TRANSFORMATIONAL CHANGE IN CONCENTRATED SOLAR POWER

TRANSFORMATIONAL CHANGE CASE STUDY - AUGUST 2021

CIF CLIMATE INVESTMENT FUNDS

ACKNOWLEDGEMENTS

The case study was prepared by Carlos Márquez from ATA Insights and Matthew Savage from Oxford Consulting.

This case study was sponsored by the Climate Investment Funds (CIF) and supported by a team, comprising Anna Williams, Daniel Morris, Joseph Dickman, Michael Ward, Regan Smurthwaite and Sarah Moin. The report benefited from the review of Tim Larson (Ross Strategic).

The case study team would like to thank the 10 experts who were interviewed for this case study: Abderrahim Jamrani (Masen), Abdulhamid Al Muhaidib (ACWA Power), Atanu Das (ACWA Power), Carlos Arenas (Enel, former Regional Secretary at Northern Chile region), Dana Younger (formerly at the IFC), Jonathan Walters (formerly at the World Bank), Luis Crespo (formerly at ESTELA), Pancho Ndebele (Emvelo), Silvia Pariente-David (formerly at the World Bank), and Zuzana Dobrotkova (World Bank).

DISCLAIMER

Please send any questions or comments about this study to ciftclp@worldbank.org.

Graphic design by Andrea Carega and Karlien Truyens.

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EXECUTIVE SUMMARY

Concentrated Solar Power (CSP) is a technology that uses mirrors to concentrate solar radiation to generate heat. This heat is then used to generate steam that drives a turbine whose kinetic energy is converted into electricity. CSP plants can integrate thermal energy storage (TES) to provide stable power output when needed, even at night-time or during cloudy periods. In this regard, CSP is more flexible than most forms of renewable energy (RE) .

Since 2009, the Climate Investment Funds (CIF), through the Clean Technology Fund (CTF), and in collaboration with national governments and multilateral development banks (MDBs), have provided concessional financing to CSP projects in Morocco and South Africa, as well as contributed to a CSP project in Chile. CTF-supported CSP projects represent approximately one gigawatt (GW) of CSP deployments, out of a total of six GW deployed globally.

Between 2009 and 2012, CSP was identified by local governments, MDBs, and CTF as a technology with transformational potential, based on five main reasons:

- Replication potential in the hundreds of GW across many countries with high levels of strong uninterrupted sunlight;
- CSP's ability, thanks to TES, to provide clean energy 24/7 to displace polluting generation technologies, such as coal (particularly in South Africa);
- Local jobs and business creation potential with high levels of component manufacturing locally;
- Potential for countries [particularly in the Middle East and North Africa (MENA) region] to export energy to Europe; and
- Reduction of fuel imports to bolster energy security and lower fiscal pressure (especially in Chile and Morocco).

Despite these advantages, CSP still faced significant barriers, including high costs compared to fossil alternatives, a lack of track record, and high costs of financing, thereby making it a good candidate for concessional financing.

When first deployed in 2009 with the intention of providing RE during the day, CSP was cheaper than solar photovoltaic (PV) technology. By 2021, the role of CSP has changed. In areas with good solar resources, PV has become the cheapest form of energy generation. CSP with TES is now used to provide RE during the evenings and nights, in areas with high levels of direct normal irradiation (DNI). The flexibility and dispatchability of CSP with TES enable variable renewables, such as PV and wind, to have a higher penetration rate.

Since 2017, CIF has, through the Transformational Change Learning Partnership (TCLP), developed a framework for understanding the dimensions and signals of transformational change. This case study analyzes the experiences of CTF in supporting CSP projects, with the intention of drawing lessons to enhance the transformational impacts of future investments. When applying the Transformational Change framework to these experiences, it is important to recognize that, when the initial CTF Investment Plans that considered CSP projects were published, between 2009 and 2012, the Transformational Change framework had not yet been developed. The intention, therefore, is not to evaluate CTF-supported CSP projects against the transformational change criteria, but to use the Transformational Change framework to reflect on and learn from the CSP projects.

CTF-supported CSP projects show signals of change across the five interrelated dimensions of the Transformational Change framework: relevance, systemic change, speed, scaling, and adaptive sustainability.

On the relevance dimension, CTF's CSP projects were conceived, designed, and implemented to maximize the possibility of transformational outcomes. CSP projects, supporting decarbonization objectives, were embedded in national RE deployment programs. They were carried out after extensive consultations with key stakeholders and co-designed with regional MDBs.

From the systemic change perspective, the CTF-supported CSP projects contributed to substantial shifts in technologies, institutions, and behaviors. They helped address key barriers to change, such as the lack of a track record, by supporting the deployment of around one GW of CSP capacity in Morocco and South Africa. The deployments demonstrated the value of the technology and supported the reductions in the cost of CSP. This change is exemplified by the difference between the renewable energy feed-in-tariffs (REFIT) granted to early projects in Spain in 2008—approximately USD 0.40 per kilowatt-hour (kWh)—and the USD 0.07 cents per kWh granted recently to the Dubai Water and Electricity Authority's (DEWA) 950 CSP-PV and Morocco's Noor Midelt I projects. The CSP projects also contributed to enhancing the institutional capacities required to carry out RE procurement in Morocco and South Africa.

From a scaling perspective, CTF-supported CSP projects mobilized approximately USD 7 billion in investments and contributed to multiple rounds of procurement within each target country. In Morocco and South Africa, CTF's interventions very likely accelerated the deployment of CSP plants by providing evidence relevant to the speed dimension of the Transformational Change framework.

There are also signs that demonstrate CSP's relevance to the dimension of adaptive sustainability. The emergence of CSP projects in China and the United Arab Emirates (UAE), as well as recent announcements in Spain, testify to the economic sustainability of CSP. From the societal standpoint, many CSP initiatives, notably in South Africa, have been designed to address past social and/or racial injustices by providing preferential employment opportunities to disadvantaged groups. CSP projects have also contributed to local economic development by achieving local content levels of 35–40 percent of total procurement. From the environmental point of view, CSP with TES has proven the value of dispatchable RE technologies in deepening the decarbonization of power generation and overall energy systems.[1]

However, the impact of CSP on greenhouse gas (GHG) emissions reductions and decarbonization remains limited, as only six GW have been deployed so far globally. CSP may still have a significant role to play, as the drive to decarbonize and the expansion of variable renewables increase the value of what dispatchable technologies, such as CSP with TES, can add to the system. Whether it can do so depends largely on if it can expand its competitive offering in terms of efficient energy storage and thus, provide RE for the evening peaks and night-time demand.

INTRODUCTION

OBJECTIVE OF THIS CASE STUDY

This case study looks at the Climate Investment Funds' (CIF) experiences in supporting Concentrated Solar Power (CSP) projects in Chile, Morocco, and South Africa, with the intention of drawing lessons to enhance the transformational impacts of future investments in the clean energy transition.

This case study explores how the role of CSP in tackling climate change has evolved since 2008. The transformational impacts of these projects, both within countries and globally, is assessed by considering change signals across the five dimensions of the Transformational Change framework: relevance, systemic change, scale, speed, and adaptive sustainability.

The analysis in this case study is based on extensive literature review and in-depth, semi-structured interviews with experts and officials directly involved in CIF-financed CSP projects.

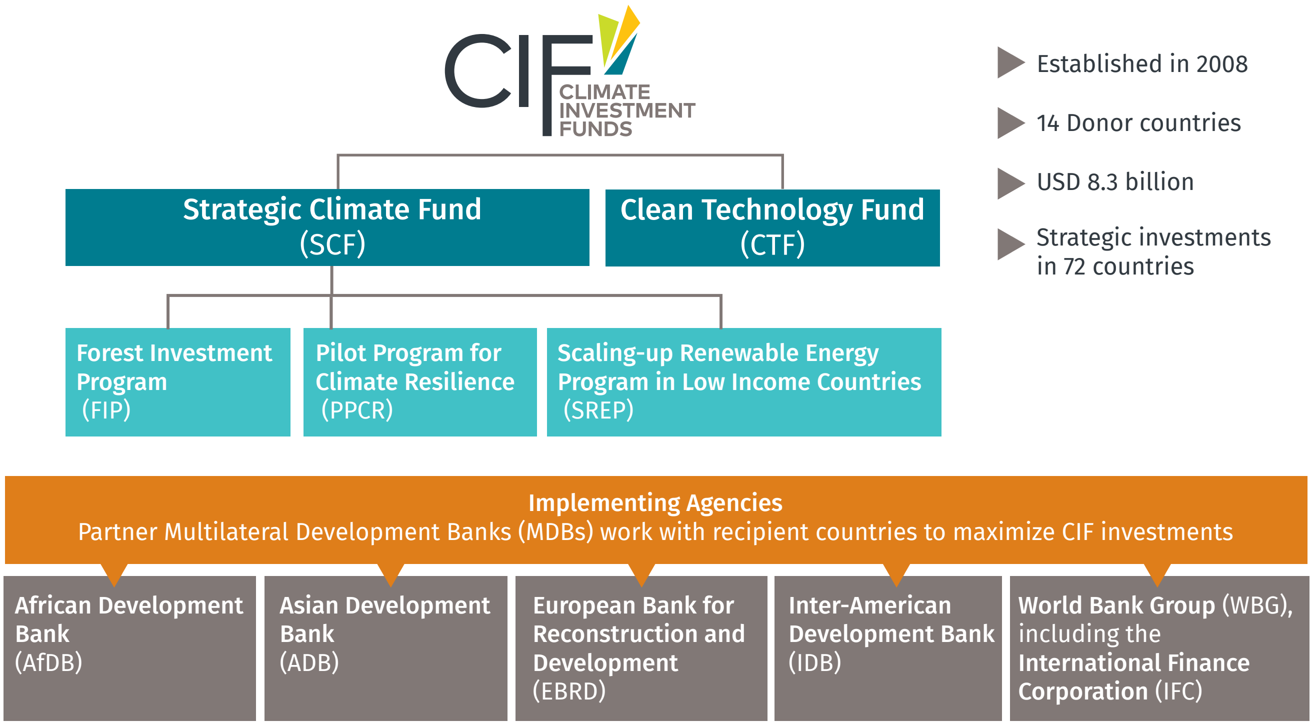
ABOUT THE CLIMATE INVESTMENT FUNDS

Since its inception in 2008, the USD 8 billion CIF has worked with local organizations, national governments, and multi-lateral development banks (MDBs) to finance projects that accelerate climate action across 72 developing countries.

By providing large-scale, low-cost, and long-term financing, CIF aims to lower investment costs and risks, thereby helping new technologies and unproven markets to establish a track record and foster investor confidence, in order to attract additional sources of financing.

CIF comprises two funds: the Clean Technology Fund (CTF) and the Strategic Climate Fund (SCF). CIF's investments in CSP were realized under the remit of CTF and implemented through MDBs.

Figure 1.
OVERVIEW OF THE CLIMATE INVESTMENT FUNDS



CTF (USD 5.4 billion) provides financing to bring to scale low-carbon technologies that have the potential to reduce carbon emissions in the long term (Itad, 2019). CSP is one such technology.

ABOUT THE TRANSFORMATIONAL CHANGE FRAMEWORK

The intention of CIF is to unlock and accelerate transformational change, which, in the context of climate change, can be defined as "fundamental change in systems relevant to climate action with large-scale positive impacts that shift and accelerate the trajectory of progress towards climate neutral, inclusive, resilient, and sustainable development pathways" (CIF, 2018). Transformational change often takes a long time, as it is the product of changes across different components of a system, which happen at different levels, ranging from the individual to the global scale. Additionally, progress towards transformational change tends to be non-linear.

The Transformational Change Learning Partnership (TCLP) identifies five interrelated dimensions of transformational change, which provide useful reflection points for learning when applied to CIF's CSP portfolio. These dimensions are set out below in the context of the decarbonization of power systems.

- **Relevance:** Ensuring alignment with prevailing power sector opportunities, particularly by addressing context-specific needs and barriers. This includes both identifying the most suitable low-carbon generation options (given potential advances in technologies and costs) and adapting to changes in the operating environment over time (e.g., as costs and demand profiles change). The transformation of the power sector should also contribute to wider social, economic, and environmental goals.

- **Systems Change:** Promoting fundamental shifts in the power system structures and functions. This can include addressing barriers (e.g., political, technical, institutional, operational, and financial) as well as building capacity and management approaches to support the uptake and deployment of new low-carbon energy technologies.

- **Scale:** Delivering contextually-large changes in power system structures. This involves the adoption and expansion of new low-carbon energy technologies at scale to meet a given demand profile in the most cost-effective way. Scale can refer to new installed capacity [e.g., gigawatt (GW)], reach (e.g., consumers), and/or enabling factors (e.g., scale of finance).

- **Speed:** Appropriately-timed power sector interventions catalyze and/or accelerate transformational change processes more quickly than would otherwise be the case. This requires support for the right technologies or investments at the right time and accelerating change at an appropriate pace for the given technology, market, and social systems, whilst recognizing the urgency of climate action.

- **Adaptive Sustainability:** Low-carbon power becomes the "new normal" in a resilient way. Investments in low-carbon generation are self-sustaining (i.e., not reliant on concessional support or other external dependencies). Low-carbon generation technologies are taken up by a broader set of constituencies (e.g., developers and policymakers). Systems learning (e.g., on social, environmental, and economic opportunities) continues over time.

TCLP recognizes that these dimensions are interlinked and proposes that all these dimensions should be present, to a greater or lesser extent, for a set of interventions to be truly transformational. Across each dimension of transformational change, TCLP employs signals as ways of recognizing progress toward transformational change in climate action.

THE URGENCY OF TACKLING CLIMATE CHANGE AND THE ROLE OF CSP

Through the Paris Agreement in 2015, the global community has indicated its acknowledgment of the need for greenhouse gas (GHG) emissions to be significantly reduced by limiting the rise in global average temperature to well below 2ºCelsius (C), preferably 1.5ºC, to avoid catastrophic climate change. Ensuring the rapid decarbonization of the power sector is a core pillar of achieving this goal. It is essential to replace fossil-fired plants with renewables, as the power generation sector accounts for a quarter of global GHG emissions (US EPA, 2020) and still relies overwhelmingly on fossil fuels (International Energy Agency, 2020).

Over the last decade, wind and photovoltaic (PV) have emerged as cost-competitive and mature renewable energy (RE) technologies, with over 1,200 GW of combined operating capacity worldwide (IRENA, 2020). They are often the most cost-effective energy generation technologies (Lazard, 2020), beating fossil-fired generation in most markets.

However, while these technologies have achieved significant penetration and cost advantage, their deployment is, to some extent, limited by the variable nature of their output. Specifically, PV and wind produce electricity only when the sun shines and the wind blows, respectively. This generation profile does not always coincide with the electricity demand (both intraday and seasonal). For this reason, it is not feasible for a power system to operate on wind and PV alone.

To achieve a low or zero carbon power system, it is necessary to combine different technologies that add flexibility to the system and can integrate a significant share of PV and wind without compromising on reliability. In this context, CSP with thermal energy storage (TES) has emerged as a viable dispatchable RE technology in areas with high solar resources.

BACKGROUND

BRIEF INTRODUCTION TO CONCENTRATED SOLAR POWER WITH THERMAL ENERGY STORAGE

CSP is a technology that uses mirrors to concentrate solar radiation to generate heat. This heat is then used to generate steam that drives a turbine whose kinetic energy is converted into electricity. CSP plants normally integrate a TES system to provide stable power output when needed, even at night-time or during cloudy periods. In this regard, CSP is more flexible than most forms of RE.

CSP is viable in areas with plentiful, direct sunlight, uninterrupted by clouds or atmospheric aerosols. Direct normal irradiation (DNI) is used as a measure for this type of sunlight.[2] The minimum DNI threshold for CSP is commonly established at around 2,000 kWh per square meter (m^2) per year. The best solar resources are found in the Atacama Desert in Chile, reaching levels as high as 3,800 kWh per m^2 annually. Many locations across the sunbelt have optimum solar resources for CSP, including sites on the Andean Plateau, Australia, the Middle East, North Africa, North America, Sub-Saharan Africa, and Western China.

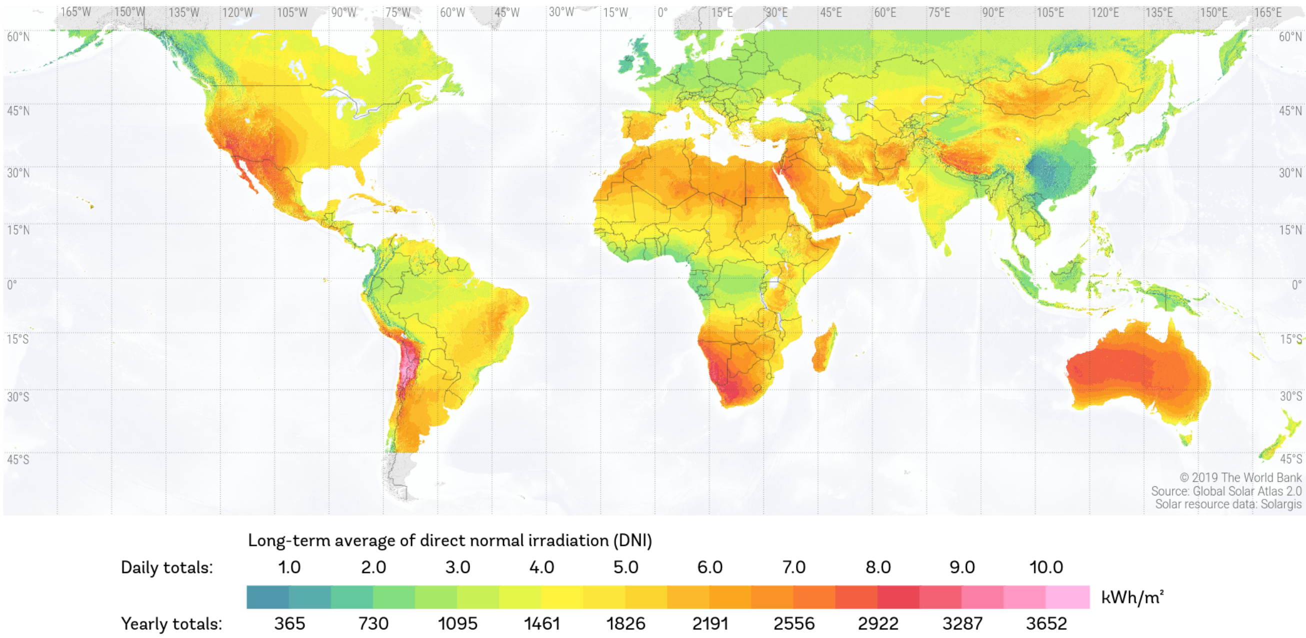
There are two main types of commercial CSP technologies: parabolic trough and tower.

Parabolic trough technology involves rows of parabola-shaped mirrors that focus sunlight on a tube at the center of the parabola. This is the most established and widely-deployed CSP technology in the world, accounting for more than 80 percent of the global capacity.

In CSP tower technology, heliostats or movable mirrors focus sunlight onto a single, elevated receiver in the middle of the solar field. CSP towers can achieve higher temperatures and better operating efficiencies than parabolic trough plants. However, the design is technically more complex than the parabolic trough.

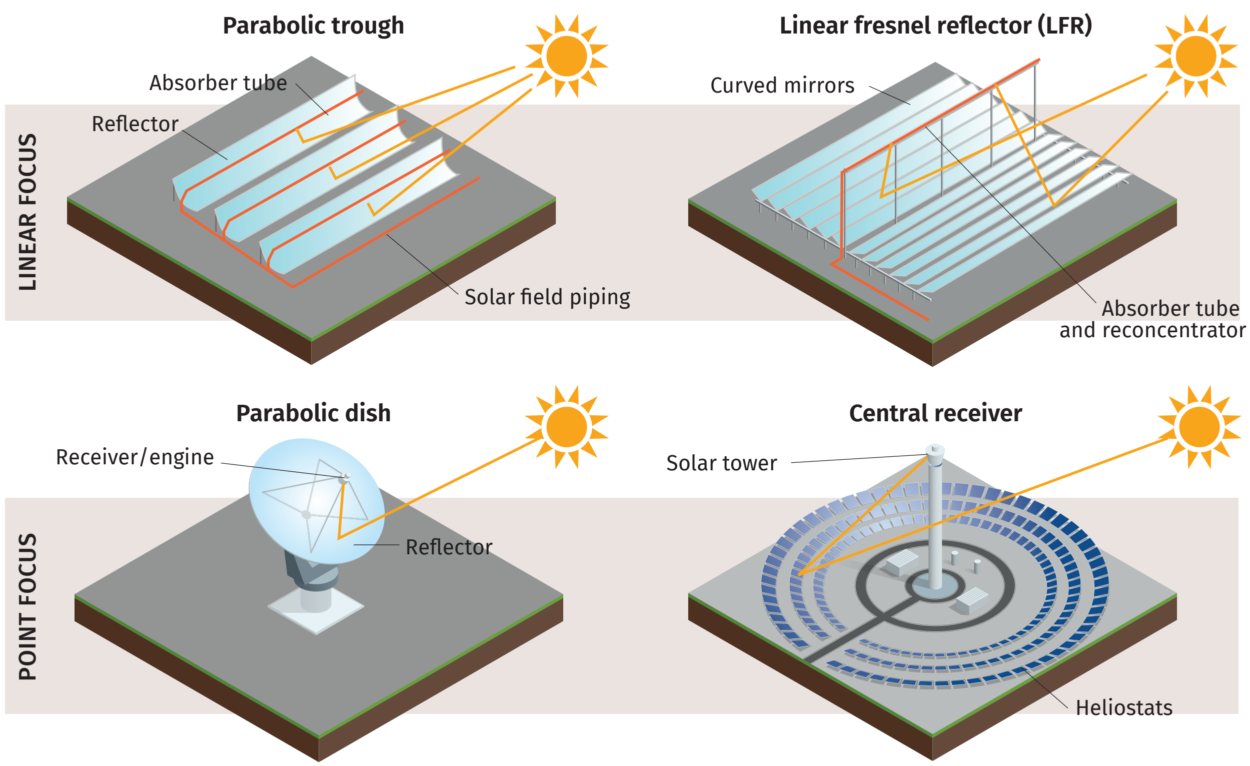
Although two other CSP concepts, Linear Fresnel and Dish, had shown promise in the early 2000s, they failed to achieve significant levels of commercialization.

Figure 2.
DIRECT NORMAL IRRADIATION MAP



Source: Global Solar Atlas 2.0 (World Bank Group, 2019)

Figure 3.
FOUR TYPES OF CSP TECHNOLOGY

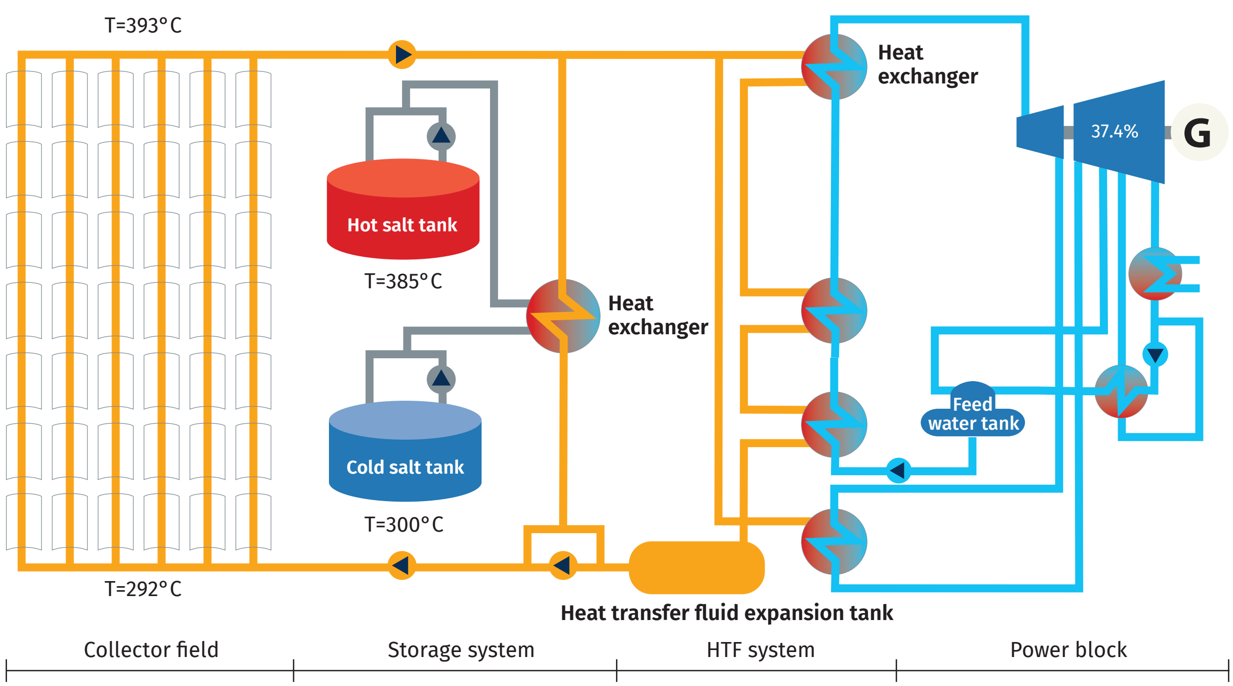


Source: World Bank, 2021

CSP plants with TES can store energy in the form of heat for long periods of time with minimal losses. This heat is then harnessed to generate electricity when required, for example, at night-time or during cloudy periods. Hence, CSP with TES can be considered a dispatchable RE technology.

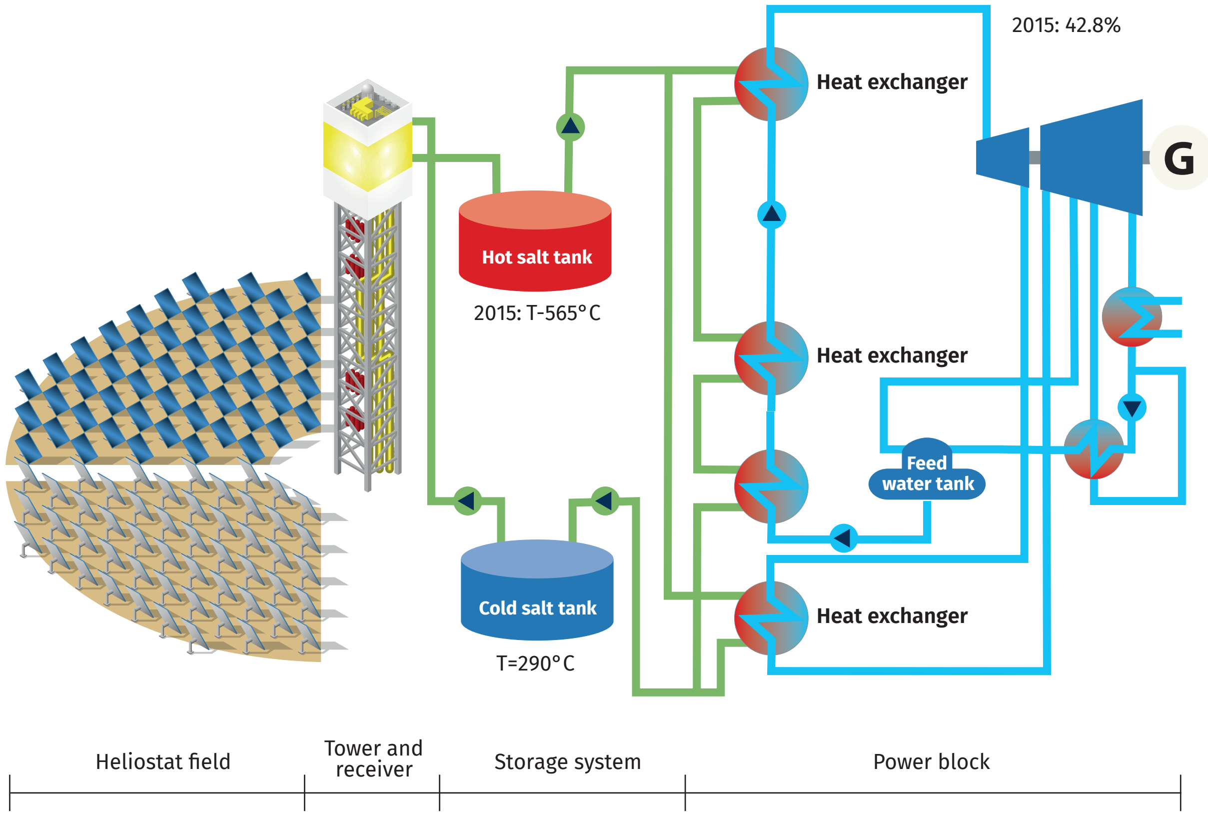
CSP with TES generally uses molten salt—a mixture of 60 percent sodium nitrate ($NaNO_3$) and 40 percent potassium nitrate (KNO_3)—as a storage medium. Although there are several concepts, all commercial CSP plants, designed to store energy for multiple hours, employ a two-tank configuration. A two-tank TES system has a tank for hot molten salts and another for cooler molten salt. The cooler salt is pumped to the solar receiver, where it is heated by concentrated radiation. Once heated, the salt is pumped to the hot tank, where it can be stored or deployed to produce steam for electricity generation. The salt exits the steam generator at a lower temperature and returns to the cold tank. The terms, "cold salt" and "cold tank", are relative: in practice, the salts require a minimum temperature of 260°C to remain in the liquid state and become solid under 230°C. The diagrams of both the parabolic trough CSP and tower CSP, with two-tank TES, are shown in Figures 4 and 5, respectively.

Figure 4.
PARABOLIC TROUGH CSP WITH TWO-TANK THERMAL ENERGY STORAGE SYSTEM (TES)



Source: Adapted from IRENA
Note: The heat transfer fluid, shown in orange, is thermal oil; the storage medium, shown in gray, is molten salt. The water/steam circuit is in blue. HTF= heat transfer fluid. G= Generator.
See the CSP animation at https://youtu.be/T-TpX9y-fkM

Figure 5.
TOWER CSP WITH TWO-TANK THERMAL ENERGY STORAGE SYSTEM (TES)



Source: Adapted from IRENA, 2016
Note: Molten salts, shown in green, serve as the heat transfer fluid and storage medium. The water/steam circuit is in blue. G= generator

As discussed in the following section, the ability to supply dispatchable power that CSP with TES provides grows in value, as the share of variable RE from PV and wind increases.

THE EVOLVING ROLE OF CSP IN THE ENERGY SYSTEM

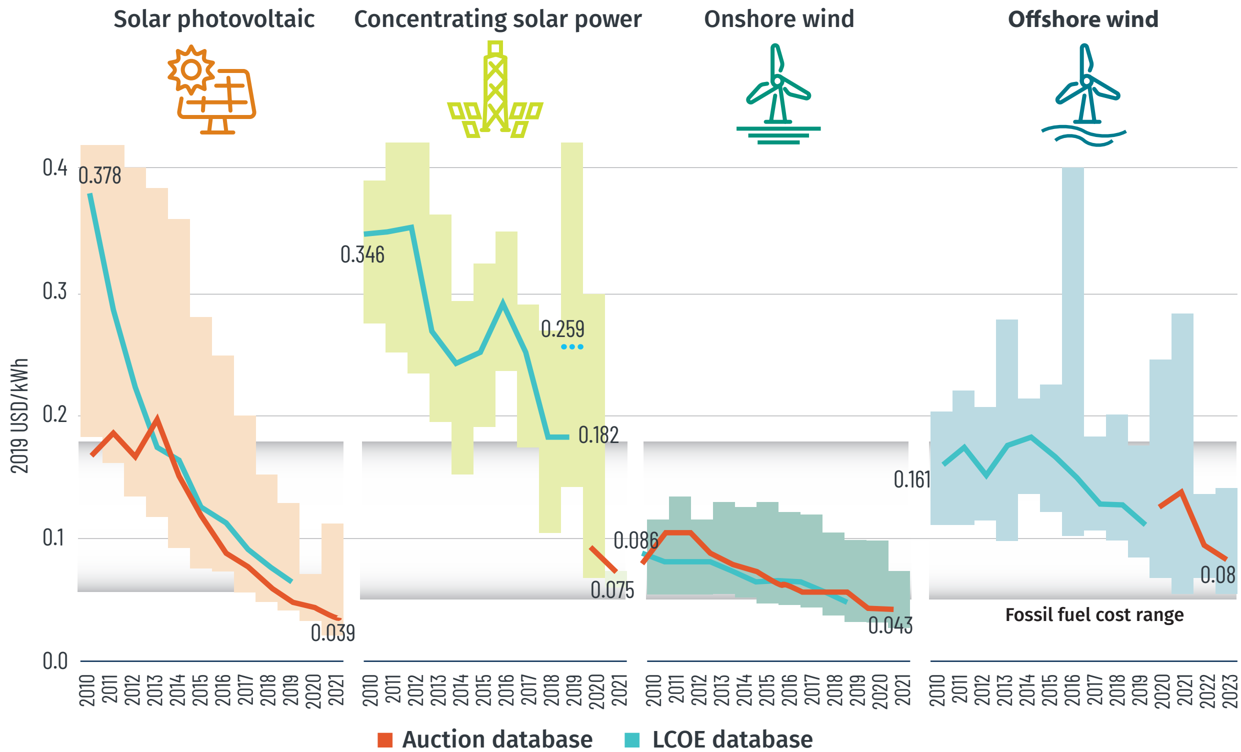
The role of CSP technology has evolved since the mid-2000s, when CSP was first seen as a way to simply add renewables to the grid in places with high levels of DNI. Currently, the main value of CSP lies in its ability to store energy to meet demand during evening and night-time peaks.

In the mid-2000s, the cost of most RE technologies, including PV and wind, was considerably higher than most fossil-fired technologies. Prompted by concerns over man-made climate change and energy security, governments of many developed countries subsidized RE. The objective of these subsidies was to create enough demand to justify higher production volumes, thus lowering costs. Higher deployments were also expected to lead to faster technological improvements and higher efficiencies, as companies across the RE supply chain tried to outcompete each other on price and performance.

During this phase, the levelized cost of electricity (LCOE)[3] of CSP without TES was lower than that of utility-scale PV. TES technology was available, but its added value was often considered to be unjustifiable vis-à-vis the additional investment it entailed. For this reason, many plants built in Spain and the United States (U.S.) between 2007 and 2015, 3.7 GW on aggregate, did not include TES.

Figure 6.

GLOBAL WEIGHTED AVERAGE LEVELIZED COST OF ENERGY (LCOE) AND AUCTION/PPA PRICES FOR SOLAR PV, CSP, ONSHORE AND OFFSHORE WIND



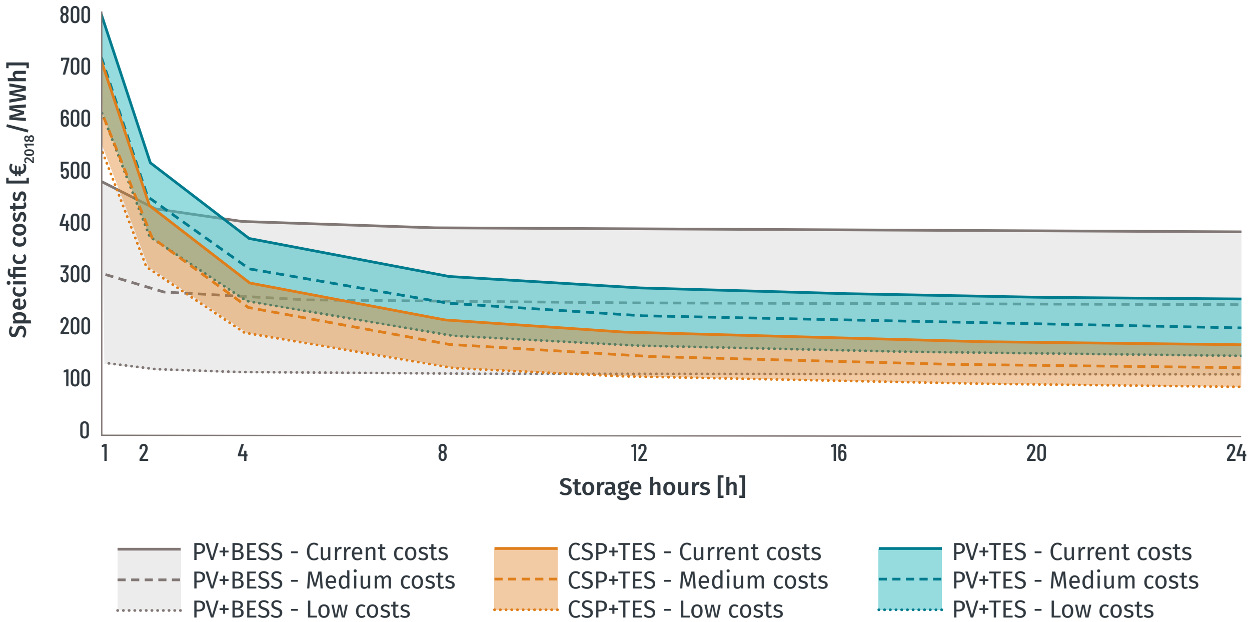
Source: IRENA, 2020

Note: The thick lines are the global weighted average LCOE, or auction values, by year. The gray bands, which vary by year, are the cost/price range for the 5th and 95th percentiles of projects. For the LCOE data, the real weighted average cost of capital is 7.5% for China and members of the Organisation for Economic Cooperation, and Development, and 10% for the rest of the world. The band that crosses the entire chart represents the fossil-fuel-fired power generation cost range. For CSP, the dashed blue bar in 2019 shows the weighted average value including projects in Israel. CSP= concentrating solar power; LCOE= levelized cost of electricity; PPA= power purchase agreement; USD/kWh= US dollars per kilowatt-hour. .

However, the plummeting costs of PV have changed this situation. Between 2010 and 2019, the LCOE of PV decreased by 82 percent—from USD 0.38 per kWh in 2010 to USD 0.08 per kWh in 2019 (IRENA, 2020). Today, for projects built in areas with high solar resources and low-cost financing, PV offers the cheapest electricity in history, according to the International Energy Agency (IEA, 2020). During the same period, the weighted average LCOE of CSP also decreased by 47 percent. Given that only six GW have been deployed in total, there is room for further cost reductions (Taylor, 2020). Nonetheless, the cost advantage is on the side of PV: the cheapest power purchase agreement (PPA) for a CSP project is USD 0.07 per kWh, whereas PV plants have consistently been awarded PPAs of between USD 0.02 and USD 0.03 per kWh, and even as low as USD 0.01 per kWh.

Because of their low costs, PV and wind are widely deployed. They form the backbone of most RE expansion plans. However, these sources of energy are variable, which means that they only produce electricity when the respective resource inputs of sunshine and wind for PV and wind power are available. The problem is that these production patterns may not match demand. Furthermore, in the absence of flexible assets, storage, or suitable regional interconnectors and power trading, when RE supplies exceed demand, then either renewables must be curtailed or baseload power generation assets, generally fossil-fired plants, must be taken offline to make way for renewable generation. Both options negatively affect the economics of energy production. This problem is expected to become even more acute, as the share of variable RE grows.

Figure 7.
POTENTIAL EVOLUTION OF THE COSTS OF THREE COMPETING FLEXIBLE RENEWABLE TECHNOLOGIES

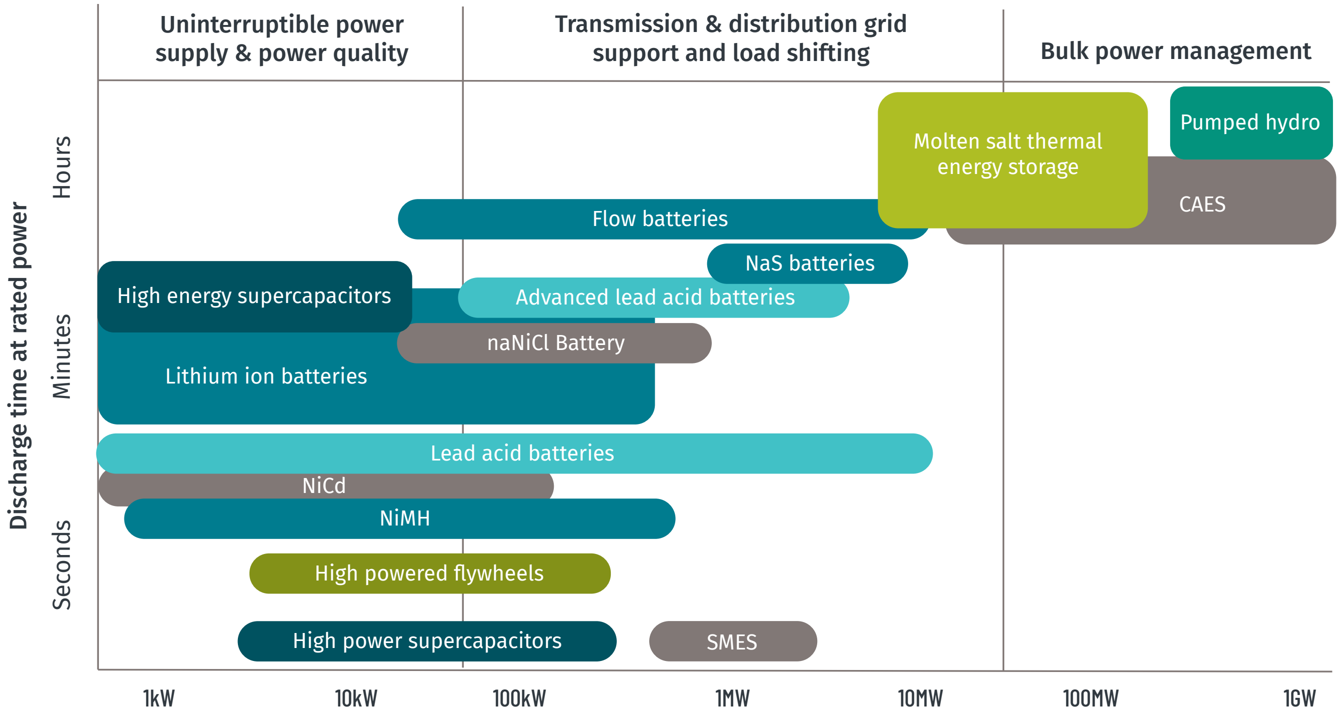


Note: The specific costs of increasing storage hours for PV+BESS, CSP+TES, and PV+TES in three cost scenarios. PV+BESS is always the most economical solution for short storage times. CSP+TES becomes competitive after 2–3 hours (h) (current cost) and 4–10 h (future cost projections). Source: Schöniger, Thonig, Resch, & Lilliestam, 2021

The added flexibility of CSP with TES helps the system to better manage the peaks and troughs of variable renewables. When PV production is at its peak, typically at midday, CSP with TES can stop dispatching electricity whilst storing energy in the form of heat. CSP with TES can then supply the electricity, as PV output declines progressively throughout the evening. This flexibility enables the grid to effectively utilize greater shares of variable renewables. Additionally, TES systems can store excess electricity output from variable renewables through the inclusion of reheaters, thus further minimizing curtailment (Crespo, 2020). Reheaters are part of the design of the Midelt I plant, which includes both CSP and PV with molten salt TES. It has also been suggested that the TES component of CSP plants can be used as a strategic reserve to supply RE during the days of highest demand in the year, which usually happen during the coldest winter days. Once stored in TES tanks, heat can be kept for many days with losses of only one degree °C per day, thereby allowing the system to keep the energy in reserve for days of low sunshine availability (Crespo, 2020).

CSP with TES is not the only way to store energy; another option is to couple PV with battery energy storage systems (BESS). Under current conditions, CSP with TES is more cost-competitive than PV with BESS for storage periods between four and 10 hours, whereas the opposite is true for shorter storage durations of up to three hours, according to a recent study entitled “Making the Sun shine at night” (Schöniger, Thonig, Resch, & Lilliestam, 2021). These findings are consistent with a 2016 study by the US National Renewable Energy Laboratory (NREL) (Feldman, Margolis, Denholm, & Stekli, 2016). However, as technologies keep on developing, which storage solution will be more cost-effective will depend on the rate of learning within a wide range of storage technologies.

Figure 8.
ENERGY STORAGE TECHNOLOGIES AND THEIR APPLICATIONS



Source: World Bank, 2021

To achieve a power system that is both low-carbon and resilient, a number of renewable generation and storage technologies must be deployed to minimize curtailment, meet demand at different times, and cover a variety of circumstances. Relying on PV and wind alone would not lead to a deeply-decarbonized energy system in most circumstances because it would, in all likelihood, result in high levels of curtailment and require a significant fossil fuel component. For this reason, new inductive project planning methodologies consider not only the cost of each individual technology, but also the overall system costs, in achieving a low-carbon energy system (Bonilla & Crespo, 2020). The precise technology mix that leads to the lowest GHG emissions at the lowest cost, whilst maintaining reliability of supply, depends on the resources available and electricity demand profiles.

Different storage technologies could play a role in achieving such a system. For example, most BESS can typically store tens of MW for up to four hours and are suitable for uses, such as frequency regulation that requires a fast response. At the other end of the spectrum, pumped hydro can be used for shifting load from one part of the day to another, because it can store GWs' worth of energy for days. In turn, in countries with high levels of DNI, CSP with TES has emerged as a valuable technology to meet evening and night-time electricity demand. It is in this capacity that future CSP deployments are expected.

Figure 8 shows the different uses of each storage technology, depending on their capacity and discharge time at a given rated power.

CTF INVESTMENT IN CSP

CIF has been a leading supporter of the demonstration and scaling of CSP technology across a number of countries. Several CSP projects have received CTF funds, most notably Noor Ouarzazate I, II, and III [510 megawatts (MW)] in Morocco, along with Xina (100 MW), Kaxu (100 MW), and Khi (50 MW) in South Africa (see Table 1).

Additionally, through dedicated regional and country programs, CTF has financed technical assistance and knowledge exchange initiatives related to CSP.

INITIAL RATIONALE FOR INVESTING IN CSP

Between 2009 and 2012, CSP was identified by local governments, MDBs, and CTF as a technology with transformational potential, due to five main reasons:

- Replication potential in the hundreds of GW across many countries with high levels of strong uninterrupted sunlight;
- CSP's ability, thanks to TES, to provide clean energy 24/7[4] to displace polluting generation technologies, such as coal (particularly in South Africa);
- Local jobs and business creation potential with high levels of component manufacturing locally;
- Potential for countries (particularly in the MENA region) to export energy to Europe; and
- Reduction of fuel imports to bolster energy security and lower fiscal pressure (especially in Chile and Morocco).

Despite these advantages, CSP still faces significant barriers, including high costs compared to fossil alternatives, a lack of track record, and high costs of financing, thereby making it a good candidate for concessional financing.

This section outlines each of these points and presents country case studies. In addition, a discussion of the impacts of these investments, from the point of view of transformational change, is conducted with regards to each country case study.

Table 1.
CTF-FINANCED CSP PROJECTS

NAME OF PROJECT (APPROVAL DATE)	**PARTNER MDBS**	**PROJECT, SIZE, AND COMMERCIAL OPERATION DATE**	**STATUS**	**CTF FINANCING** (USD MILLION)	**CO-FINANCED BY PARTNER MDBS AND OTHER INSTITUTIONS**	**TOTAL COST** (USD MILLION)
Sustainable Energy Acceleration Program (SEAP) (2010; 2013)	African Development Bank (AfDB) & International Finance Corporation (IFC)	Xina CSP 100 MW, Parabolic Trough, South Africa	Operational since 2018	44	147	**649**
		Kaxu CSP 100 MW, Parabolic Trough, South Africa	Operational since 2015	42	200	**1,300**
		Khi CSP 50 MW, Tower, South Africa	Operational since 2016			
Middle East and North Africa (MENA) CSP Scale-up Initiative	AfDB & International Bank for Reconstruction and Development (IBRD)	Noor Ouarzazate I 160 MW, Parabolic Trough, Morocco	Operational since 2016	197	964	**1,438**
		Noor Ouarzazate II 200 MW, Parabolic Trough, Morocco	Operational since 2018	238	1,352	**1,900**
		Noor Ouarzazate III 150 MW, Tower, Morocco	Operational since 2018			
		Noor Midelt 800 MW, PV-CSP hybrid, Morocco	Due to reach financial close in 2021 on a 30-month schedule.	25	626	**802.25**

Sources: (CIF, 2020), (World Bank, 2013), (World Bank, 2015)

REPLICATION POTENTIAL ACROSS MANY COUNTRIES WITH HIGH LEVELS OF DNI

As proposed at the time, many sites around the world had the requisite levels of solar resources and land availability to host substantial quantities of technically-viable CSP plants. For example, Eskom, the state-owned power utility, estimated that South Africa could potentially host 40 GW of commercial CSP plants. This capacity could be doubled or trebled by considering the potential of neighboring Namibia and Botswana (CIF, 2009). The Third Update Note of the CTF Investment Plan for MENA also estimated that the MENA region could host "several hundred GW" of CSP (CIF, 2014). Aside from MENA and Sub-Saharan Africa, CSP could be deployed across vast areas of the Andean Plateau, the Tibetan Plateau and Central Asia, North America (particularly across the southwestern U.S. states and northern Mexico), along with Australia.

One of the goals of investing in CSP was to trigger a demonstration and replication effect across countries with high levels of DNI. The logic behind this strategy was that the successful completion of a number of flagship CSP projects across the developing world would prove the value of the technology, thereby lowering perceived technology and project risks as well as increasing the likelihood that other countries would build CSP plants. The higher levels of CSP deployment would support lower costs through economies of scale, thus leading to a virtuous circle of greater demand.

PROVIDING CLEAN ENERGY 24/7 TO DISPLACE POLLUTING GENERATION TECHNOLOGIES, SUCH AS COAL

CSP can be designed to store large amounts of energy that can be deployed during the night or over cloudy periods. This makes CSP with TES a potential substitute for fossil-fired baseload generation.

The potential for CSP to displace coal, a particularly polluting fuel, was one of the main reasons why CTF financed CSP projects in South Africa. When the first CIF South Africa Investment Plan was published in 2009, South Africa's annual carbon dioxide (CO_2) emissions were about 10 tons per capita, the eighth highest in the world. Its power generation accounted for 70 percent of total CO_2 emissions, mainly because coal accounted for two-thirds of its energy generation (CIF, 2009).

Additionally, CSP with TES can cater to evening demand peaks (CIF, 2014), which are observed in many countries with high levels of solar irradiation. The ability to supply the evening peak demand with clean energy enhances CSP's potential for displacing fossil fuels.

CSP's capacity to dispatch when required by demand, even at night, could not be matched by either PV or wind in 2009, as utility-scale BESS were still far from the commercialization stage. In this context, CSP with TES offered a clear advantage, in terms of decarbonization potential.

LOCAL JOBS AND BUSINESS CREATION POTENTIAL

CSP is a greater catalyst of local job and local business creation than other RE technologies because much of the assembly work must be done on-site. Between 2007 and 2013, around 30,000 jobs were created in Spain by the deployment of 2.3 GW of CSP. Emvelo's Ilanga CSP 1 project in South Africa employed about 1,500 workers—85 percent of whom were locals—during peak construction (Hashem, 2018). Regarding local content, CSP projects in South Africa reported that around 40 percent of all components and services were purchased locally. This is in line with the threshold for local content requirements in the bid windows of the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). This could potentially be higher: up to 65 percent of all CSP-specific components could be sourced from South Africa due to a strong manufacturing base and local access to raw materials (Bhula, 2020).

The possibility of producing socio-economic benefits within the host country was also considered an advantage of CSP, compared to other RE technologies that are generally manufactured abroad and imported before the assembly of the parts on-site.

ENERGY EXPORTS TO EUROPE

CTF's MENA CSP Investment Plan (2009) considered the possibility of building a large number of CSP projects in the MENA region to export electricity to Europe as well as serve local demand. The rationale for this plan was that solar resources were better in MENA than in Europe, making the LCOE of CSP plants built in MENA lower. In order to achieve this aim, the investment plan made provisions for supporting interconnections between MENA countries as well as between MENA and Europe. The goal was to create stronger interconnections to increase the resilience of energy systems and boost the commercial gains of CSP projects in MENA by connecting them to a larger electricity market.

REDUCE FUEL IMPORTS TO BOLSTER ENERGY SECURITY AND REDUCE FISCAL PRESSURE

In the case of Morocco and Chile, which rely on fuel imports to supply most of their energy needs, developing RE offered them a way of reducing imports, boosting their energy security, and reducing the foreign currency drain caused by high fuel imports.

Fuel price volatility in international markets presents additional challenges to import-dependent countries. Often, countries that depend on imports for a large share of their energy needs struggle to keep domestic energy prices stable in the face of changing fuel prices in international markets. Building CSP plants and other RE technologies can thus provide a hedge against fuel price volatility.

DEPLOYING CONCESSIONAL FINANCE TO UNLOCK THE POTENTIAL OF CSP WITH TES

Four main barriers to the deployment of CSP were identified when the CTF investment plans for MENA and South Africa were first drafted:

- Higher overall electricity costs compared to the fossil-fired technologies it was trying to displace;
- High up-front capital costs, meaning that most of the investment must be made at the start of the project, with the returns generated only after many years of successful operation;
- A relatively limited track record of deployment, which increased perceived performance risks, thus making it difficult for CSP to obtain commercial financing at reasonable rates; and
- Knowledge gaps: CSP was relatively unknown in 2009 and had never been built on a large scale in either MENA or South Africa. This meant that the knowledge on how to select and procure CSP had to be acquired in these markets before any projects were built.

CTF investments were aimed at supporting the development of the first batch of large-scale CSP projects across developing countries with high solar resources. Concessional financing from CTF and other MDBs would lower the weighted average cost of capital (WACC) and draw financing from other multilateral institutions and commercial banks. Additionally, CTF funds would also be made available for providing technical assistance to recipient countries in order to establish the regulatory and managerial infrastructures required to run tenders for large-scale CSP projects. The resulting CSP projects would thus serve as successful examples, leading to replication across other markets. This would create a virtuous circle: more deployments would lead to lower costs, thanks to economies of scale and a faster rate of technological improvements—both of which would lead to the deployment of more CSP projects.

In the following section, the case study analyzes how these investments have played out in three relevant markets: Morocco, South Africa, and Chile.

CSP INVESTMENTS IN CONTEXT: THE CASES OF MOROCCO, SOUTH AFRICA, AND CHILE

MOROCCO

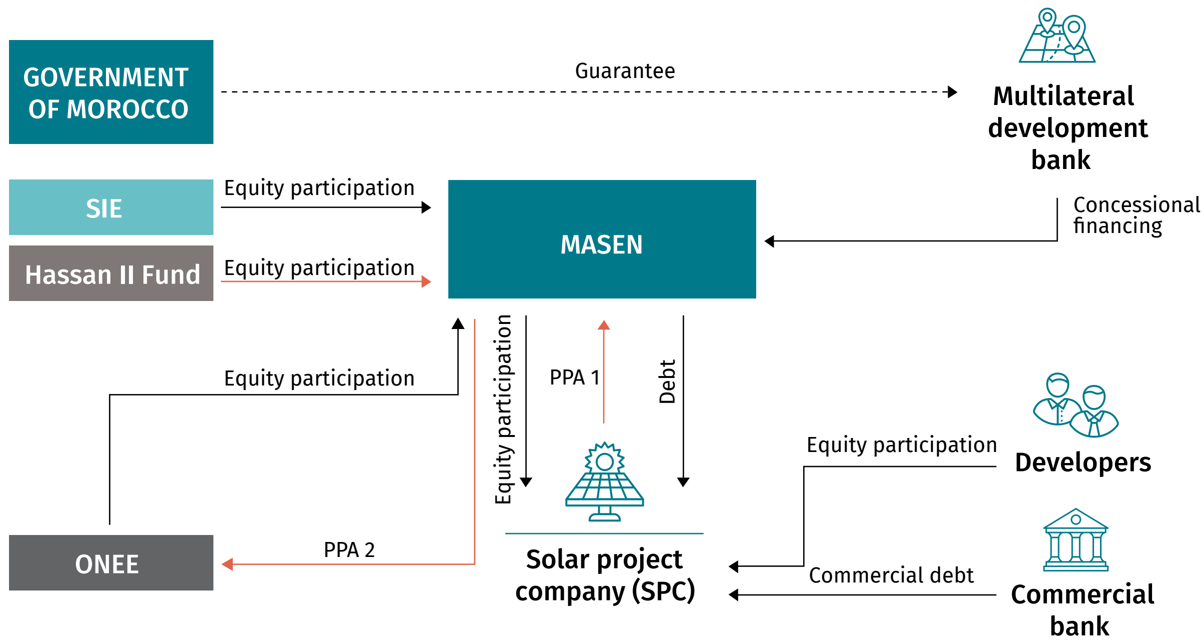
When the initial CTF investment plans for Morocco were approved in 2009,[5] the country was already implementing policies aimed at boosting the role of RE to meet growing energy demand, whilst mitigating dependence on fuel imports.

Between 2000 and 2006, electricity demand, underpinned by solid economic growth and a rising population, was increasing by 8.2 percent annually. Fossil fuels dominated the energy mix, accounting for 95 percent of the primary energy supply, with Morocco reliant on imports to meet 95 percent of its energy demands (CIF, 2009). Dependence on imports placed the government under significant fiscal strain, particularly as it tried to maintain affordable and stable prices for retail consumers in the face of high and volatile global energy prices.

To tackle these challenges, the government of Morocco developed the National Energy Strategy, published in 2009. This document established five main objectives: 1) optimize the energy mix in the power generation sector; 2) accelerate the deployment of RE; 3) promote private investments in the power sector; 4) prioritize energy efficiency; and 5) promote greater interconnections with neighboring countries (Schiko et al, 2019). In this policy document, the RE target was set at 42 percent of generating capacity by 2020.

Two RE plans—the Moroccan Solar Plan (MSP) and the Moroccan Integrated Wind Program—were launched to fulfill these targets. Both aimed to install two GW of solar and wind power, respectively. Additionally, the government announced investments in pumped hydro storage (one GW), transmission grid reinforcements, and gas-to-power projects (UN ESCWA, 2018).

Figure 9.
INSTITUTIONAL FLOW CHART FOR LARGE-SCALE SOLAR PROJECTS



Note: SIE is the acronym of Sociétés d'Investissements Energétiques (Energy Investment Company), created in 2010. Its name has been changed to Société d'Ingénierie Energétique.
Source: UN ESCWA, 2018

The Moroccan government also created a series of institutions to deliver these programs. One of them—the Moroccan Agency for Solar Energy (Masen)[6]—has played a central role in the development of solar energy in Morocco. It was established in 2010 to deliver the MSP.

One of the main missions of Masen is to deploy RE power plants through a public-private partnership (PPP) approach (Masen, n.d.). Under this approach, the developers of large-scale PV and CSP projects are selected through a bidding process. Once the winning developer is chosen, a solar project company (SPC) is created: both the developer (typically a consortium) and Masen will have equity in the project. The SPC signs a PPA with Masen at a set price, guaranteeing a stable revenue stream. The electricity is then resold to the national utility and grid operator—*Office National de l'Électricité et de l'Eau Potable* (ONEE)—at grid prices that are variable and lower than PPA prices. The Moroccan government then pays Masen the difference between the two contracts. In this setup, Masen also consolidates the concessional financing provided by international financial institutions (IFIs). Concessional financing is, in turn, backed by a sovereign guarantee (UN ESCWA, 2018).

The aim of this institutional framework is to encourage international and private sector participation in large-scale solar projects by reducing market risks and creating attractive investment potential.

As Morocco was scaling up its commitment to RE, the CTF Investment Plan for MENA-CSP was approved in December 2009. This USD 750 million-plan aimed to leverage an additional USD 5 billion in financing to fund the deployment of around one GW of CSP plants across Algeria, Egypt, Jordan, Libya, Morocco, and Tunisia, as well as two related interconnection projects (CIF, 2014). One of the main objectives of the plan was to demonstrate the potential of CSP to encourage replication projects that would produce dispatchable clean energy for domestic consumption and export into Europe.

However, the eruption of the Arab Spring in 2010 made it impossible for many of the participant countries to commit the financial and institutional resources required to build CSP projects. Additionally, the sovereign debt crises that affected Italy and Spain resulted in reduced energy consumption in these markets, therefore delaying the prospects of importing renewable power from MENA (CIF, 2014). As a result, although feasibility studies were carried out and potential sites were identified in several countries, Morocco was the only country in this program, which finally built CSP plants with support from CTF.

These plants are part of the Noor Ouarzazate Solar Complex (510 MW CSP and 70 MW PV): the CSP component, built in three phases, has been fully operational since 2019. These projects are considered a success on many fronts. Concessional financing from CTF and other institutions reduced the WACC[7] to four percent, significantly lower than commercial lending rates, and lowered the tariff by 20 percent (Walters, 2017). The PPAs signed for the Noor Ouarzazate projects have consistently been competitive and among the most affordable for CSP projects, whilst procuring approximately 34 percent of the components in Morocco (Hamane, 2020).

As the first CSP projects were being built, King Mohammed VI announced the New Energy Roadmap during the 21st Conference of the Parties (COP21) in Paris in 2015. This roadmap raised Morocco's RE targets to 52 percent of generating capacity by 2030, which would amount to approximately 12.9 GW.

Since 2016, with the enactment of Law 37-16, Masen has been placed in charge of managing the development of all the RE projects in Morocco. Additionally, Masen has signed agreements of cooperation with several African nations to further RE development in the region.

Regarding the prospects of furthering cross-border electricity trade between Morocco and Europe, the Sustainable Electricity Trade (SET) Roadmap was signed by France, Germany, Morocco, Portugal, and Spain at COP22. The SET Roadmap is a joint declaration of the countries' intention to progressively open their renewable electricity markets to one another, thereby making their overall national energy systems more robust. This initiative has been supported by CTF-funded studies and technical assistance under the World Bank MENA CSP Knowledge and Innovation Program.

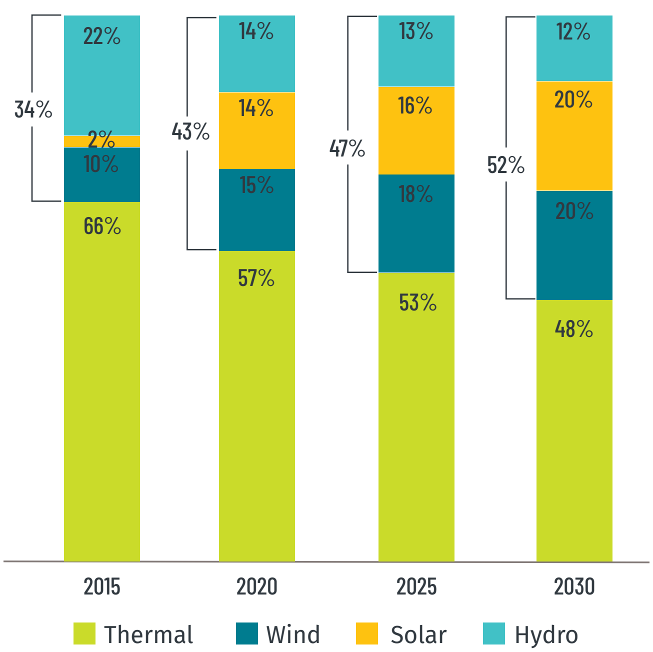
More recently, in 2019, an additional USD 25 million of CTF funds have been provided to the Noor-Midelt Project—an 800MW CSP-PV hybrid with five hours of storage capacity. The tender, won in May 2019 by a consortium led by *EDF Renouvelables*, in collaboration with United Arab Emirates' (UAE) renewables developer and operator Masdar and local partner Green of Africa, set a new benchmark of USD 0.07 per kWh for peak power dispatch. It was one of the lowest tariffs achieved by a CSP-PV hybrid project globally.

Table 2.
CHARACTERISTICS OF THE THREE CSP PLANTS OF THE NOOR OUARZAZATE SOLAR COMPLEX IN MOROCCO

	NOOR OUARZAZATE I	NOOR OUARZAZATE II	NOOR OUARZAZATE III
TECHNOLOGY	PARABOLIC TROUGH	PARABOLIC TROUGH	TOWER
Capacity [megawatt electric (MWe)]	160	200	150
Cooling	Wet	Dry	Dry
Thermal Storage (hours)	3	7 to 8	7 to 8
Annual Production [Gigawatt-hour (GWh)]	520	699	515
Surface area [hectares (ha)]	485	600	580
CTF Financing (USD millions)	197	238 for both NoorO II and NoorO III	
Tariff (USD/kWh)	0.189	0.14	0.15
Status	Operational	Operational	Operational

Sources: (Stitou, 2017), (Hamane, 2020)

Figure 10.
RENEWABLE ENERGY TARGETS IN MOROCCO (PERCENTAGE OF GENERATING CAPACITY)



Source: UN ESCWA, 2018

THE EXPERIENCE OF CSP INVESTMENTS IN MOROCCO THROUGH THE LENS OF TRANSFORMATIONAL CHANGE

Relevance:

The CTF investments in CSP are highly relevant and have contributed to transformational change towards a lower-carbon power generation system in Morocco. In terms of objectives, the investments have been clearly aligned with the government's aim of increasing the share of solar energy from almost zero in 2009 to 20 percent by 2030.

The intervention was designed with the energy needs of Morocco in mind, as the inclusion of TES at the CSP plants allowed these solar projects to supply evening and night-time demand. In 2009, when the government of Morocco, MDBs, and CTF came together to finance these projects, Morocco was paying USD 0.30 per kWh for its fuel-oil plants (Kramer, 2020). Compared to this price, the USD 0.18 per kWh of Noor I was considerably more affordable. Additionally, at the time of the development, CSP with TES was clearly the most cost-competitive solar technology that was capable of incorporating bulk storage to facilitate the dispatch of electricity whenever required. For long-duration storage (six hours plus), it remains so today, although PV, coupled with BESS, have improved their cost competitiveness.

With regards to mitigating reliance on energy imports, the investments in the Noor I, II, and III projects also supported this objective, as they have made the country more secure and lessened the burden of imports on its public finances. This is a highly relevant objective in the case of Morocco that had relied on imports for over 90 percent of its energy needs.

The creation of Masen by the government of Morocco to manage RE projects and the risk-mitigating structure created around the CSP projects show that key institutions and stakeholders should be mobilized to support the development of such projects.

Systemic change:

There are several signals in Morocco that suggest progress towards transformational change at the systemic level. From a practical standpoint, the Noor Ouarzazate projects were divided in three stages precisely so that the lessons learned could be applied to new stages. Lessons learned locally, as well as those garnered by developers and EPC contractors in international markets, have contributed to lowering PPAs from around USD 0.18 per kWh for Noor Ouarzazate I, the first large-scale CSP project in Morocco, to around USD 0.07 per kWh for the latest project of this kind announced in Morocco, the Midelt I CSP-PV project. The Midelt I project is also an example of innovation: it is the first project that will store energy from PV in molten salt tanks through an electric heater and store energy from CSP. Hybridizing PV and CSP has been proposed as a way to combine the strengths of both technologies, with PV providing energy during the day and CSP after sunset.

However, a lack of transparent information on the construction experience and the performance of the CSP project remains one of the biggest barriers to the wider development of CSP. This problem that is not exclusive to Morocco slows down the rate of learning and technological improvement, both within the country and internationally. It is reasonable for companies to protect their intellectual property and know-how, but anonymous information sharing on project experiences and plant performance would make it much easier to find solutions to common problems and would contribute to lowering technology risks in CSP. The recent report, "Concentrating Solar Power Best Practices Study" (Mehos, et al., 2020), provides an example on how information on the most common issues encountered in CSP projects could be shared anonymously for the benefit of the industry.

From an institutional standpoint, the government of Morocco has mobilized significant resources to create a regulatory and institutional framework that would support its RE objectives. This shift did not happen because of the CTF investments in CSP, though it can be argued that these investments have supported this institutional shift indirectly (e.g., CIF's direct support of the development of procurement and bidding frameworks). Today, Masen is a point of reference in the region and has established links with several African countries seeking to boost their RE deployments.

Scale:

The operating CSP capacity in Morocco rose from zero in 2009 to 530 MW in 2019, amounting to about four percent of the country's installed capacity (10.9 GW). An additional 200 MW will come online once the Midelt I project is completed. This progress signals that CSP is contributing to the transformation of Morocco's energy system by propelling it toward a lower-carbon path.

However, coal and other fossil fuels still play an important part in Morocco's energy mix; thus, the transformation is far from complete. As the costs of RE and storage technologies decrease, it is possible that the government of Morocco would find it beneficial to establish even more ambitious RE targets, as it did in 2016 when its 2030 RE target was increased from 42 percent to 52 percent of Morocco's generating capacity.

Table 3.
ELECTRICITY GENERATION BY SOURCE IN MOROCCO, 2010–2019

YEAR	TOTAL (GWh)	COAL	OIL	HYDRO	WIND	NATURAL GAS	OTHER SOURCES	SOLAR PV	SOLAR THERMAL
2010	23,835	46%	24%	15%	3%	12%	0%	0%	0%
2019	41,650	65%	2%	4%	11%	11%	3%	0%	4%

Source: IEA, 2020

Speed:

The speed of deployment of CSP in Morocco—a country with no previous experience of CSP development—is noteworthy. Its CSP capacity grew from zero to more than 530 MW between 2009 and 2019, with an additional 200 MW of CSP from Midelt I coming soon. The rapid deployment of CSP forms part of a rapid acceleration of growth of installed RE capacity in the country.

However, coal continues to dominate. The contribution of coal-fired plants to total electricity generation rose by 19 percent between 2010 and 2019. In 2019, coal provided 26,900 GWh of electricity to the grid, compared to 1,581 GWh from solar, 1,654 GWh from hydro, and 4,699 GWh from wind (IEA, 2020). This suggests that the speeds of both RE deployments and coal retirement need to increase for Morocco to move towards a low-carbon energy system.

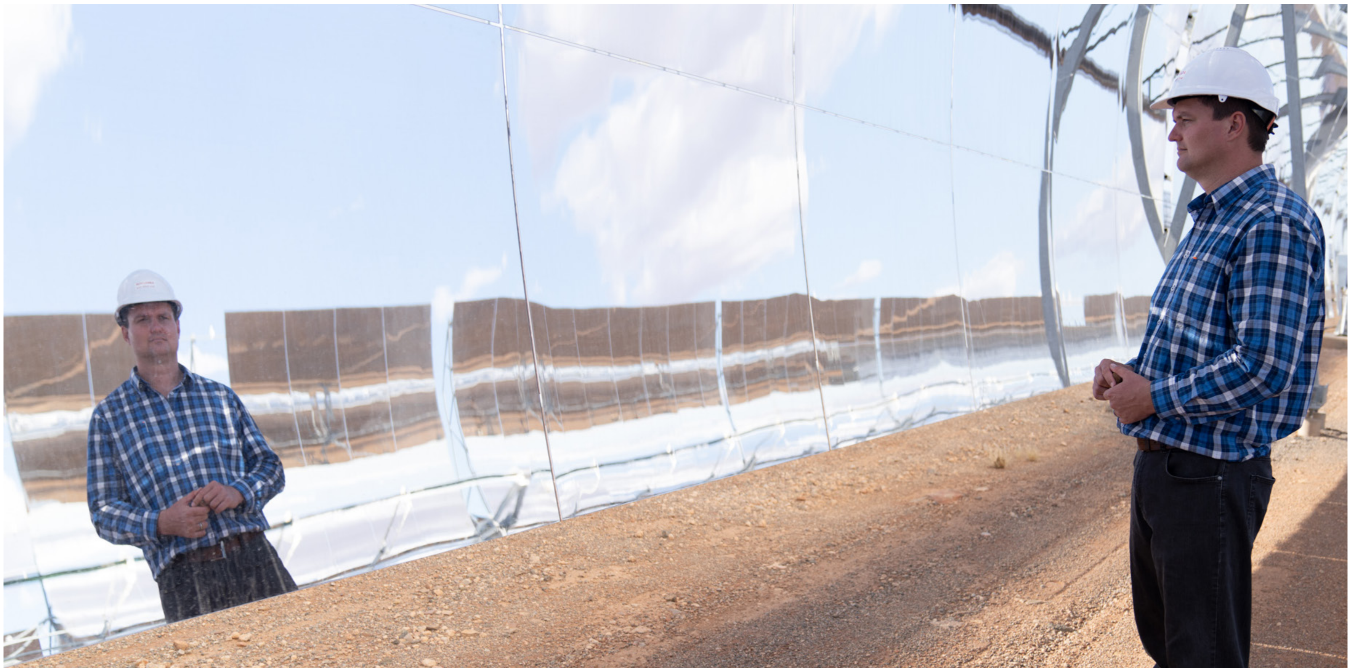
It is also worth noting that the share of oil-generated electricity has decreased by 22 percent. Given the fact that oil-fired plants tend to be among the most expensive due to its high dependence on oil imports, diversifying away from oil makes sense, in terms of cost savings and energy independence.

Adaptive sustainability:

From an economic standpoint, there are emerging signals of transformational change towards adaptive sustainability in Morocco. As noted above, the cost of CSP has dropped significantly (61 percent) between the first CSP project in Morocco, Noor Ouarzazate I (operational since 2016), and Midelt I (awarded in 2019). Further cost reductions are expected, as lessons learned and economies of scale from global deployments accumulate.

From a societal point of view, around 35 percent of the components purchased for the Noor Ouarzazate CSP projects were locally sourced. This signals positive effects for the local economy from CSP projects, which could potentially create a reinforcing cycle that would favor further CSP deployments. The Government of Morocco is keen to promote industrial strategy and employment as a core part of the clean energy transition.

From the environmental perspective, water consumption in CSP projects evolved from wet cooled in Noor Ouarzazate I to dry cooling in Noor Ouarzazate II and III, therefore minimizing the consumption of water—a scarce resource in Ouarzazate.



SOUTH AFRICA

In 2009, when the first CTF Investment Plan for South Africa was approved, the country's economy had been growing at an annual average rate of four percent over ten years. Buoyed by its strong economic performance, electricity demand increased by 60 percent in 12 years between the end of apartheid in 1994 and 2006. Three quarters of the energy consumed was supplied by coal-fired plants. The abundance of cheap coal and the predominance of energy-intensive extractive industries, such as mining, made South Africa the largest emitter of GHG emissions in Africa and the 11th largest in the world (CIF, 2009).

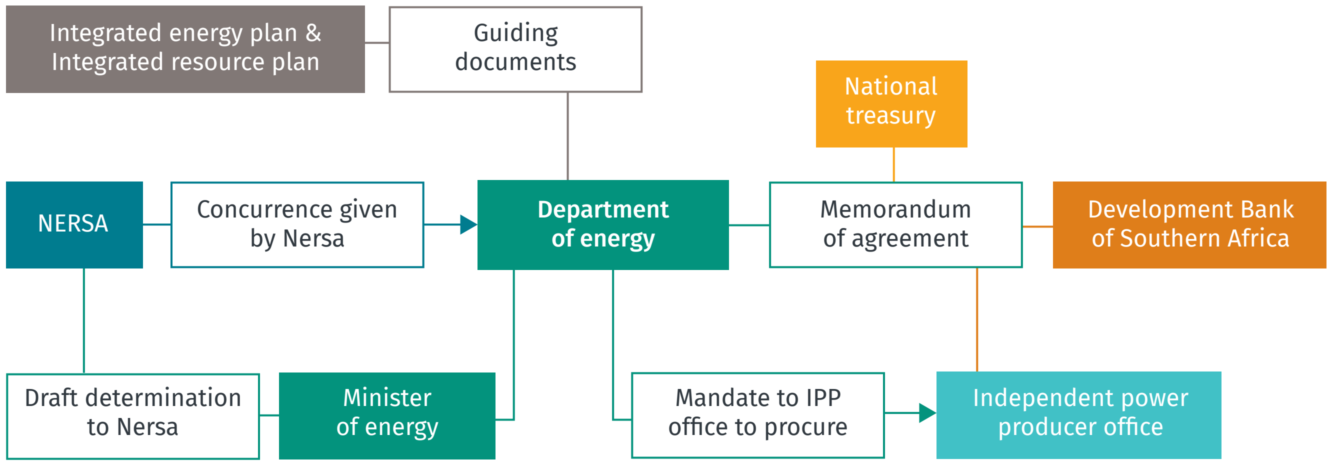
However, its awareness of the threat posed by climate change motivated the South African government to carry out a series of studies that would inform its climate change mitigation strategy. The results were published in the Long-Term Mitigation Scenarios (LTMS)—an official document released in 2007. According to the business-as-usual scenario of the LTMS, should the country make no changes, South Africa's emissions would quadruple in the period between 2003 and 2050, reaching approximately 1,600 megatons of CO_2 equivalent per year (Department of Environmental Affairs and Tourism, 2007).

Since the electricity sector accounted for 45 percent of GHG emissions in 2003, according to the LTMS (Energy Research Centre, 2007), the government considered the deployment of RE and mitigating measures, such as Carbon Capture and Storage (CCS). However, South Africa was also facing a shortage of generation capacity. As such, the government plans had to balance the need to build more power plants to sustain economic development with the need to mitigate GHG emissions.

With these objectives in mind, the government acted to tackle the energy supply gap in the first place, whilst putting South Africa in a position to mitigate GHG emissions in the medium term. In 2005, the government and Eskom launched a new build program that included 9.6 GW of coal, a 1.2 GW pumped hydro facility, and grid-reliability investments[8]. In addition, the country set a target of generating four percent of electricity from renewable sources by 2013 and improving energy efficiency by 12 percent by 2015. In parallel, the National Energy Regulator of South Africa (NERSA), in support of the government's RE objectives for 2013, commissioned a Renewable Energy Feed-in Tariff (REFIT) at the end of 2007, and after much consultation, launched it in March 2009.

Figure 11.

GOVERNANCE STRUCTURE OF SOUTH AFRICA'S INDEPENDENT POWER PRODUCER OFFICE



Source: GreenCape, 2020

In this context, the Country Investment Plan submitted to CIF proposed two pioneering RE projects by Eskom (October 2009). The Sere wind project (100 MW) and the Kiwano Concentrated Solar plant in Upington, a 100 MW tower with TES. The main purpose of these interventions was to de-risk RE investments in South Africa by supporting the country's RE goals and demonstrating the wider socio-economic benefits of RE.

In December 2009, scarcely two months after the publication of the first Country Investment Plan for South Africa, President Jacob Zuma pledged at the United Nations Climate Change Conference (COP15) to reduce South Africa's emissions by 34 percent (below the business-as-usual scenario) by 2020 and 45 percent by 2025. This pledge was conditional on South Africa obtaining support from the international community, in terms of finance, technology development, and capacity-building.

In 2011, the Department of Energy[9] published the Integrated Resource Plan (IRP) 2010–2030. This document has shaped the development of the RE sector in South Africa by shifting the focus of RE procurement toward competitive tenders and away from REFIT. This change of approach led to the creation of the REIPPPP whose objective was to encourage competition and foster the participation of the private sector in the RE build-up.

Given Eskom's position as the national utility with a dominant position in all areas of power generation and transmission, the Independent Power Producer Office (IPPO) was created to separate powers and avoid conflicts of interest. The governance structure of this institution can be seen in Figure 11 (GreenCape, 2020).

REIPPPP accepts bids only from companies with the means to build the projects they submitted and ensures that the local economy and the local population would benefit from these projects. Procurement is organized around closed-bid tenders, called bid windows, which set the total capacity to be procured by RE technology. Then IPPO issues a Request for Proposals (RFP). After the project submissions in response to the RFP are evaluated, the participants with the highest score are granted preferred bidder status.

One of the defining features of REIPPPP is that the bidder and the financiers must provide much of the due diligence and incur costs that are generally covered by the local authorities in other procurement processes. For example, bidders are responsible for the costs of connecting their project to the substation.

Additionally, REIPPPP has promoted local participation by requiring that 40 percent of each project is owned by South African citizens, 12 percent by black individuals, and 2.5 percent by the local community (Eberhard & Naude, 2016). It also placed minimum local job and local content requirements, as well as targets.[10] One percent of the CSP plant's earnings is reinvested in the local community. Winning bidders sign a 20-year PPA contract with Eskom as the off-taker. PPAs are denominated in the South African Rand (ZAR) and indexed to inflation, as measured by the consumer price index in South Africa. Additionally, PPAs are guaranteed by the government through a mechanism called an Implementation Agreement.

Despite objections raised by the labor movement, REIPPPP has been considered a success by most stakeholders. It led to the procurement of more than 6.4 GW of renewable power and lowered electricity prices at each successive round. Seven CSP projects to install a total capacity of 600 MW have been procured so far. Over three projects, accounting for 250 MW of the total capacity, have been financed, at least partially, by CTF and its partner MDBs: Kaxu (100 MW, Parabolic Trough) and Khi (50 MW, Tower) in Window 1 of the REIPPPP, along with Xina (100 MW, Parabolic Trough) in Window 3.

The Kiwano CSP project, the first to be proposed in the original CTF Investment Plan for South Africa in 2009, was not implemented and the funds were redirected to a BESS project. Nonetheless, some of the early research that informed the development of the Kiwano CSP project provided insights that supported the subsequent development of CSP in South Africa, including the three CTF-financed CSP projects.

CSP tariffs declined by 40 percent over the four bidding rounds between 2011 and 2014. This was possible thanks to accumulated know-how and the establishment of a track record of utility-scale CSP projects with TES (Eberhard & Naude, 2017).

Ten years after the publication of the first IRP 2010–2020, South Africa has made great strides towards promoting RE. However, the country still depends on coal for over 80 percent of its energy needs and the generation capacity shortage persists, leading to programmed rationing of electricity as a means to avoid generalized blackouts. On the economic front, South Africa is facing a global health and economic crisis that has been worsened by the COVID-19 pandemic, thus making it harder for the country to fulfill its development objectives.

Nonetheless, the success of REIPPPP highlights the potential of PPPs in delivering key RE assets at ever decreasing prices. The role of the private sector in financing and building the RE projects in South Africa has the potential to transform the energy sector in the country. Linked to additional socio-political reforms, it also has the potential to contribute to the alleviation of poverty by generating local jobs and fostering economic activity. As South Africa continues expanding its share of PV and wind energy, building flexible assets, such as CSP with TES, would help the country to manage the variability of these resources to minimize the curtailment of RE investments and realize their full value.

Beyond South Africa, Botswana and Namibia have recently announced that they are exploring the possibility of deploying five GW of CSP and PV over the next 20 years to supply both domestic and regional electricity markets through the Southern African Power Pool (SAPP) that connects 17 countries (Bellini, 2019). Given its potential for creating local jobs and fostering local economic activity, CSP with TES has the potential to serve as a catalyst for economic and social development in the entire Southern Africa region.

THE EXPERIENCE OF CSP INVESTMENTS IN SOUTH AFRICA THROUGH THE LENS OF TRANSFORMATIONAL CHANGE

Relevance:

The CSP projects financed by CTF are highly relevant in that they support the GHG mitigation objectives of the government of South Africa. When the first CTF projects for South Africa were approved in 2010, CSP with TES was clearly the most cost-competitive dispatchable solar energy technology. The deployment of this technology was aimed at enabling South Africa to displace coal from evening and night-time generation, which other RE technologies, such as wind power, could not deliver with certainty.

Additionally, the intervention has supported South Africa's development objectives by setting up quotas and targets in support of local employment and local content requirements. From a societal point of view, the projects were designed to provide ownership and employment opportunities to black citizens as well as factor in the need to benefit local communities by requiring the reinvestment of one percent of the projects' earnings in social programs. At the time, the World Bank procurement practices did not allow for preferential procurement arrangements. After substantial negotiations, the World Bank procurement requirements were changed to allow for the use of country policies favoring local content. This, arguably, made the CSP investments in South Africa more relevant to the local context and enhanced the transformational aspect of these investments.

Systemic change:

The evolution of CSP with TES and RE in South Africa offers indications of early signals of systemic change toward a lower-carbon energy system. From the operational point of view, the CSP projects in South Africa have shown that this technology can be deployed in sub-Saharan Africa and perform well in this context. CIF and partner MDB-supported initiatives contributed to systemic transformation by supporting early innovation and proof of concept. This laid the foundation for further innovation, an example of which is ACWA Power's Bokpoort CSP project (50 MW with 9.3 hours of storage). In 2020, it set a record for CSP by operating for 13 days continuously (SolarPACES, 2020).

From the regulatory and institutional points of view, the framework set up by the government of South Africa shows a high level of awareness of the barriers to the deployment of RE. By shifting from a REFIT policy to REIPPPP, South Africa moved decisively to create the conditions for private sector participation in the deployment of RE and contributed to lower costs of electricity at each round by encouraging competition between bidders. Whereas the REFIT policy yielded few concrete results, the REIPPPP's competitive bidding approach resulted in the deployment of 6.5 GW of RE, including 600 MW of CSP.

However, South Africa continues to suffer from the same deep structural problems that the government had set out to solve in 2008, including a lack of generating capacity, which causes rolling blackouts and an over-reliance on coal, thereby undermining the government's GHG emissions reduction objectives.

Scale:

CSP in South Africa grew from zero to 500 MW between 2009 and 2019, with a further 100 MW under construction. Its installed CSP capacity, representing approximately a quarter of the total installed solar capacity in South Africa, has grown rapidly with each successive round of the REIPPPP. These projects have helped to establish a track record of performance for the technology in South Africa, thus paving the way for future projects.

However, the South African authorities have recently opted to promote other RE technologies, such as PV and wind, instead of CSP, because it does not meet the least cost criteria.

It is possible that the relatively high PPAs awarded to early CSP projects in South Africa are having an adverse effect on new CSP deployments, even though the technology has seen its costs plummet since 2009. As South Africa deploys more PV, not least in

Table 4.
ELECTRICITY GENERATION BY SOURCE IN SOUTH AFRICA, 2010-2019

YEAR	TOTAL (GWh)	COAL	NUCLEAR	HYDRO	OIL	BIOFUELS	WIND	SOLAR PV	CSP
2010	259,601	93.2%	4.7%	2.0%	0.1%	0.1%	0.0%	0.0%	0.0%
2019	252,568	87.6%	5.4%	2.2%	0.1%	0.2%	2.6%	1.3%	0.6%

Source: IEA, 2020

the distributed sector that is growing rapidly, the need to deploy storage technologies may make the South African authorities reconsider the potential contribution of CSP with TES.

Speed:

Electricity generation from CSP and other RE sources has grown significantly in South Africa, showing emerging signals of progress towards transformational change. However, coal still accounts for the vast majority of electricity generated, which suggests that the rates of both RE deployments and coal retirement need to accelerate.

At a national scale, between 2009 and 2019, the contribution of coal to electricity generation has fallen by around 5.5 percent, while the combined contribution of wind, PV, and CSP has increased by 4.5 percent. But coal still accounts for nearly 88 percent of the electricity generated in South Africa (IEA, 2020).

Adaptive sustainability:

Reducing technology and project risks to encourage the deployment of additional CSP projects in South Africa was one of the main objectives of CTF investments. Early CTF-supported CSP projects in South Africa such as Kaxu provided important learning opportunities and contributed to opening up the sector for further investment. The fact that 450 MW of CSP have subsequently been financed and built, most of it without support from CTF, shows emerging signals of adaptive sustainability. Thanks to lessons learned globally, the cost of CSP has decreased, further strengthening the sustainability of CSP developments.

However, worsening general economic conditions in South Africa, as reflected by the downgrade of the country's credit rating in November 2020, represent a challenge to the continued development of CSP and other RE technologies in South Africa. The coronavirus pandemic has worsened an already difficult economic situation and caused tax revenues to decrease. In October 2020, the National Treasury posted a budget deficit of over 15 percent—the highest since the end of apartheid. The debt-to-GDP ratio is also expected to increase from the current 63.3 percent to 90 percent in three years (Mukherjee, 2020).

Given the impact of these adverse economic conditions on South African citizens and the pressing short-term challenges facing the country, any future interventions to boost the role of RE in South Africa should be designed to help the country alleviate pressing problems, such as inequality, poverty and unemployment, which have been afflicting South Africa for a long time and are made worse by the coronavirus pandemic.

CHILE

The Chilean economy had been growing steadily for 10 years at an average annual rate of 4.5 percent when the CTF Investment Plan developed by the Government of Chile was approved by the Trust Fund Committee in 2012 (World Bank, 2020). At the time, there was a strong expectation that the economy would continue growing at this pace.

From an energy standpoint, one of Chile's main concerns was to mitigate dependence on energy imports that represented over 50 percent of its total imports and accounted for more than 75 percent of its primary energy consumption (CIF, 2012). It remains a key challenge today.

Additionally, the country had to find a way to diversify away from hydroelectric power whose contribution to the grid had been reduced by periodic droughts. In an attempt to diversify, Chile had invested in natural gas infrastructure to import fuel from neighboring Argentina. However, during a period of domestic fuel shortages in 2004, Argentina passed a law banning gas exports to Chile, leading to widespread blackouts (CIF, 2012).

In this context, the development of RE presented itself as an opportunity for the country to reduce its dependence on fuel imports and the concomitant exposure to price volatility. Chile possesses strong solar resources, with the highest levels of DNI in the world in the Atacama region, as well as strong potential for the development of wind, marine, hydro, and geothermal energy.

Moreover, Chile, with its stable and attractive regulatory regimes, offers a favorable investment climate for energy investors. Furthermore, relatively high domestic energy prices make RE even more competitive for RE investors. All aspects of the Chilean electricity industry have been mainly in private hands since the 1980s.

In 2013 and 2014, the Government of Chile took a series of steps to accelerate the deployment of RE. Firstly, it amended Law 20527 to require utilities with more than 200 MW of capacity to meet 20 percent of their contractual obligations with renewables by 2025. Then, in 2014, the government put in place tender mechanisms that enabled bidders to compete in auctions to supply power at specific time windows during the day. As these auctions were technology-agnostic, it forced RE developers to bid for the time periods during which they could best serve the market in order to outcompete fossil-fired options. Finally, the government implemented a tax on carbon emissions and issued regulations to allow distributed generators to be compensated for the excess electricity they supplied to the grid (BNEF, 2019). Later, in 2019, the government of Chile passed a law requiring all coal plants in the country to be decommissioned by 2040. Additionally, the government declared its intention to make Chile carbon-neutral by 2050.

The combined result of all these policies is that RE has quickly gained ground: it now accounts for almost 28 percent of Chile's installed capacity, excluding hydro which accounts for 23.2 percent of installed capacity. However, challenges lie ahead for the further decarbonization of Chile's energy mix. The lower-than-expected economic growth has led to lower growth in electricity demand. At the same time, the expansion of variable RE has contributed to the collapse of prices in spot electricity markets, thereby putting the financial viability of a continued expansion of PV into question. Additionally, by 2017, the curtailment of RE had already risen to seven percent annually of the electricity generated by solar and wind energy (394 GWh) (BNEF, 2019).

THE CERRO DOMINADOR CSP PROJECT

In 2012, the Government of Chile designed a plan to support the development of CSP with TES. This plan involved a competitive tender whose winner would get a public grant of USD 20 million, a concession for public land in the Atacama region, and access to concessional finance, including a USD 67 million CTF loan through the Inter-American Development Bank (IDB) Group, along with other donor funding. This CTF loan was included in the 2012 CTF Investment Plan for Chile.[11]

The tender was conducted as planned during 2013, and in January 2014, it was awarded to Abengoa, based on its proposal for a 110 MW CSP tower plant with 17.5 hours of storage. The project, involving a total capital investment of USD 1.1 billion, was signed with a PPA of USD 0.11 per kWh.

Construction began in 2014, but stopped two years afterwards, when the developer, Abengoa, began to experience financial issues. The project was sold in 2018 to EIG Global Energy Partners which subsequently secured USD 758 million in commercial financing without the need for concessional resources. The power plant was inaugurated on June 8, 2021. (France24, 2021)

Even though the Cerro Dominador project did not receive CTF funding and suffered delays, the availability of CTF resources contributed to the government's 2012 plan to support the CSP technology. Chile was also able to demonstrate that its established regulatory framework could create the conditions for CSP projects to be financed in commercial terms.

Relevance:

The support for CSP and other renewable energies in Chile was aligned with the country's objective to diversify toward RE to mitigate its dependence on fuel imports. When the CSP project was proposed, in 2012, CSP and PV were approximately equivalent in price, with CSP having the advantage of including storage to supply the evening peaks.

Systemic change:

There are advanced signals of systemic change towards low-carbon energy systems at the institutional level in Chile. The combination of the mandates for utilities and technology-neutral auctions for specific time windows has enabled RE to grow, often outcompeting fossil fuel-based energy generation. CTF was instrumental in the first pilot financing to accelerate coal transition. It offered interest rate reductions against the emissions reductions generated by the early phase-out of coal-fired power plants and their replacement by clean energy, thereby providing a signal effect toward the decarbonization of the energy sector in the country.

Scale:

The Cerro Dominador project (110 MW CSP) is the first utility-scale CSP project in South America. This, by itself, does not signal scale. However, the overall growth of RE and the evolution of the energy market in Chile hint at a potential role for CSP with TES as a source of RE during the evening and night.

There are already signs that the Chilean market is experiencing the effects expected in places with a high share of variable renewables. First, seven percent of electricity from wind and PV was curtailed in 2017. Second, the prices have collapsed in certain wholesale electricity market nodes, particularly during the day (BNEF, 2019). This suggests that the electricity market during the day, when PV is most productive, is becoming saturated, and that further growth in the RE market would be after sunset. This points to a role for dispatchable RE technologies, such as CSP with TES and a range of other energy storage technologies that can provide the flexibility and cost structures required to maximize the integration of RE into the energy system.

Speed:

Although there is only one CSP project in Chile, the rapid growth of PV and wind provide early signals that Chile is transitioning towards a lower-carbon system. Between 2010 and 2021, PV has grown from zero to 3.6 GW and wind from 201 MW to 2.7 GW (ACERA, 2021).

However, as observed in many other markets, coal-fired plants still provide a third of the electricity generated in Chile, ahead of any other source. Over the past 10 years, coal's share of electricity generated has grown by 4.6 percent, whereas oil's contribution has decreased by 12 percent. It is, however, significant that, during the 2016–2020 period, coal's contribution to generation has declined both in absolute (almost 5,000 GWh) and relative terms (almost nine percent), while conventional and non-conventional RE increased from around 0.5 percent to 17 percent.

The government of Chile plans to retire all coal capacity by 2040. If RE is to take coal's place, renewables would have to be deployed at a faster pace alongside dispatchable technologies, such as CSP with TES and BESS.

Adaptive sustainability:

The fact that the Cerro Dominador CSP project has obtained financing from commercial sources is an indicator of adaptive sustainability.

When the Cerro Dominador CSP project was first considered, several RE projects in Chile were supported by concessional finance. More recently, it seems that commercial financiers have become very comfortable with financing all types of RE projects in Chile, including CSP. This may be a signal that concessional financing for solar projects is not required in this market.

The challenge now seems to be centered around designing a market that furthers RE investments without leading to unsustainably low energy prices for wholesale energy. This conundrum is not unique to Chile; solving it would contribute to the economic sustainability of low-carbon energy systems.

Table 5.
ELECTRICITY GENERATION BY SOURCE IN CHILE, 2010–2020

YEAR	TOTAL (GWh)	COAL	OIL	NATURAL GAS	HYDRO	WIND	OTHER SOURCES	SOLAR PV	GEOTHERMAL
2010	58,258	30.0%	12.6%	19.5%	36.4%	0.5%	1.0%	0.0%	0.0%
2020	77,746	34.7%	0.7%	17.9%	26.5%	7.1%	2.9%	9.8%	0.3%

Source: Coordinador Eléctrico Nacional, 2021

SIGNALS OF TRANSFORMATIONAL CHANGE FOR CIF CSP PROJECTS

CIF-supported CSP projects are typically large-scale flagship RE projects, embedded in national energy planning processes. They are also designed to support the development of regional/global RE technology markets.

Signals of transformational change associated with CSP investments have the potential to contribute to "advanced" transformational change in that they are influencing higher-level macro systems (national, regional, and global) across each of the individual dimensions.

Over the last decade, CIF's CSP projects have achieved success in evolving the operational efficiency of large-scale CSP plants, successfully meeting dispatchable requirements at the national level and demonstrating significant reductions in generation cost benchmarks in global terms.

Nonetheless, CSP remains a relatively niche technology. There are signs that wider adoption may be under way (based on investments in China, UAE, and announcements in Saudi Arabia, as well as rising regional interest and new commitments in developed markets such as Spain). However, rapid reductions in the cost of other RE technologies, better RE forecasting and grid management, along with the emergence of storage alternatives for dispatchable power, mean that it remains unclear whether CSP will become a widespread technology in countries with highly suitable climatic conditions.

RELEVANCE

CIF's CSP projects were highly relevant to supporting the energy sector transformation in targeted countries. At the time of the project development (2009–2012), CIF's CSP projects:

- Were designed to support the regional and global transformation of energy systems through a focus on a promising RE technology.
- Aimed to demonstrate the technical, financial, and economic viability of CSP to policymakers and financiers in suitable countries.
- Backed the lowest-cost solar energy solution at the time (cheaper than solar PV), with the potential for utility-scale deployment.
- Provided reliable dispatchable power to meet peak load profiles and address variability concerns associated with other RE technologies.
- Were targeted at countries and regions with suitable climatic conditions (high DNI) that make CSP feasible;
- Had the technical potential to make a substantial contribution to national climate change and energy sector decarbonization targets.
- Offered a significant opportunity to deliver cost/technology improvements through demonstrations and economies of scale.
- Delivered co-benefits by displacing imported fossil fuels as well as improving energy security, balance of payments, and power costs (Morocco).
- Had the potential to contribute significantly to the development of domestic supply chains, local content, and job creation (South Africa).

To facilitate transformational impact, CIF's CSP projects were anchored within national energy planning processes. CIF's CSP projects:

- Were subject to significant processes of national stakeholder consultation and planning, as part of CTF's Country Investment Plans.
- Were delivered through key national energy planning processes and institutions (e.g., Masen in Morocco and REIPPPP in South Africa) and supported them.
- Were co-designed with key ministries and other stakeholders in national governments, and supported by the wider MDB eco-system.

CIF's CSP projects continued to remain relevant during implementation. In particular, they:

- Facilitated learning and course corrections through multiple rounds of CSP procurement, thereby delivering efficiency and cost improvements.
- Encouraged innovation by supporting innovative contracting models and integrated CSP-PV tenders to maximize system benefits.
- Adapted to the realities of commercial and political challenges (e.g., developer bankruptcy in Chile and the challenges of getting the Eskom approval in South Africa).

SYSTEMIC CHANGE

CIF'S CSP PROJECTS HAVE RESULTED IN A RANGE OF SIGNALS OF SYSTEMIC CHANGE, SPREAD ACROSS PRACTICAL, INSTITUTIONAL, AND SOCIAL SYSTEMS.

In terms of *practical* systems (addressing technology and financing barriers), CIF's CSP projects:

- Supported significant learning for project developers on design efficiencies and turnkey approaches for the delivery of large-scale CSP.
- Oversaw the increase in thermal storage capacity (hours), thereby significantly improving the efficiency and economics of CSP.
- Designed integrated packages of support to CSP developers to facilitate developer interest (e.g., grid access, transport, and utilities).
- Used blended finance approaches to reduce the cost of capital, while the technology market matured and CSP became more competitive.
- Embraced innovative CSP-PV hybrid approaches to capture the dual benefits of cost reductions and dispatchability.
- Contributed to reducing costs, as exemplified by the contrast between the latest PPAs (at approximately USD 0.07 per kWh in 2020) compared to the 2008 REFIT in Spain (at approximately USD 0.40 per kWh).

In terms of *institutional* systems, CIF's projects:

- Helped build strong capacities in key procurement and contracting agencies to ensure effective appraisal and project delivery (Masen and REIPPPP).
- Encouraged more competitive procurement and bidding approaches for large-scale CSP projects (e.g., auctions), resulting in lower costs.
- Nurtured a global eco-system of project developers and financiers with capabilities to bid, finance, and deliver large-scale CSP projects.
- Developed national capacity and supply chains for the delivery of large CSP projects (including civil engineering and selected components).

In terms of *social* systems, CIF's support to CSP:

- Established the credibility of CSP among policymakers in target regions as a core RE technology, leading to multiple bidding rounds.
- Built social acceptability by including local content mandates and revenue-sharing for poorer communities (e.g., South Africa and Morocco).

However, significant systemic barriers remain, particularly in relation to cost competitiveness vs alternative RE technologies. They are further set out in the section on "Adaptive Sustainability".

SCALING

CIF'S CSP PROJECTS HAVE MADE A SIGNIFICANT CONTRIBUTION TO SCALING CSP AS AN ENERGY TRANSITION TECHNOLOGY, IN TERMS OF TECHNO-ECONOMIC, SPATIAL, AND SOCIAL-INSTITUTIONAL REACH.

In terms of *techno-economic* scaling, CIF's CSP projects have:

- Directly supported deployment in target countries (e.g., one GW of CIF-enabled CSP capacity deployed or in development).
- Supported wider rollouts, replications, and follow-ups of CSP projects in CIF countries (e.g., in South Africa, Morocco, and Chile).
- Informed subsequent project design and the delivery of larger-scale projects (e.g., in UAE) by CIF-supported CSP developers.
- Made a significant contribution towards the total current global installed CSP capacity of six GW.
- Crowded-in large-scale public and private finance for utility-scale CSP projects in target countries, including project developer equity.

In terms of *spatial* scaling, CIF's CSP projects have:

- Built interest in neighboring territories for CSP uptake (e.g., Botswana and Tunisia).
- Transferred know-how to key markets with the potential for further scaling and economies of scale (e.g., China, UAE, and Saudi Arabia).

In terms of *socio-institutional* scaling, CIF's CSP projects have:

- Supported the regional reach of supported CSP agencies (e.g., Masen) to support neighboring countries on RE sector planning in North Africa.
- Influenced the regional uptake of more competitive RE procurement approaches (e.g., the shift from REFIT to auctions).

However, the contribution of CSP to the global energy mix has remained small, with only six GW of operating capacity.

SPEED

CIF'S INVESTMENTS IN CSP HAVE BEEN ABLE TO HELP ACCELERATE THE DEPLOYMENT OF CSP AT SCALE TO A TIMETABLE THAT MIGHT NOT HAVE HAPPENED OTHERWISE, PARTICULARLY IN MOROCCO AND SOUTH AFRICA. CIF'S SUPPORT HAS:

- Built the capacity of governments in key countries to contract CSP in a structured way by streamlining tender and bidding processes.
- Delivered utility-scale projects (100 MW+) in countries with no previous experience or supply chains within a five-year period.
- Contributed to reductions in costs by 47 percent over a period of 10 years (measured in terms of LCOE), with rapid learning on technical and operational approaches.
- Brought forward operational efficiencies (e.g., storage capacity) and accelerated learning rate.

In addition, 10 years of demonstration support has allowed technical and cost learning that can potentially help accelerate subsequent stages of global CSP deployment, particularly as countries start to absorb higher levels of variable RE (PV and wind) and experience a greater need for dispatchable power.

However, the pace of global deployment remains relatively slow (six GW in total). CIF's CSP projects have also faced practical delays in political approval (e.g., the MENA region in 2009 during the Arab Spring saw most countries pause and postpone their CSP projects) and implementation (e.g., commercial bankruptcy in Chile).

ADAPTIVE SUSTAINABILITY

CIF'S PROJECTS HAVE CONTRIBUTED TO SIGNALS OF ADAPTIVE SUSTAINABILITY FOR CSP IN A NUMBER OF WAYS:

In terms of *economic* sustainability:

- CSP PPAs have fallen from around USD 0.40 per kWh in 2008 to USD 0.07 cents per kWh in 2020, thereby making CSP increasingly competitive.
- CSP projects have begun to be financed without concessional support (e.g., in Chile) based solely on project economics.
- Strategic investments in sector capacity by China and other countries have the potential to further improve cost economics.
- Higher levels of variable RE penetration are increasing the economic value of dispatchable power generation technologies (including CSP with TES).

In terms of *social* sustainability:

- CSP has reduced fossil fuel dependence in Morocco, whilst reducing the costs of power generation, with distributional benefits for poor consumers.
- CSP projects have supported increased levels of local content, leading to job creation and domestic supply chains, supporting just transitions.

In terms of *environmental* sustainability:

- CSP projects provided countries with the comfort to make commitments to ambitious GHG abatement targets in the energy sector (Morocco and South Africa).

***However,* sustainability remains uncertain, as technology markets evolve:**

- CSP remains uncompetitive against most fossil fuel baseload power plants without targeted concessional support.
- The slower historic pace of cost reductions of CSP, compared to alternative RE technologies, means that CSP is not the least-cost RE option.
- Political support for CSP in CIF countries (e.g., South Africa and Morocco) has declined, as procurement shifts to a technology-neutral basis.
- Limited scaling has reduced the relative impact of CSP on global emissions.
- Emerging alternative approaches to supply clean dispatchable power (e.g., BESS and other energy storage options) have become increasingly competitive.
- Limited geographies where conditions are suitable for CSP reduces opportunities for global markets/ economies of scale.
- Investments in CSP are large-scale, less flexible, and require longer lead times, with high capital requirements compared to RE alternatives.
- Political and economic instability has the potential to affect many potential markets where CSP could be economically viable.
- COVID-19 has the potential to reduce the borrowing capacities for large capital-intensive projects in developing countries.

CONCLUSIONS: THE WAY FORWARD FOR CSP

CTF investments have contributed directly to one GW in CSP deployments and helped the technology establish a track record that it can built upon for further deployments. Institutionally, CTF investments in CSP have yielded a wealth of experience that utilities and government institutions around the world can draw upon to procure and support the deployment of CSP and other renewable energies. Currently, there are approximately six GW of operating CSP capacity worldwide and this could double in the next decade based on announcements such as those in Spain, where a further five GW of CSP with TES has been announced.

However, the deployment of CSP plants remains low at a global scale and has progressed at a slower pace than most RE technologies. It is possible that CSP may yet fulfill its deployment potential of hundreds of GW across regions with high levels of DNI, as a higher share of low-cost, variable renewable technologies are deployed in a drive to decarbonize energy systems. In fact, the greater the share of variable renewables, the greater the value provided by CSP with TES to the overall energy system.

PROVIDING FLEXIBLE RENEWABLE ENERGY ON DEMAND: COMPETING TECHNOLOGY OPTIONS

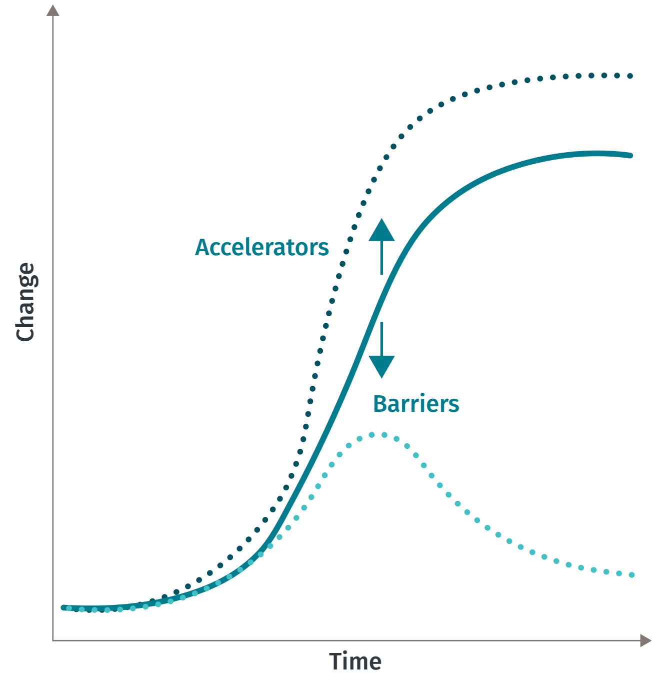
The main value of CSP with TES resides in its ability to store energy to provide dispatchable renewable electricity during the evenings and nights, in places with high levels of solar irradiation. In this capacity, CSP with TES allows for a deeper decarbonization of energy systems by displacing fossil-fired capacity after sunset. Additionally, with the inclusion of reheaters, TES tanks can store excess power from variable renewables, which would otherwise be curtailed, for its deployment whenever it is needed, even if this is after sunset. This helps energy systems derive the maximum utility from variable RE. Overall, the flexibility and dispatchability provided by CSP are valuable assets in energy systems with a large share of variable renewable energies, which are expected to form the backbone of low-carbon energy systems in most geographic areas.

Whether CSP with TES becomes one of the main providers of bulk storage services should depend, to a large extent, on its ability to compete on costs and performance with other technologies providing similar services, such as PV with TES. Currently, CSP with TES is considered more cost-effective for longer-duration storage, lasting four hours or more, whereas PV with BESS is regarded as more cost-effective for shorter-duration storage of up to two hours. Whether CSP can retain its cost advantage depends largely on continued deployments to lower costs through technological improvements.

At this moment, it is not clear which technology or combination of technologies will emerge as being best suited to meet the requirements for dispatchable green energy in systems with high shares of variable renewables. The key added value of CSP with TES—reliable dispatchable power—has now become the main area of competitive focus in the further development of green power generation and grids going forward. Regional grids and interconnectors, BESS, more flexible demand-side management, and CSP-hybrids may all have their roles to play, but it is not clear in what combination they will emerge.

Technologies may emerge and have success, in terms of initial deployment, systems development, and scaling, only to face ongoing technical or financial barriers, or simply be outcompeted by alternatives. This is illustrated in Figure 12:

Figure 12:
TRANSFORMATION CURVES FOR EMERGING TECHNOLOGIES



In the process of evaluating the contributions of technologies capable of providing dispatchable RE, it has become clear that the models that consider costs only would be inadequate, as they would not be capturing the full value provided by these technologies. New inductive projection planning methodologies, as opposed to least-cost expansion plans, consider not only the LCOE of each technology, but also system robustness and the cost of curtailment, to arrive at an energy mix that delivers a low-carbon energy generation system at the lowest possible cost. As more accurate inductive power system planning methodologies are deployed, it is more likely that dispatchable renewable technologies, such as CSP with TES, will be considered as a component of a low-carbon, robust, and affordable power generation mix.

POTENTIAL SOCIO-ECONOMIC CONTRIBUTIONS OF CSP WITH TES

Regarding the socio-economic dimension, CSP projects have the potential to contribute to the economic development of host countries. Since much of the work needs to be done on-site, CSP projects tend to create a significant number of local jobs. Additionally, a large part of the components and materials required in CSP projects can be manufactured in most countries, which opens up the possibility of local industrial development. In addition to the more direct economic benefits, a number of social and human benefits are also linked to the development of CSP. Given the siting of CSP projects in areas of high irradiation and thus, dry landscapes, CSP installation creates development opportunities in often underdeveloped areas. This includes infrastructure development as well as social services, such as clinics and improved basic education. Skills development associated with the operation and maintenance of CSP plants opens new employment opportunities for the youth in local communities. These contributions should not be overlooked in the context of a just transition to low-carbon energy systems.

LESSONS FOR FURTHER INVESTMENTS IN RE TECHNOLOGIES

These CSP case studies illustrate the challenges faced by climate finance institutions in predicting future developments in energy technology efficiency, cost, and the wider system dynamics at the program design stage. “Picking winners” is not straightforward. It is, therefore, important for climate funds, such as CIF, to support the early backing of a portfolio of potentially high-impact technologies and business models by ensuring that the most effective and cost-efficient are allowed to mature. This will also mean that some efforts may not succeed in the long run and that there should be a higher tolerance of failure than is currently acknowledged.

There should also be a recognition that efforts to mobilize around a technology need to be undertaken at scale. The economies of scale and learning benefits associated with CIF-supported CSP have required billions of dollars of capital investment from development partners and the private sector. Focused global programs with large scale concessional resources are, therefore, also vital for overcoming the hurdles by delivering the benefits of demonstrations and alleviating investor risk perceptions.

Given that carbon emissions are still growing, it is essential that the pace of RE deployment accelerates and the most polluting forms of power generation, particularly coal, are retired as early as possible. In this context, supporting, and learning from, the deployment of innovative renewable technologies, such as CSP with TES, can play a fundamental role in the transformation of energy systems in countries with relevant environmental, social, technological, and economic contexts.

ACRONYMS AND ABBREVIATIONS

ADB	Asian Development Bank
AfDB	African Development Bank
BESS	Battery Energy Storage System
CCS	Carbon Capture and Storage
CIF	Climate Investment Funds
CO_2	Carbon Dioxide
CSP	Concentrated Solar Power
CTF	Clean Technology Fund
DEWA	Dubai Electricity and Water Authority
DNI	Direct Normal Irradiation
EBRD	European Bank for Reconstruction and Development
EPC	Engineering Procurement and Construction
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Gigawatt
GWh	Gigawatt-Hour
IDB	Inter-American Development Bank
IBRD	International Bank for Reconstruction and Development
IEA	International Energy Agency
IFC	International Finance Corporation
IFI	International Financial Institution
IPPO	Independent Power Producers Office
IRP	Integrated Resource Plan
kWh	Kilowatt-Hour
LCOE	Levelized Cost of Electricity
LTMS	Long Term Mitigation Scenarios
m^2	Square Meter
Masen	Moroccan Agency for Sustainable Energy
MDB	Multilateral Development Bank
MENA	Middle East and North Africa
MSP	Moroccan Solar Plan
MW	Megawatt
MWe	Megawatt Electric
NERSA	National Energy Regulator of South Africa
NREL	National Renewable Energy Laboratory
PPA	Power Purchase Agreement
PPP	Public-Private Partnership
PV	Photovoltaic
RE	renewable energy
REFIT	Renewable Energy Feed-In Tariff
REIPPPP	Renewable Energy Independent Power Producers Procurement Programme
RFP	Request for Proposals
SCF	Strategic Climate Fund
SET	Sustainable Electricity Trade
SPC	Solar Project Company
TES	Thermal Energy Storage
TCLP	Transformational Change Learning Partnership
UAE	United Arab Emirates
USD	United States Dollar
UN ESCWA	United Nations Economic and Social Commission for Western Asia
WACC	Weighted Average Cost of Capital
WBG	World Bank Group

ENDNOTES

1 In this document, the term, **power system,** refers specifically to the generation of **electricity**, its transmission from power generation plants to centers of consumption as well as its distribution to households, businesses, and institutions for final consumption. The term, **energy system,** refers to a broader set of energy-related activities, including the extraction of energy commodities, their processing and refining into fuels, and their consumption, which are classified under four broad categories — transportation, heating, industrial process heat, and electricity. The generation of electricity (power generation)—an important part of contemporary energy systems—is responsible for about a quarter of global GHG emissions.

2 "Solar radiation reaches earth's surface as: (1) direct (beam) solar radiation, (2) diffuse solar radiation, and (3) reflected radiation, which can be neglected." (Sarbu & Sebarchievici, 2017)

3 "Levelized Cost of Electricity (LCOE) is an economic measure used to compare the lifetime costs of generating electricity across various generation technologies. The lifetime costs for generation can be categorized into the following groups: Capital Costs: up-front costs to construct a power plant (...). Operation and Maintenance (O&M) Costs: costs incurred to run a power plant. (...). Disposition Costs: costs typically incurred at the end of the useful life (...)." (Raikar & Adamson, 2020)

4 While the provision of CSP/TES energy 24/7 is not achievable, or even aspirational, in all developments, it is becoming increasingly possible: "Concentrating solar power (CSP) with thermal energy storage can provide flexible, renewable energy, 24/7, in regions with excellent direct solar resources." (World Bank, 2021)

5 Two CTF plans aimed at fostering RE in Morocco were published in 2009: the CTF Investment Plan for Morocco (October 2009) aimed at supporting the deployment of wind power plants and the CTF Investment Plan for MENA-CSP (December 2009) that supported CSP investments.

6 In 2016, Masen became the Moroccan Agency for Sustainable Energy.

7 Definition of WACC: "The weighted average cost of capital of a company is the cost of capital of all its equity and debt instruments proportionately weighted. These instruments may include common shares, preferred shares, and debt instruments of a company. The cost of capital is the required rate of return of a company on any project." (CFA Journal, 2021)

8 The plants included are two coal-fired stations: Medupi (4,764 MW) and Kusile (4,800 MW), and the Ingula pumped-storage scheme (1,332 MW). Source: New build programme

9 Since June 2019, the Department of Energy has been known as the Department of Mineral Resources and Energy.

10 In Bid Window 4, the job creation component of the elements of economic development criteria were the following (threshold | target): South Africa-based employees who are citizens (50 percent | 80 percent); South Africa-based employees who are black people (30 percent | 50 percent); skilled employees who are black (18 percent |30 percent); South Africa-based employees who are citizens from local communities (12 percent | 20 percent). Local content. Value of local content spending: Threshold 40–45 percent, target 65 percent.

11 The original CTF investment plan, approved in 2012, envisaged up to USD 1.2 billion of investment across a range of areas, including solar PV power and energy efficiency.

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THE CLIMATE INVESTMENT FUNDS

The Climate Investment Funds (CIF) were established in 2008 to mobilize resources and trigger investments for low carbon, climate resilient development in select middle income and developing countries. To date, 14 contributor countries have pledged over US$ 8.5 billion to the CIF, which is expected to leverage an additional US$ 61 billion in co-financing for mitigation and adaptation interventions at an unprecedented scale in 72 recipient countries. CIF's large-scale, low-cost, long-term financing lowers the risk and cost of climate financing. It tests new business models, builds track records in unproven markets, and boosts investor confidence to unlock additional sources of finance. The CIF is the largest active climate finance mechanism in the world.

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