technologies.

The labour required for manufacturing the principal components of a 100 MW solar plant with ten hours of TES is relatively similar for the PT (96 100 person-days) and ST (100 299 person-days) technologies. Table 6 provides an overview of the average human resource effort required.

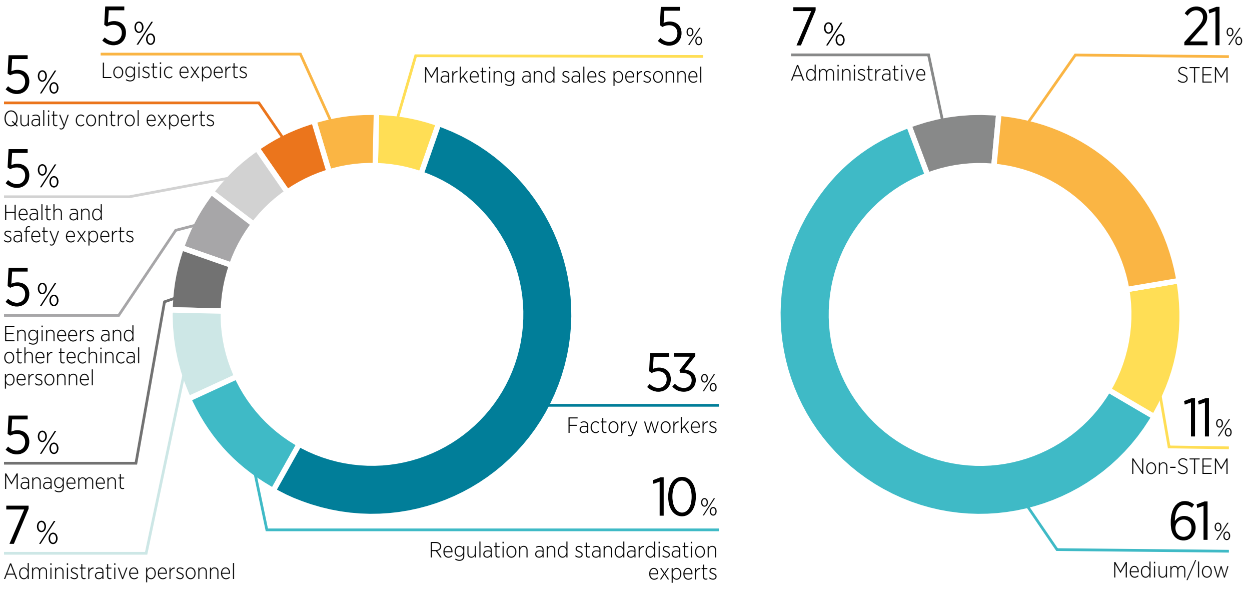
Table 6 ■ **Average labour required for manufacturing components of a 100 MW + ten-hour TES plant that utilises the PT or the ST technology (person-days)**

Type of labour	Solar field	Steam generator	Power block	TES and HTF	Foundation and auxiliary buildings	Wiring and piping	Total
Factory workers	29 102	4 799	4 400	6 244	2 300	4 835	**51 680**
Regulation and standardisation experts	5 629	368	1 288	1 142	402	1 030	**9 859**
Administrative personnel	3 562	671	688	843	301	637	**6 702**
Management	2 895	600	550	701	250	516	**5 512**
Engineers and other technical personnel	2 816	514	500	637	230	487	**5 184**
Health and safety experts	2 677	514	400	606	250	44	**4 902**
Quality controls experts	2 677	514	400	605	250	456	**4 902**
Logistic experts	2 671	431	445	580	213	454	**4 794**
Marketing and sales personnel	2 568	416	430	559	206	437	**4 945**
TOTAL	**54 597**	**8 827**	**9 101**	**11 917**	**4 402**	**9 307**	**98 151**
(as %)	**55.6%**	**9.0%**	**9.3%**	**12.1%**	**4.5%**	**9.5%**	

Notes: HTF = heat transfer fluid; MW = megawatt; PT = parabolic trough; ST = solar tower; TES = thermal energy storage.

The solar field demands the largest allocation of labour (55.6% of total person-days). The allocation is significantly greater than that for the TES and HTF systems (12.1%). Wiring and piping work (9.5%) follows, while the power block (9.3%) and the steam generation system (9.0%) require slightly less labour. The foundations and auxiliary buildings require the least labour (4.5%).

Figure 12 ■ **Average distribution of labour required for manufacturing the components of a 100 MW CSP plant with ten-hour TES capacity, by occupation and skill set**



Notes: CSP = concentrated solar power; MW = megawatt; STEM = science, technology, engineering and mathematics; TES = thermal energy storage.

Factory workers represent more than half of the labour force in plant construction (52% in PT and 53% in ST). Industrial engineers account for 5% of the labour force for both technologies. In PT plants, the majority of the industrial engineering labour is devoted to the solar field (2 020 person-days) and the TES and HTF systems (1 000 person-days). In ST plants, the distribution of engineering labour varies across the different plant sections. Figure 12 depicts the distribution of the labour required for manufacturing the principal components for both types of CSP technologies.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3.4 Operation and maintenance

The construction, operation and maintenance of a solar thermal power plant provides jobs locally for a minimum of two years. In this analysis, a general average case is considered, due to the small variations in total figures per category between the PT and ST technologies.

Operational integrity is paramount to ensure the economic effectiveness of a power plant over its lifetime. Minimising downtime due to potential damage requires a predictive maintenance strategy, supported by regular monitoring. Unaddressed issues such as heat loss, leaks, contamination, positioning inaccuracies or component failures can diminish plant output and hamper profitability. Power plant operators must, therefore, employ advanced technical solutions, including digital automated monitoring systems, to maintain operational excellence. The complexity of plant operations necessitates a highly skilled workforce. New hires must therefore undergo comprehensive training by seasoned personnel, specifically to minimise operational errors and improve early detection of potential system malfunctions.

Operating a 100 MW CSP plant with ten hours of TES entails on average 22 721 person-days per year; 58% of those person-days are devoted to operations activities and the remaining 42% to maintenance activities. Table 7 details the distribution of these person-days across various human resource categories and activities, while the proportional allocation of labour by job type and skill level (STEM, Non-STEM, Mid/Low and Administration) is depicted in Figure 13.

Over the 23 years of a power plant's operation,[7] an average productivity gain of 0.5% per year is expected, as stated earlier. Considering this productivity gain, during a plant's life span, the number of person-days devoted to O&M activities will total approximately half a million person-days.

Table 7 ■ **Labour required for O&M of a 100 MW CSP plant with ten-hour TES capacity (person-days/year)**

Type of labour	Operation	Maintenance	Total
Operators	8 096	-	**8 096**
Maintenance workers	-	6 409	**6 409**
Engineers and other technical personnel	253	2 024	**2 227**
Health and safety experts	759	759	**1 518**
Chemists	1 265	-	**1 265**
Administrative personnel	1 241	-	**1 241**
Accountants	783	-	**783**
Management	506	-	**506**
Instrumentation and control experts	253	253	**506**
Environmental experts	120	-	**120**
TOTAL	**13 276**	**9 445**	**22 721**
(as %)	**58%**	**42%**	

Notes: CSP = concentrated solar power; MW = megawatt; O&M = operation and maintenance; TES = thermal energy storage.

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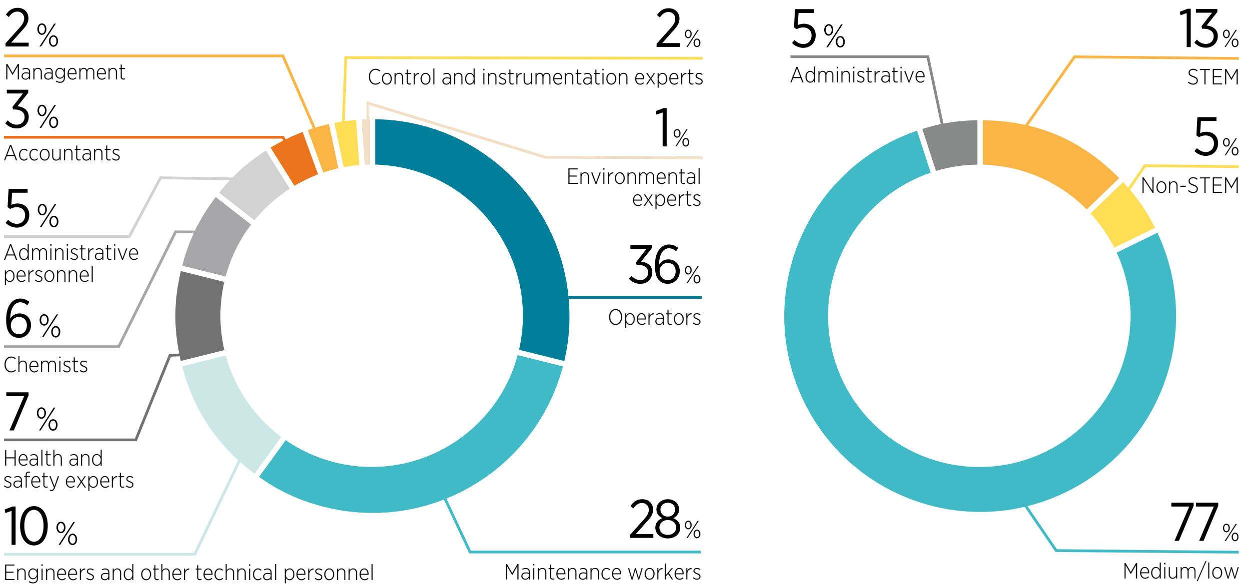
[7] *The full project (planning to operation) is estimated to take 25 years, including two for planning and construction.*

Figure 13 ■ **Distribution of human resources related to O&M of a 100 MW CSP plant with ten-hour TES capacity**



Notes: CSP = concentrated solar power; MW = megawatt; O&M = operation and maintenance; STEM = science, technology, engineering and mathematics; TES = thermal energy storage.

O&M predominantly involves technical personnel with medium/low STEM skill levels. Throughout a plant's operational tenure, operators, maintenance staff, engineers, chemists, and instrumentation and control experts collectively contribute over 80% of the total person-days required for effective plant O&M; only 2% is attributed to top management roles. The significance of local involvement in O&M activities is further highlighted in Box 6.

Box 6 ■ **O&M: Typical activities and opportunities for localisation**

Operation

Control room operators meticulously document operational data in logbooks and databases. These data encapsulate critical information such as turbine operation times; lists of offline equipment; operational incidents and resource consumption metrics for gas, electricity and water. Besides serving as official records, these data are scrutinised by performance engineering staff, to ensure they are reliable and in an effort to optimise plant efficiency.

The operations team employs analytical models to deepen their understanding of the variables affecting the plant's performance. These models leverage insolation and meteorological data collected on-site and forecast expected electrical and thermal performance. Effective utilisation of these models enables the engineering team and operators to identify and address underperforming systems, allowing for timely corrective action. The precision of these models is contingent upon the quality of the meteorological data input. A central, quality-controlled weather station is therefore vital for accurate measurements of insolation, wind speed and temperature.

Maintenance

During the warranty period, equipment manufacturers often handle a portion of a plant's maintenance. Subsequently, specialised subcontractors may assume responsibility for certain segments of the installation. Maintenance includes corrective measures for malfunctions as well as preventive strategies to pre-empt future failures and preserve optimal performance levels.

Common maintenance tasks within a concentrated solar power facility include the cleaning of heliostats or collectors, servicing of receivers, repairs to ball joint connections, assessment of tracking systems, inspections of salt tanks, analysis of the heat transfer fluid. system and water treatment for the steam cycle. Advanced predictive maintenance involves vibration analysis, thermographic evaluations, baroscopic inspections of piping and ultrasonic tests for corrosion detection. Regular analysis of the heat transfer fluid is also essential.

Localising O&M

The localisation of operation and maintenance (O&M) activities is recognised as being fundamentally important for renewable energy projects to be sustainable and for value creation within local economies. In the domain of concentrated solar power plants, where precision and efficiency in O&M practices are directly tied to plant performance and economic outcomes, engaging local workforce is particularly impactful. Such practices are not only instrumental in generating job opportunities and energising local economies, they also ensure plants are operated and maintained effectively. The potential benefits of such localisation, as suggested by Morocco's Ouarzazate Solar Power Station, include:

- **Job creation.** The project provided a diversity of employment opportunities directly within the plant as well as in the surrounding region, benefiting local residents.
- **Skill development.** Skill improvement for the local workforce through exposure to advanced technologies and operational practices is leading to improved livelihoods.
- **Infrastructure development.** The project led to infrastructure improvements, leaving a lasting impact on the region's overall development.
- **Supply chain and economic growth.** The operation of the plant stimulates the local supply chain and induces broader economic growth, enriching service sectors and business opportunities.
- **Technological advancement.** The plant's presence facilitates training, technology transfer and innovation; this in turn fosters regional expertise in renewable energy.
- **Sustainable practices and tourism.** The project signifies a shift towards sustainability, establishing Ouarzazate as a renewable energy hub and an eco-tourism destination.

These impacts hint at the transformative power of integrating local labour in renewable energy projects, which can in turn generate multi-faceted economic and environmental benefits. Similarly, experiences from South Africa emphasise a reliance on local personnel for efficient O&M, enabling socio-economic benefits to also reach disadvantaged communities, as discussed further in section 4.2.

3.5 Decommissioning

Once a CSP plant's functional life cycle is complete, decommissioning is undertaken, unless feasible methods are identified to modernise and improve the facility. The plant's constituent materials are either recycled, where possible, or they are responsibly disposed of. The foundation is completely removed, restoring the site to its original condition – a typical prerequisite for securing the necessary project permits.

Decommissioning for a CSP plant includes four main activities: planning, dismantling, equipment and waste disposal, and site clearing. These activities can generally be performed by local labour forces. Table 8 illustrates the labour allocation across these activities.

Table 8 ■ **Labour required for decommissioning a 100 MW CSP plant with ten-hour TES capacity**

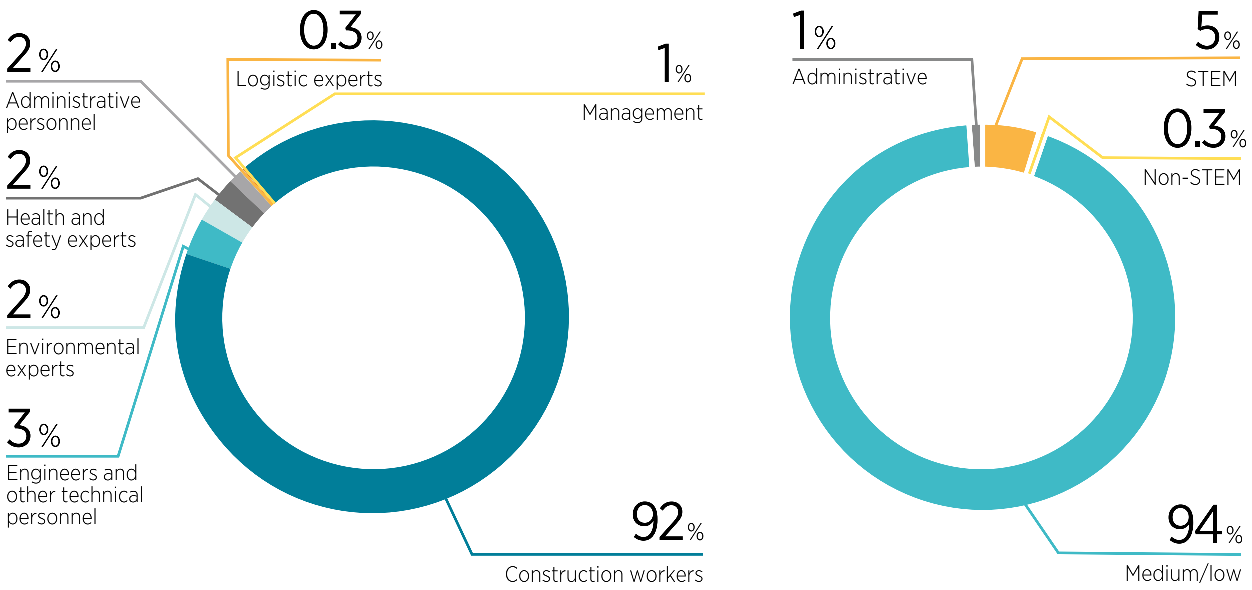
Type of labour	Planning	Dismantling	Equipment disposal	Site clearing	Total
Construction workers	-	22 100	3 600	5 600	**31 300**
Engineers and other technical personnel	43	855	-	57	**955**
Environmental experts	51	360	80	181	**672**
Health and safety experts	30	360	58	128	**576**
Administrative personnel	2	-	405	7	**414**
Logistics experts	2	-	59	-	**92**
Management	2	45	0	3	**50**
TOTAL	**161**	**23 720**	**4 202**	**5 976**	**34 059**
(as %)	**0.5%**	**69.7%**	**12.3%**	**17.5%**	

Notes: CSP = concentrated solar power; MW = megawatt; TES = thermal energy storage.

While labour requirements remain the same for the ST and PT technologies, marginally more labour is required for dismantling a CSP plant utilising the ST technology. Approximately 34 055 person-days are needed to dismantle a 100 MW CSP plant with ten hours of TES. The bulk of labour, about 23 700 person-days (69.7% of the total labour), is allocated to the disassembly of plant systems. Equipment and waste disposal require 4 200 person-days (12.3%) and site clearing requires approximately 5 975 person-days (17.5%). Planning for dismantling requires the least labour, just about 160 person-days (0.5%).

In terms of labour categories, construction workers and technical staff form the largest segment, constituting 81% of the total workforce. This is followed by engineers and other high-level technical personnel, who account for 12%. This distribution is depicted in Figure 14.

Figure 14 ■ **Distribution of effort by type of human resource related to the decommissioning of a 100 MW CSP plant with ten-hour TES capacity**



Notes: CSP = concentrated solar power; MW = megawatt; STEM = science, technology, engineering and mathematics; TES = thermal energy storage.

3.5.1 Planning for decommissioning

To date, three CSP plants (Solar Energy Generating Systems, a company in the, United States) have undergone dismantling. Upon completion of their efficient operational phase, over 90% of the constituent materials has been recyclable. During project planning, engineers must formulate a decommissioning plan, to be factored into the total installation cost for economic viability analysis. Most regulatory frameworks necessitate such a plan for licensing of solar plant installations.

3.5.2 Dismantling

This phase must be developed in a systematic way; key steps include:

- Removal of all potential sources of environmental contamination for land restoration in the post-decommissioning phase.
- Re-conditioning or reuse of equipment or parts thereof after the solar thermal power plant unit has been dismantled.
- Reduction of all possible impacts on the health and safety of the labourers involved in dismantling through proper training and the use of safety equipment.
- Deconstruction of the facility following safety guidelines.
- Sale of recyclable scrap material after deconstruction to scrap dealers to minimise waste.
- Planning for the safe disposal of hazardous materials in line with national regulations.
- Identification of socio-ecological risks and impacts early in the planning phase.
- Rehabilitation of existing plants to improve their efficiency.

The dismantling phase includes the decommissioning activities for the solar field; the tower (for the ST technology); the tank system, from which the salts must first be drained; the piping and wiring; and the auxiliary buildings. The steam generation system and the power block must also be dismantled if a similar installation is not established at the same location; otherwise, these installations could be reconditioned and given a second life. The infrastructure to connect to the electricity grid and the power substations need not necessarily be dismantled; they can be reused for other power installations.

The equipment and labour required for dismantling mirror those used in a plant's construction and are available in most countries. Essential equipment includes cranes, heavy machinery, tools for mechanics and electricians, and protective gear.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3.5.3 Equipment and waste disposal

The waste and materials to be disposed of must be treated properly before they are subsequently disposed of in landfills. Materials to be recycled will be transported to specific points for treatment and reuse.

The constituent materials of the solar field, mainly metals and glass, could be dismantled and recycled. The non-corroded steel that is a constituent material of the salt tanks can also be reused in other industries. Molten salts can be recycled if they are not contaminated during their lifetime. In addition, the synthetic oil, which loses its properties after so many years of operation, will undergo a distillation process to be recycled. The copper in the wiring can be resold to another industry once the wiring is dismantled, to be reused.

The above activity will require loaders, scrap cutting equipment, protective equipment and trucks for transporting the materials.

Decommissioning encompasses a vibrant and inter-disciplinary agenda of interest to many branches of industry. It is also a stimulating topic for policy makers and regulators, who should provide clear strategy, guidance and funding mechanisms with rewards for minimising impacts due to the entire life cycle of infrastructure, not just during the operational generation phase. The interplay between the challenges to decommissioning creates a need to balance the diverse social, organisational, and cultural needs and demands of all stakeholders.

3.5.4 Site clearing

The purpose of site clearance is to restore land to its pre-development state, according to landowner, municipal or government agreements. If a site had vegetation originally, then replanting efforts are initiated. The equipment required in this phase includes excavators, loaders and personal protective equipment.

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4. CASE STUDIES

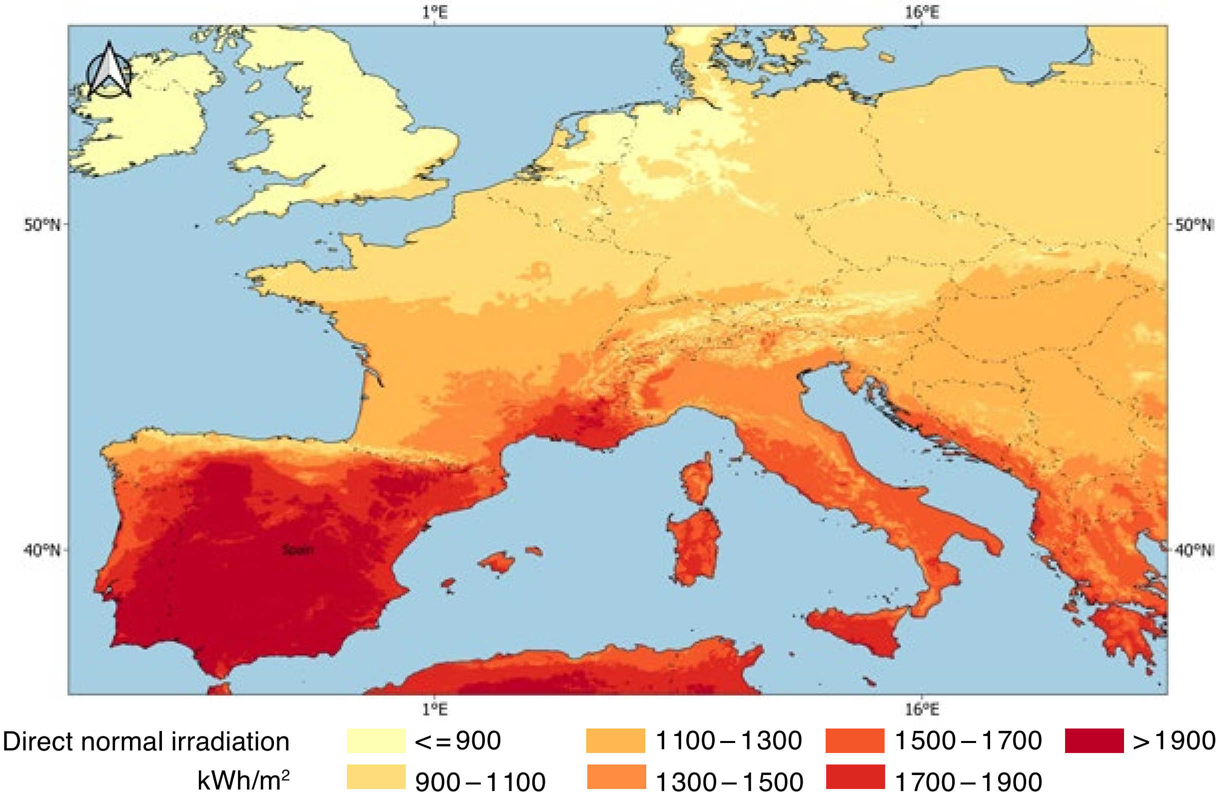
4.1 The case of Spain: Factors enabling CSP deployment

Spain's robust CSP deployment was initially propelled by a suite of supportive policies, including feed-in tariffs (FiTs), investment subsidies, and dedicated research and development (R&D) programmes (Martín *et al.*, 2015). These initiatives were complemented by Spain's favourable climatic conditions and vast expanses of available land, which were instrumental in the industry's success. The vigorous growth of Spain's CSP sector can be attributed to several foundational factors: resource endowment, supportive policies and other economic and industrial factors, and technology development. These factors are discussed in the following subsections.

Resource endowment

As can be seen clearly in Figure 15, Spain has the highest solar irradiation in the European Union. Annual global horizontal irradiance and annual DNI range from 1 750 to 1 850 kilowatt hours per square metre (kWh/m^2) and 1 900 to 2 000 kWh/m^2, respectively, in the south and middle, while they are in the range of 1 600 kWh/m^2 and 1 800 kWh/m^2, respectively, in the north (Polo, 2015). The figures are substantially higher than for most other European countries.

Figure 15 ■ **Direct normal irradiance in Europe**



Source: Global Solar Atlas (ESMAP 2019). Base map: UN Boundaries.

Notes: kWh/m^2 = kilowatt hours per square metre. Maps are also available from the IRENA Global Atlas for Renewable Energy.

Disclaimer: The map, which uses UN boundaries, is provided for illustration purposes only. The boundaries shown do not imply endorsement or acceptance by IRENA.

The southern expanse of Spain is among Europe's most solar resource–rich regions. Annual DNI levels exceed 2 000 kWh/m^2 here. Additionally, the low population density and the presence of large tracts of flat territory have made it an ideal location for CSP development (Navarro *et al.*, 2016).

Supportive policies and other economic and industrial factors

Spain's energy sector has undergone significant transformation to reduce the country's overall reliance on fossil fuels. Energy security, cost-effectiveness and environmental sustainability goals have led to a shift in Spain's energy policy, shaped by EU directives for cutting greenhouse gas emissions and strengthening the consumption of renewable energy.

The introduction of the FiT system, one of the earliest in Europe, substantially boosted CSP capacity. A series of legislative acts, including Royal Decrees 28128/1998, 841/2002 and 436/2004, provided essential financial support. They established a framework of regulated tariffs and premium payments over and above the revenue from electricity sales. A conducive environment for investment was thus created.

Notably, Royal Decree 436/2004 stipulated fixed tariffs for CSP producers, calculated as a percentage of the average electricity tariff, and increasing the appeal of CSP ventures. This decree was instrumental in fostering the development of the initial 200 MW of solar thermal electricity in Spain. Competitive tariffs were offered for the first 25 years of operation. Projects such as PS10, Andasol I and Gemasolar emerged, their realisation bolstered by additional support from entities such as the European Commission.

Further improvements under Royal Decree 661/2006 were crucial in promoting CSP investments. This decree set forth new tariffs and premiums for various facilities, including renewable energy, waste-to-energy and hybrid systems, within a specialised regulatory framework. CSP installations benefited greatly from this policy, which established technology- and capacity-specific limits and offered bonuses for high system efficiency or reactive energy use.

This confluence of supportive factors unleashed a wave of development, propelling the CSP sector to flourish beyond expectations. CSP projects had cumulatively reached nearly 2.3 GW of capacity, which was substantially higher than the initial 1 GW target the government had set in its renewable energy plans (IRENA, 2022).

Technology development

Spain's legacy in CSP innovation is deeply rooted in the establishment of the Plataforma Solar de Almería (PSA),[8] a beacon of knowledge and technological advancement in CSP technologies since the late 1970s. Collaboration among PSA, Spanish universities and the broader European industry has catalysed a robust scientific and technological milieu, which is optimally positioned to leverage regulatory frameworks for stimulating renewable energy sectors, CSP included.

As stated earlier, Spain's cumulative installed capacity of over 2.3 GW as of 2023 represents 33% of the global total. As shown in Figure 16, this impressive figure is spread across 49 plants, underscoring the country's widespread adoption of CSP technology.

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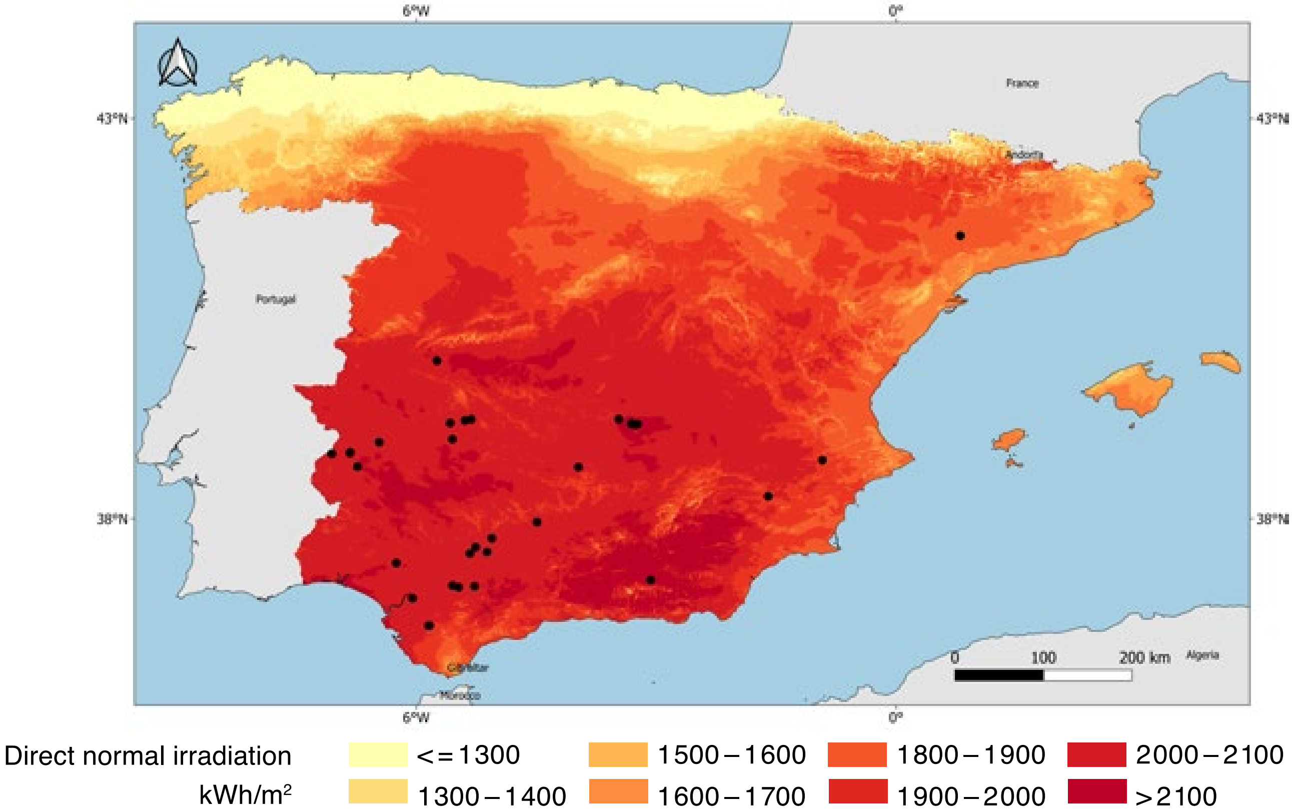
[8] *The PSA, a dependency of the Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), is the largest R&D and testing centre for the CST technology in Europe. Activities of the PSA are integrated in the CIEMAT organisation as an R&D division of the Department of Energy.*

Figure 16 **Locations of the 49 CSP plants in operation in Spain**



Source: Direct normal irradiance – Global Solar Atlas (ESMAP, 2019). CSP power plants – (©) Institute for Advanced Sustainability Studies (IASS) and others 2022. Data by Lilliestam@IASS, Thonig@IASS, Zang@CAS, Gilmanova@CAS and others. Base map: UN boundaries.

Notes: CSP = concentrated solar power; GW = gigawatt; kWh/m² = kilowatt hours per square metre. Maps are also available from the IRENA Global Atlas for Renewable Energy.

Disclaimer: The map, which uses UN boundaries, is provided for illustration purposes only. The boundaries shown do not imply endorsement or acceptance by IRENA.

From a technological standpoint, PT systems have predominantly been selected for CSP development in Spain – a trend strongly influenced by the established success of the solar energy-generating systems in California. The preference for PT systems, which was rooted in the banking sector's familiarity with this specific technology, was reflected by Spain's choice of this technology, especially for projects developed under FiTs. Given that the only commercially operated CSP technologies at that time were PT systems, Spanish banks were more inclined to finance these over other technologies such as tower systems or Fresnel reflectors. This comfort with proven operational efficiency facilitated financing and promoted the swift deployment of the PT technology. In parallel, Spanish CSP installations have propelled the technology forward by integrating TES systems, significantly improving energy management.

Status and perspectives

Despite rapid growth and technological progress in the sector, outlined earlier, the 2008 global economic downturn and an expanding tariff deficit – partly attributed to the rise of renewable energy subsidies under the “special regime” after 2006 due to rapid growth of CSP and PV capacity (Linden *et al.*, 2014), led to a roll-back of numerous renewable energy incentives in Spain. This roll-back included the withdrawal of Royal Decree 436/2004 in 2012, supplanted by a complementary payment regime following a moratorium on renewable energy instituted that same year. The shift from a previously guaranteed profitability of 7.5% to a range of 4%-5% in January 2020 induced policy uncertainties; this in turn triggered a fiscal strain on CSP projects, and impeded further expansion within the industry (Frisari *et al.*, 2014; Coronas *et al.*, 2022).

Substantial capital investment requirements for CSP projects remain a significant barrier to their advancement in Spain, especially in the absence of subsidies. While the global capital costs for CSP projects are on a decline, the LCOE for CSP continues to be higher than that for other renewable energy sources (IRENA, 2024) (Dersch *et al.*, 2020). The benefits of CSP, such as its dispatchability and substantial local content, are not yet adequately compensated for by the prevailing electricity market structures. However, progress in techno-economic aspects has the potential to decrease capital costs substantially and improve economic viability, in turn positioning CSP as a more competitive player in the renewable energy arena (Ferruzzi *et al.*, 2023; Libby and Gould, 2022). Also, revisions to electricity market regulations to appropriately value dispatchability, along with support to local employment and recognition of high local content through national or regional incentives in Spain, could greatly encourage the country’s commercial CSP sector and expedite the establishment of commercial CSP plants.

Despite the challenges mentioned earlier, Spanish firms remain influential in CSP projects globally, underscoring Spain’s substantial contribution to the industry. The ongoing evolution of technology and economic conditions will continue to influence the trajectory of the CSP industry both within and beyond Spain’s borders.

In September 2024, Spain updated its National Energy and Climate Plan (NECP) for 2021–2030 (Ministry for Ecological Transition and the Demographic Challenge, 2024). The revised NECP underscores the growing importance of CSP and CST technologies in advancing the country’s decarbonisation efforts. By 2030, the operational installed CSP capacity is anticipated to reach 4.8 GW, more than doubling the current capacity. Furthermore, CSP plants are projected to contribute 3% of the total electricity generation mix by the same year, up from the current 2%. This growth reaffirms the strategic role of CSP technologies in Spain’s energy transition. In addition, a carbon-neutral energy system requires developing CST systems to deliver industrial heat (within the range of 60-400°C) to cover over 30% of the energy demand in the industrial sector. Some Solar Heat for Industrial Processes (SHIP) systems have been used in the agri-food sector for the decarbonisation of processes such as pasteurisation, drying, sterilisation, cooking, steam production, distillation and biochemistry, among many others. To promote an understanding of this application, the Institute for Energy Diversification and Saving (IDAE) launched a technological guide (IDAE Guía 033) containing information and documentation available on the systems’ performance and costs, and presenting successful cases implemented in the European market (Guía IDAE, 2022).

For these reasons, CSP should be recognised as a contributor to meeting energy needs, creating new opportunities for the European industry and supporting Spain’s decarbonisation agenda. A SWOT (strengths, weaknesses, opportunities and threats) analysis shows that, despite its significant strengths and opportunities, the Spanish CSP sector has weaknesses and faces threats, some of which are specific to the country’s political and regulatory context and could be overcome with appropriate support from the Spanish administration (see Box 7).

Box 7 ■ SWOT analysis for Spain’s CSP sector: Industry, research and deployment perspectives

Strengths

1. Leader in the construction and operation of concentrated solar power (CSP) plants
2. Presence of a well-established construction industry and international CSP projects
3. Production of CSP components to global standards, with some exports
4. Strong local CSP research and development (R&D) output
5. Top-level CSP research centres and university groups
6. Globally competitive local manufacturing, especially in the automotive industry
7. Dispatchable technology helping solar photovoltaic and wind to achieve significant penetration ratios in scenarios where reliance is fully on renewables

Weaknesses

1. Lack of strong national support for R&D in the CSP field
2. Local industrial R&D and productivity lower than in other countries leading in CSP
3. High overall cost and local costs for the materials for certain CSP components
4. Limited CSP-specific skills and training programmes
5. Unstable political commitment to renewable energy

Opportunities

1. Ideal solar resource conditions for CSP in Europe
2. Governmental support for high local content in CSP projects
3. A growing need for storage and dispatchable renewable energy sources, such as CSP, in the Spanish electricity system
4. Opportunity to lead in CSP technology due to its nascent stage
5. Potential for exporting to nearby, Middle Eastern and Hispano-American, countries with strong solar resources
6. Willingness for international co-operation and technology transfer
7. Possible use of thermal energy storage to save curtailments of photovoltaic and wind energy

Threats

1. Financial challenges due to foreign investors’ preference for established technologies
2. Low CSP capacity allocation in government energy plans
3. Lack of appropriate market signals in support of their value propositions
4. Increased international competition
5. Uncertainty regarding CSP’s future due to political and policy instability
6. Rapid advancement in and cost reduction for competing renewable technologies

Note: SWOT = strengths, weaknesses, opportunities and threats.

4.2 The case of South Africa

As in Spain, CSP deployment in South Africa has been supported by a combination of natural resource endowment, technological advancements and supportive governmental policies, which have been instrumental in the industry's growth. The following subsections discuss the supporting factors.

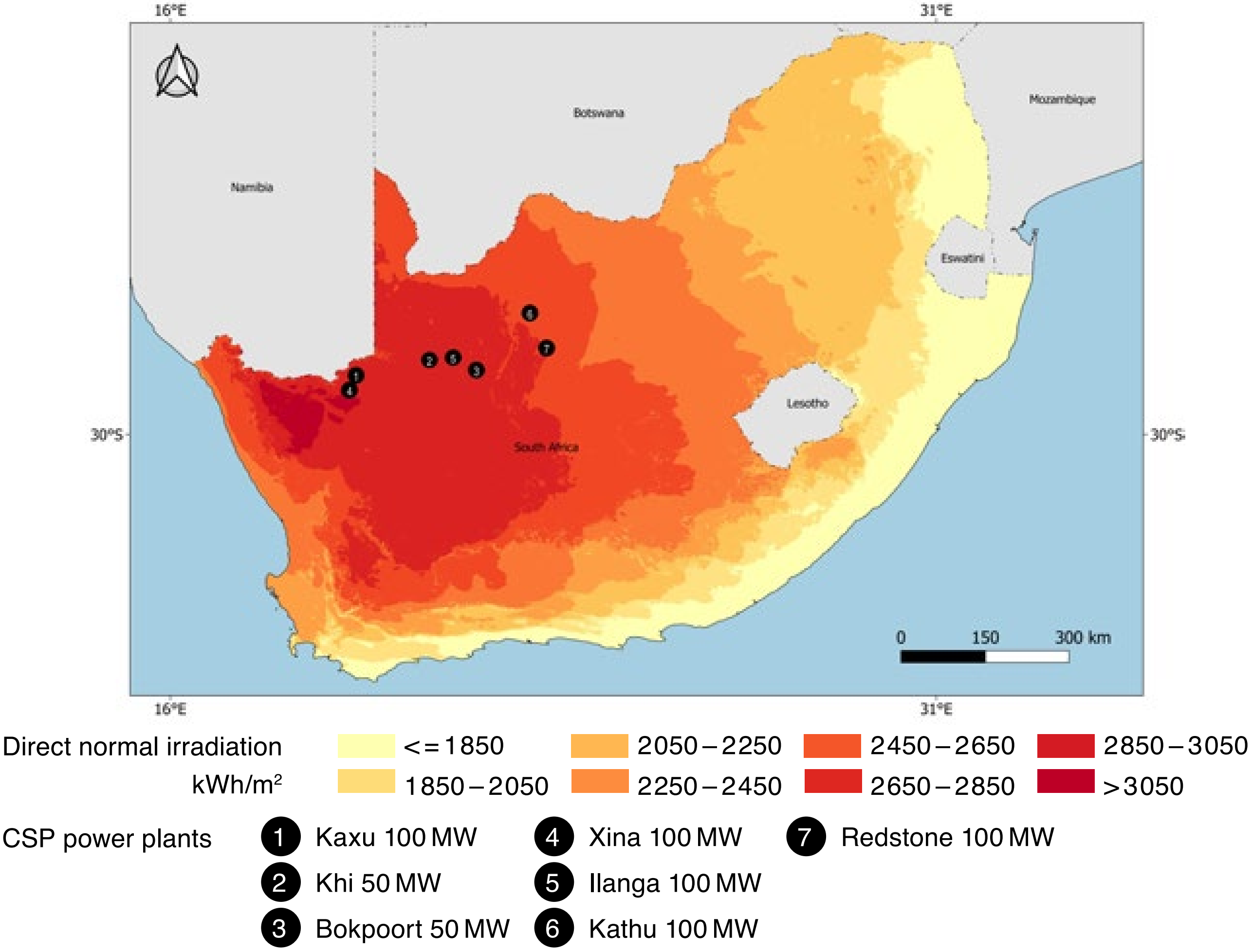
4.2.1 Factors enabling CSP deployment in South Africa

Resource endowment

The Northern Cape of South Africa claims to be among the world's most solar resource–rich regions. Ample sunlight in the region, coupled with large expanses of semi-arid land and relatively low population density, creates an ideal environment for CSP deployment.

South Africa is endowed with an exceptional solar resource. It receives ample sunlight year-round. The country's solar irradiance, quantified in terms of DNI, shows long-term annual averages ranging from 1 460 - 3 287 kWh/m² between 1994 and 2015, as illustrated in the Solargis DNI map (Figure 17). This is notably superior to that of Spain, which boasts the highest solar resource within the European Union.

Figure 17 ■ **Direct normal irradiance in South Africa and locations of CSP projects**



Source: Direct normal irradiance – Global Solar Atlas (ESMAP, 2019). CSP power plants – (©) Institute for Advanced Sustainability Studies (IASS) and others 2022. Data by Lilliestam@IASS, Thonig@IASS, Zang@CAS, Gilmanova@CAS and others. Base map: UN boundaries.

Notes: CSP = concentrated solar power; MW = megawatt; kWh/m² = kilowatt hours per square metre.

Disclaimer: The map, which uses UN boundaries, is provided for illustration purposes only. The boundaries shown do not imply endorsement or acceptance by IRENA.

Supportive policies and other economic and industrial factors

Considering its carbon dioxide emissions are the highest on the African continent due to its coal-centric energy sector, South Africa has been proactive in diversifying its energy sources. The Renewable Energy Feed-In-Tariff, the Integrated Resource Plan and the Renewable Energy Independent Power Producer Procurement Programme have been foundational in steering the nation towards a more sustainable energy policy framework. In this strategic pivot, CSP was identified as a promising component (Pieters *et al.*, 2014). Despite this, the momentum for new CSP projects has not been sustained past 2019, due to, for example, financial constraints, regulatory uncertainties, and the rapid evolution of other renewable technologies that have attracted attention and investment.

South Africa's mature automotive and materials industries, together with the electromechanical equipment and services sector, are well positioned to create a significant impact on future CSP development. Some 50-60% of the component value for large-scale CSP tower plants could be sourced domestically; this would add considerable local value and foster employment opportunities, especially in regions where unemployment is high. The domestic production of the fundamental components, which represent roughly 10% of a plant's value, emphasises the critical role of local manufacturing in strengthening economic growth. Table 9 delineates potential South African suppliers of goods and services for the CSP technology, highlighting the extensive domestic manufacturing capabilities (Craig *et al.*, 2019).

However, fully harnessing this potential requires fostering partnerships with countries leading in CSP and increasing the country's R&D budget. Such strategic collaborations are essential for increasing economic value locally and promoting job creation.

Table 9 ■ **Potential South African suppliers of CSP goods and services**

Component manufacturing		Potential suppliers
Heliostats	Mirrors	Sarchwell (foam injection)
		Rigifoam (foam)
		PFG Building Glass (silvering)
		PFG Building Glass (glass)
	Gears/drives	Actom
	Steel suppliers for structures	Macsteel, Aveng Trident, Duferco and Arcelormittal SA
	Controls	Helio 100 (intelligence), Wirecon (wiring) and Reutech
	Trackers	Helio 100, Reutech
Receiver		John Thompson, defence industry
Tower		Brolaz, Macsteel, Trident, Duferco, Sectional Poles and Graffo
Storage		Intertherm, steel companies and EPC contractors (storage container only)
Power block		n/a
EPC services		Group Five, Aveng and Crowie Concessions

Source: (WWF, 2015).
Notes: CSP = concentrated solar power; EPC = engineering, procurement and construction; n/a = not applicable.

The outlook for the CSP sector in South Africa must balance the acknowledged potential of local industries to enhance economic value and generate employment against the realities of recent years. A careful approach, informed by the sector's challenges and a realistic appraisal of future prospects, is essential for moving forward.

Technology development

Development of CSP infrastructure in South Africa has been substantial. The country achieved an installed capacity of 500 MW, primarily based on the PT technology, within a relatively short time frame, from 2016 to 2019. The rapid deployment highlights the country's potential for further growth, with support from renewable energy policies specifically to mitigate the environmental impacts of conventional electricity generation.

South Africa's commitment to CSP advancement is underscored by initiatives such as the South African Renewable Energy Technology Centre, which promotes technology transfer and workforce training in renewable technologies, including CSP. Collaboration among South African universities, research institutions and international partners has nurtured a conducive environment for R&D in CSP.

The factors discussed earlier have together led to a significant increase in CSP activity in South Africa, with rapid installation of substantial capacity. Echoing Spain's experience with CSP, South Africa has preferred PT systems due to their proven reliability and the availability of skilled labour. Integrating TES into CSP projects increases grid stability and energy dispatchability, reinforcing CSP's role in South Africa's energy portfolio.

4.2.2 Status and perspectives

Challenges remain, particularly the need for adequate water resources and the necessity to adjust tariff rates to remain competitive with alternative forms of energy. However, the solid foundation established by the factors discussed in the previous section offers a promising base for the continued growth and viability of CSP technologies in the region.

The strength of South Africa's industrial sectors, most notably its automotive and materials industries, lays the groundwork for potential economic improvement and job creation offered by the CSP industry. These sectors are especially crucial in areas with elevated unemployment levels, presenting opportunities to revitalise industry and diversify the energy sector.

The CSP landscape in South Africa presents a complex array of challenges and opportunities (see Box 8). Capital investment requirements remain a considerable obstacle, especially in the absence of substantial subsidies. The LCOE for CSP continues to exceed that for other renewable energy sources, despite a decline of capital costs for CSP globally. In South Africa, this is partly due to the nascent stage of CSP development.

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Box 8 ■ SWOT analysis of South Africa’s CSP sector: Industry, research and deployment perspectives

Strengths

1. Globally competitive local manufacturing, especially in the automotive industry
2. Experience in constructing major energy plants
3. Production of concentrated solar power (CSP) components to global standards, with some exports
4. Strong local CSP research and development (R&D) output
5. Presence of a well-established construction industry and international CSP projects

Weaknesses

1. R&D lags relative to that in the global leaders
2. Local industrial R&D and productivity are lower than in other countries leading in CSP
3. High local costs for the materials for CSP components
4. Limited CSP-specific skills and training programmes
5. Costly transportation for imported components
6. Unstable political commitment to renewable energy

Opportunities

1. Ideal solar resource conditions for CSP
2. Government support for high local content in CSP projects
3. Potential for integrating CSP with existing power infrastructure
4. Opportunity to lead in CSP technology due to its nascent stage
5. Potential for exporting to other African countries with strong solar resources
6. Willingness for international co-operation and technology transfer

Threats

1. Financial challenges due to foreign investors’ preference for established technologies
2. Restrictive qualification criteria for local CSP bids
3. Low CSP capacity allocation in government energy plans
4. Competition from manufacturers in regions with less solar resources
5. Uncertainty regarding CSP’s future due to political and policy instability
6. Rapid advancement in and cost reduction for competing renewable technologies

Note: SWOT = strengths, weaknesses, opportunities and threats.

CSP’s inherent advantages, including its capability for dispatchable energy and the prospect for significant local content generation, present as yet untapped potential within South Africa’s energy market. Although the current market structure has not fully recognised these benefits, they hold considerable potential for integration as the technological and economic landscapes evolve.

To increase CSP’s economic feasibility, South Africa may need to update regulations to more accurately reflect the value of CSP’s dispatchability. Incentives specifically for local job creation and promoting industrial development could be crucial for stimulating the domestic CSP market. Such measures would facilitate faster establishment and growth of CSP facilities, in turn aiding in the country’s pursuit of energy diversity and security.

South African enterprises are well positioned to utilise the country’s extensive solar resources and develop expertise in CSP to establish a formidable global presence. Technological advancements, along with a favourable geographic and economic environment, are anticipated to shape the trajectory of the CSP industry within South Africa and, potentially, throughout the African continent.

5. CONCLUSIONS AND RECOMMENDATIONS

The socio-economic advantages of renewable energy are now a central consideration in advocating for its widespread implementation. Governments recognise renewable energy's potential to drive sustainable economic development, create jobs and improve societal welfare through strategic investment. A number of measures are essential to support sustained CSP deployment:

- **Establishing clear renewable energy targets.** A transparent and long-term perspective on market development trajectories must be provided. When paired with suitable deployment policies, these targets foster a stable and predictable investment climate.
- **Definition of specific targets for dispatchable renewable technologies.** Either in addition to or in combination with the previous targets, conventional baseload plants will have to be replaced to achieve high renewable energy penetration ratios, and this is essential for feasible full decarbonisation scenarios.
- **Mandating local content and incentivising domestic procurement.** Local content requirements, which stipulate a minimum percentage of locally sourced materials and labour for CSP projects, promote industrial growth and job creation, with a specific focus on women and other discriminated groups of society. Complementing these requirements, government incentives can encourage local procurement, for example, through tax reliefs or other benefits for firms prioritising domestic sourcing.
- **Cultivating local supply chains.** Fulfilling local content stipulations requires strengthening local supply chains. Interventions increasing domestic firms' competitiveness, for example, industrial upgrade and supplier development programmes, are vital in this context. These measures should be supported by collaborations for technical assistance, financial incentives and technology transfer.
- **Targeted financing and investment incentives.** Financing options provided by governments, including concessional loans or grants, are essential to spur growth of the CSP industry. Investment incentives and tax breaks for entities investing in CSP further stimulate local industry development.
- **Encouraging innovation and R&D.** Advancing innovation and R&D within domestic industries maximises local value. This can involve government funding for sector-specific R&D and the cultivation of local innovation ecosystems through research institutes and incubators. One example would be the Chinese R&D tax deduction mechanism, which allows companies to deduct a significant portion of their R&D costs from their taxable income.
- **Facilitating technology transfer and knowledge exchange.** Active technology transfer and knowledge exchange are required to enable local industries to stay abreast of CSP advancements. Collaborations with international bodies can help the local workforce up-skill itself and local firms become technologically empowered.
- **Community engagement in planning and decision making.** Inclusive involvement of local communities in CSP project planning fosters broader support and equitable distribution of benefits. Governments should implement consultation mechanisms and educate communities on the benefits and risks of CSP. In addition, education and training, which are crucial for addressing skill shortages, must match the skill demands of the CSP sector so that local employment prospects, especially for women and other groups who face long-standing discrimination, are improved and systemic barriers are broken down, in turn promoting greater justice and inclusion, and creating equitable opportunities for all.

In summary, CSP deployment holds tremendous potential for local value creation. Realising this potential hinges on establishing policies that nurture local industry growth, foster innovation and engage communities. Such strategic policy making can ensure that the socio-economic benefits of CSP projects are widely distributed and can support the long-term sustainability of renewable energy initiatives. Further, as stated earlier, the potential of commercial CST systems to be used for process heat and fuel production is yet to be realised, along with the benefits it promises, across many countries.

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