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Asociación Española para la Promoción de la Industria Termosolar

CSP – definition, services and future

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20 April 2022

About Protermosolar

Protermosolar is the Spanish Association of the Solar Thermal Electricity Industry, which brings together most of the main companies in the sector in Spain. It was established in 2004 by Abengoa, Cobra and Sener.

Protermosolar represents all the CSP owners in Spain, most of the O&M Contractors, the main EPC companies, as well as the most representative business developers, key suppliers and advisors.

Protermosolar's main objective is to promote the expansion and development of solar thermal technology both in Spain and in the rest of the world.

Protermosolar's head office is in Madrid.

Introduction to CSP

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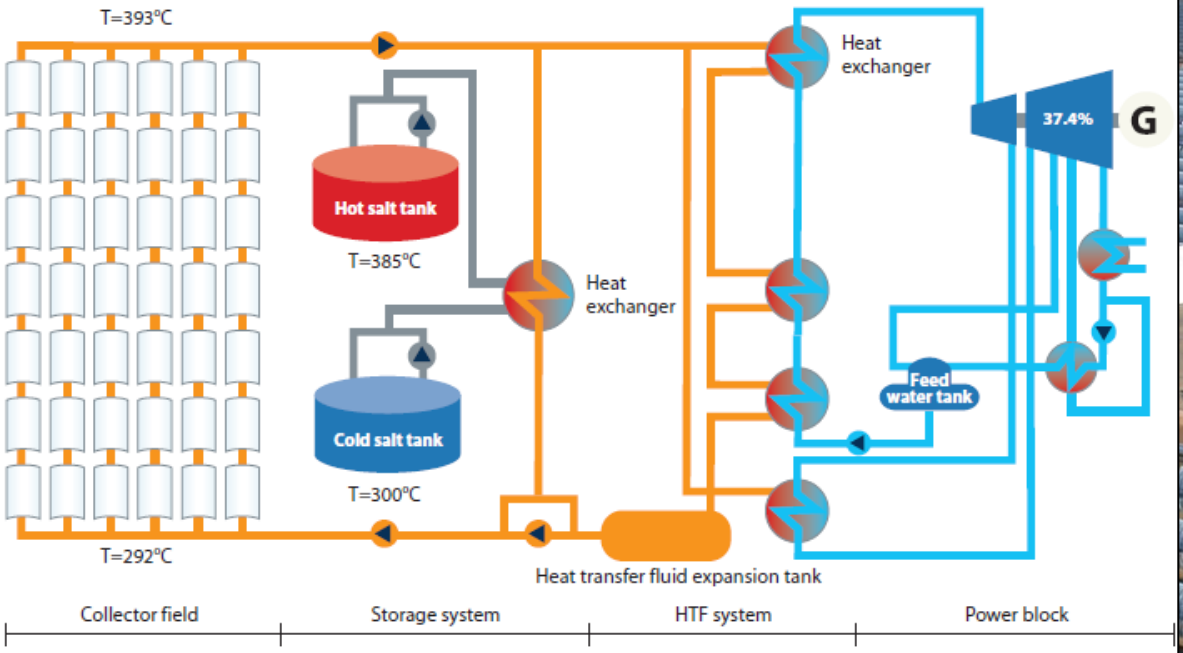
1. What is CSP? Services to the system
2. Worldwide outlook
3. The future

1. How the technology works

There are two main designs: Parabolic trough and Tower

FIGURE A.2 Parabolic trough design



Source: Adapted from IRENA (2016).
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.

Left: Parabolic trough design extracted from World Bank. 2021. Concentrating Solar Power: Clean Power on Demand 24/7. Washington, DC: World Bank.
Right: Extresol plant in Spain with Thermal Energy Storage (TES) system.

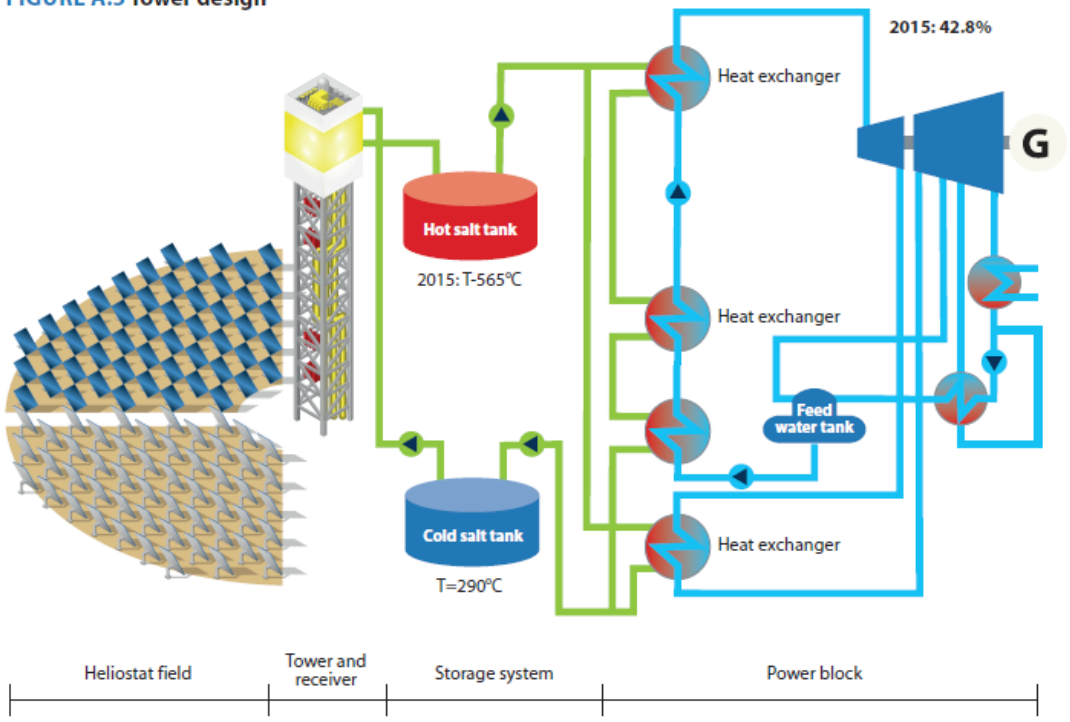
- There is a Heat Transfer Fluid (HTF) heated up into the Solar Field.
- The thermal energy can be stored into the hot salt tank by exchanging the energy between the HTF and molten salts.
- The thermal energy (directly from the Solar Field or from the Thermal Energy Storage) generates steam that goes into a turbine.

→ The output is synchronous power that can work both day and night.

1. How the technology works

Tower can achieve a higher yield although its track record is lower

FIGURE A.5 Tower design



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

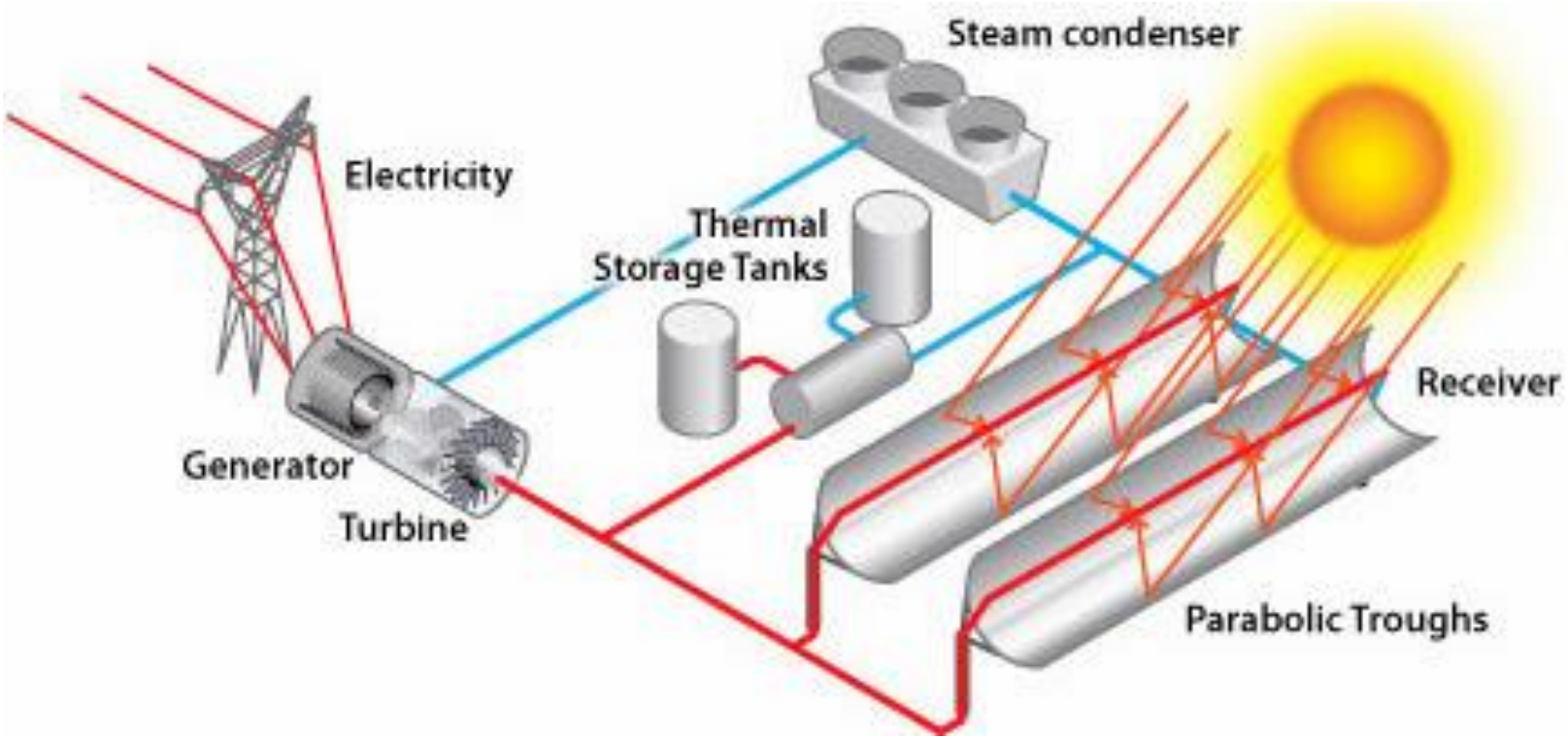
Left: Tower trough design extracted from World Bank. 2021. Concentrating Solar Power: Clean Power on Demand 24/7. Washington, DC: World Bank.
Right: PS10 tower plant in Spain

- In the Tower design, the HTF can be either steam or molten salts.
- Designs include storage of long duration.
- In theory could be more efficient than Parabolic trough (due to higher temperatures) but there is lower track record worldwide.

→ Both Tower and Parabolic trough designs can be adapted to the grid demand in terms of power and storage.

1. How the technology works

Thermal Energy Storage (TES) allows operation round the clock



4 julio, 2011

La planta de 19,9MW Gemasolar alcanza las 24 horas de producción ininterrumpida

Bokpoort Breaks a Solar Record – CSP Operating Round the Clock 13 Days:

October 28, 2020

1. SCARABEUS project

Aim and impact into the energy market

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> The aim of the SCARABEUS project is to demonstrate that the application of supercritical CO_2 blends to CSP plants has the potential to reduce CAPEX by 30% and OPEX by 35% with respect to state-of-the-art steam cycles, thus exceeding the reduction achievable with standard supercritical CO_2 technology. This translates into a LCoE lower than 96 €/MWh, which is 30% lower than currently possible. The project will demonstrate the innovative fluid and newly developed heatexchangers at a relevant scale (300 kWth) for 300 h in a CSP-like operating environment.

The ultimate impact of SCARABEUS is to introduce a step change in the current paradigm of CSP technology which, if the current techno-economic scenario remains, will progressively be less competitive compared to PV and wind technologies. The SCARABEUS concept will tackle CSP costs at their very heart by enabling significant size reductions of all the components of the plant (power block, solar field and thermal energy storage system), thus bringing about a significantly lower LCoE. The successful completion of SCARABEUS is expected to contribute to a new scenario of the Energy sector in Europe wherein this new renewable energy technology will ensure dispatchability and cost competitiveness simultaneously. This has not yet taken place since PV and wind are cost-competitive (LCoE between 60 and 100 €/MWh) but not dispatchable, whilst state-of-the-art CSP is dispatchable but has significantly higher costs (~150 €/MWh). In fact, the economic comparison between the technologies is not consistent as CSP includes a TES whose specific cost is between 20 and 40 €/kWh , while battery costs (not accounted in the LCoE of PV and Wind) are around 200 €/kWh. In addition to the lower cost than batteries, no shortage of the raw material supply for CSP plants is expected, while some studies outlined the uncertain reserve availability and resource depletion for lithium or rare earth metals which casts doubts on the overall security of supply and sustainability of battery deployment.

Indeed, dispatchability sets CSP apart from other technologies with regards to increasing renewable energy penetration and reduction of curtailment. This has been confirmed by a study carried out by IEA and IRENA where it is claimed that the overall installed capacity of CSP will increase from 4 GWel to 100 GWel by 2030 and 300 GW by 2050, resulting in an annual installed capacity of 10 GWel in 2030 and 20 GWel in 2050. According to these figures, and assuming a specific capital cost of a CSP plant of 3000 €/kWel (therefore with a further reduction with respect to the SCARABEUS target as a consequence of improvements in components other than the power block), the annual CSP market volume will reach 30,000 M€ and 60,000 M€ by 2030 and 2050 respectively. The market size and number of jobs that will be created by SCARABEUS as a function of technology penetration are reported in the figure below, where the SCARABEUS share refers to the overall CSP market adopting the SCARABEUS technology (this assessment is based on the assumption that the power block accounts for 30% of the overall CSP plant cost). These numbers translate into the estimated number of employees shown on the right-hand side of the figure below, according to the assumption that one employee corresponds to an annual investment of 100 k€ (value indicated by industrial partners). In the optimal case where SCARABEUS is applied to all the new CSP plants installed, the number of employees that are related to the SCARABEUS concept will be 90,000 and 180,000 in 2030 and 2050, respectively.

1. How the technology works

CSP is the alternative to fossil fuels dependence

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a

CSP is not an alternative to the use of PV → CSP is actually an alternative to *fossil fuels*

b

Neither an "expensive" RES → indeed CSP improve the cost dynamics of the system

CSP is a dispatchable RES that, together with other dispatchable RES such as hydro or biomass, shall provide the necessary back-up to intermittent RES to fully decarbonize the electricity generation

List of acronyms:
CSP: Concentrating Solar Power
PV: Photovoltaics
RES: Renewable Energy Source

1. CSP is already cheaper than fossil fuels in some locations

CSP competes against fossil fuels and other dispatchable RES (Biomass and Hydro)

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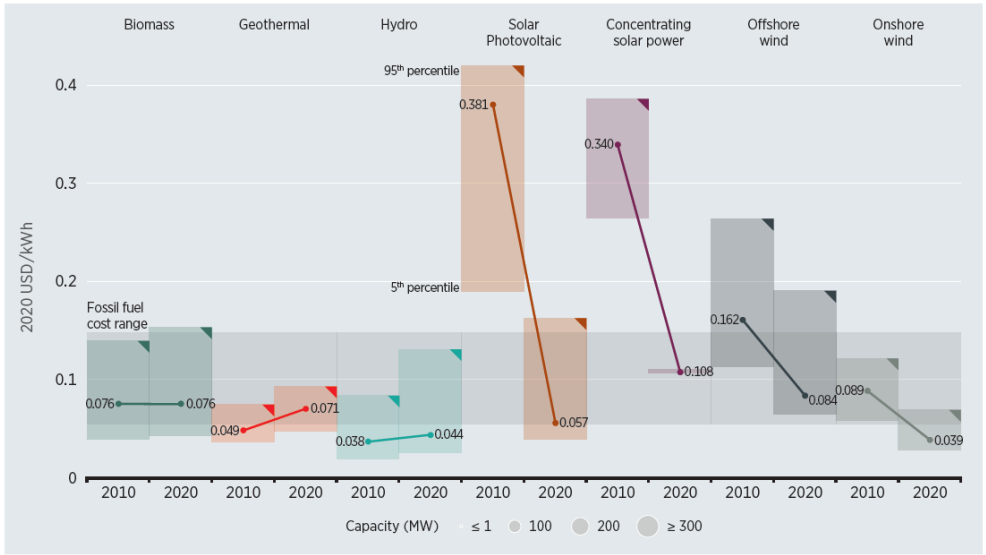
CSP, due to its solar resource needs, has lower growth potential than PV affecting its global installed capacity

However, for the same installed capacity, the cost reduction is almost 2x

CSP has still a significant potential for cost reduction, not only coming from R&D but also from greater installed capacity.

Nonetheless, PV and CSP will not compete but complement each other.

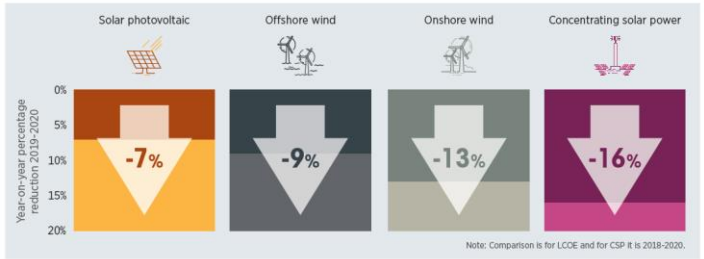
Figure ES.2 Global LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2020



Source: IRENA Renewable Cost Database

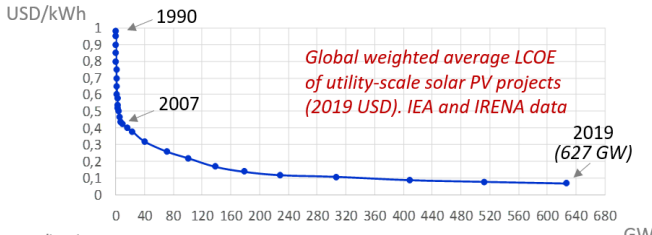
Note: This data is for the year of commissioning. The thick lines are the global weighted-average LCOE value derived from the individual plants commissioned in each year. The project-level LCOE is calculated with a real weighted average cost of capital (WACC) of 7.5% for OECD countries and China in 2010, declining to 5% in 2020; and 10% in 2010 for the rest of the world, declining to 7.5% in 2020. The single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

Figure ES.1 Global weighted-average LCOE from newly commissioned, utility-scale solar and wind power technologies, 2019-2020

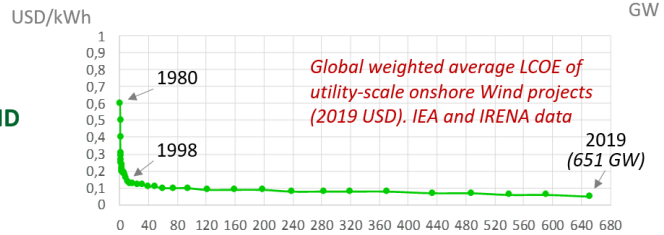


Source: IRENA Renewable Cost Database

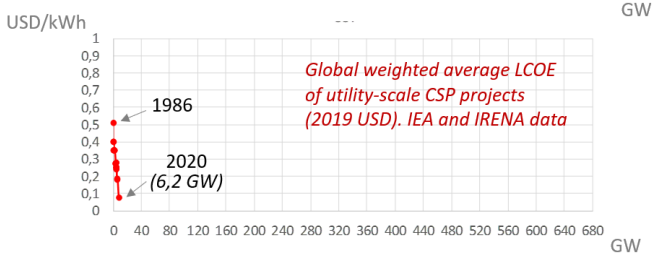
PV



WIND



CSP

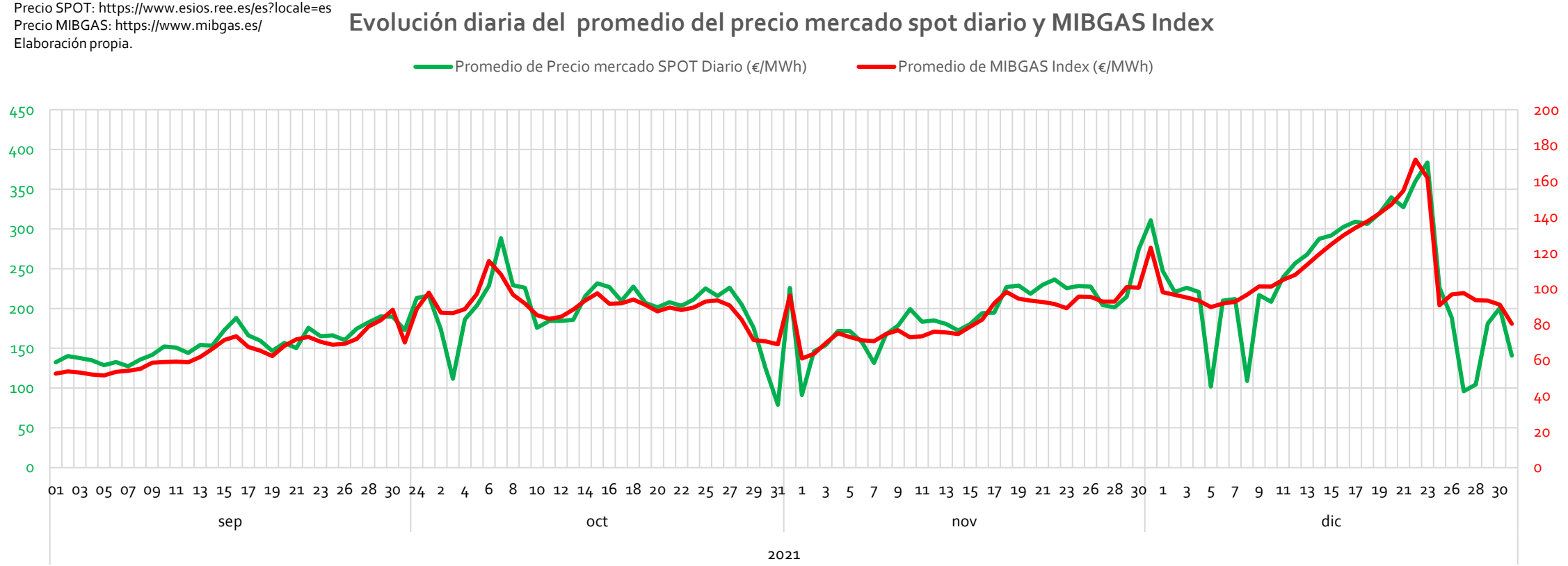


Source: Julian Blanco. PSA Internal working document

1. CSP shall become the back-up for intermittent RES

Savings are in the pool price, also by no longer keeping excessive fossil fuels plants.

Precio SPOT: https://www.esios.ree.es/es?locale=es
Precio MIBGAS: https://www.mibgas.es/
Elaboración propia.



Spain

Spain has the most significant shares of excess capacity of all the countries included in this report, where 13 GW or 36% of fossil fuels installed in the country was not required to service peak demand in 2019.

Retiring excess fossil fuel capacity would yield total annual savings of €425 million EUR ($476 million USD) from FOM costs. The early retirement of the aging coal capacity alone would save nearly €361 million EUR ($405 million USD) per year.

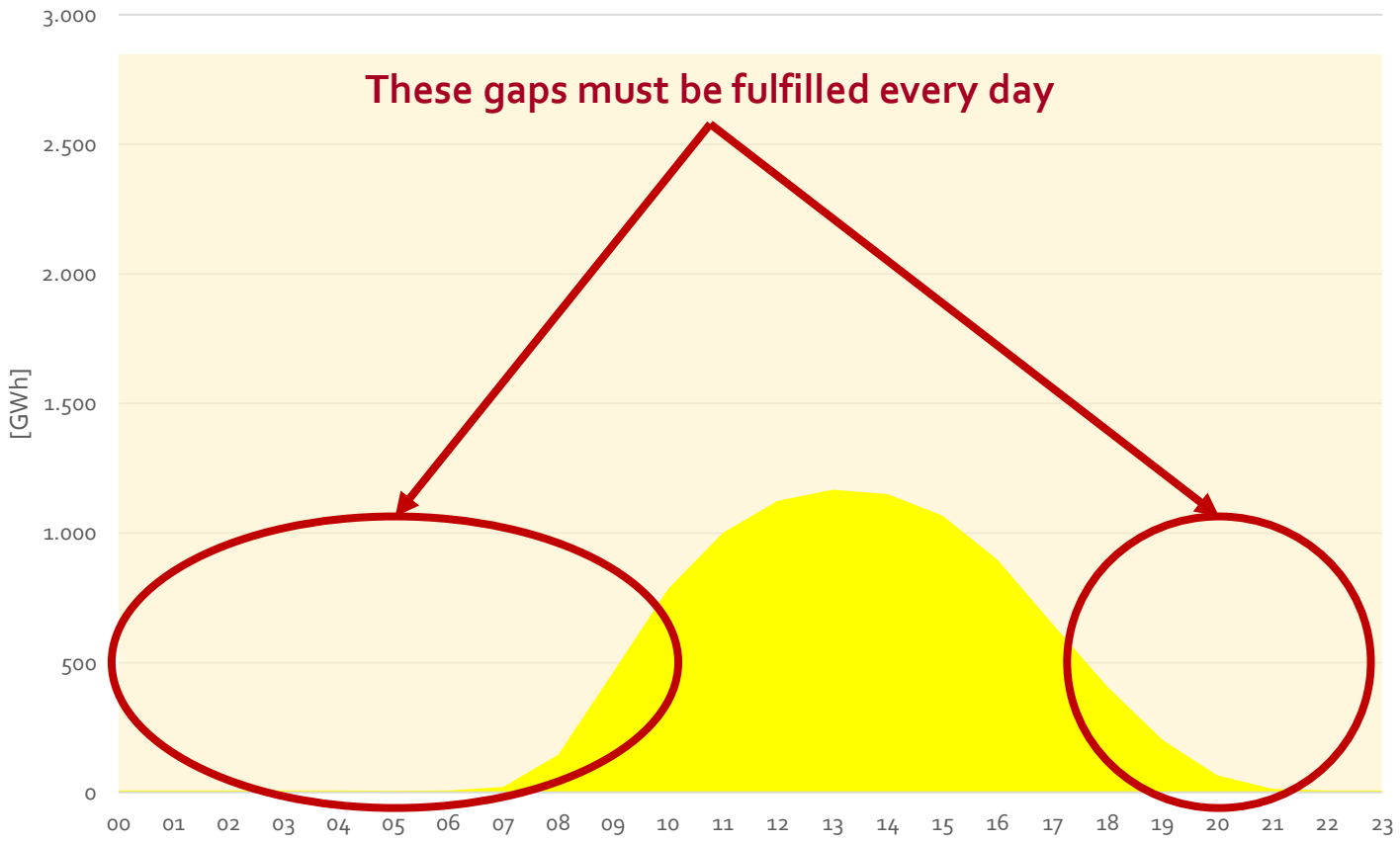
Source: Ripe for Closure: Accelerating the energy transition and saving money by reducing excess fossil fuel capacity. September 2021. Centre for Research on Energy and Clean Air.

1. Photovoltaics must be complemented every day

Photovoltaics (PV) only/mainly produce when the Sun is shinning

PV Generation in Spain

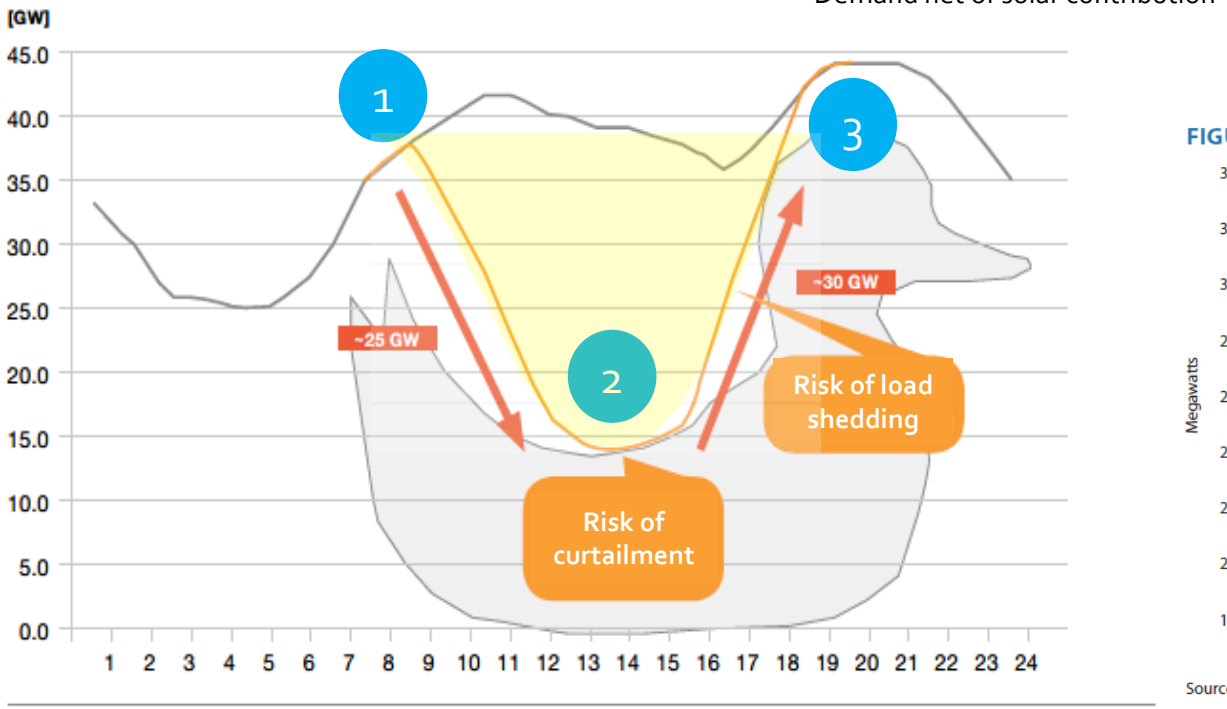
Cumulative per hour in 2019



1. Intermittent RES pose a risk to the electricity market

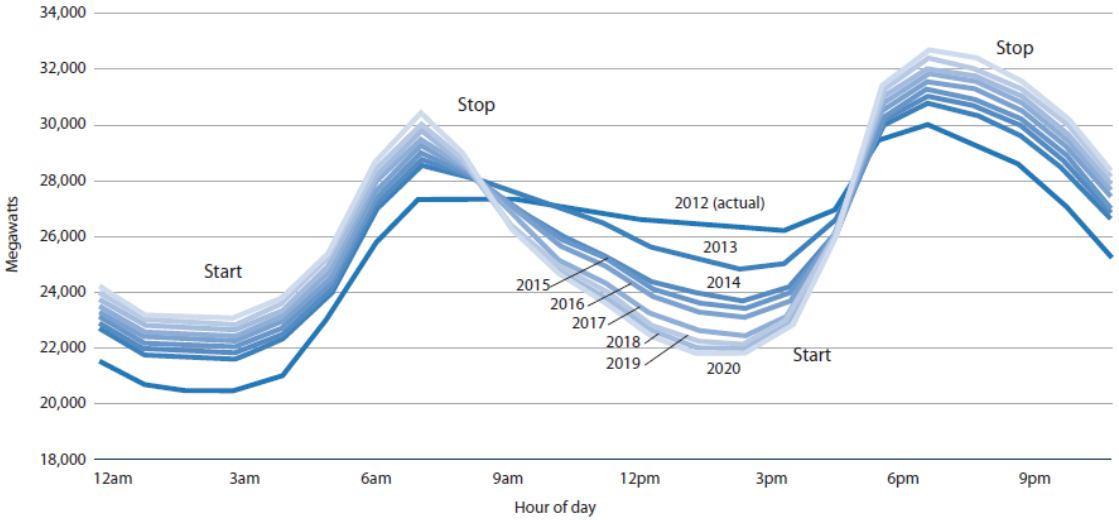
The electricity market might present dysfunctionalities with lack of dispatchable RES

Duck curve 2030 - Spain
Source: Made by PwC with data from REE



https://www.fundacionnaturgy.org/publicacion/integracion-de-las-tecnologias-renovables-en-la-transicion-energetica/

FIGURE 1.5 Peak times of daily net electricity load (after solar PV): California's "duck curve"



Source: CAISO 2016.

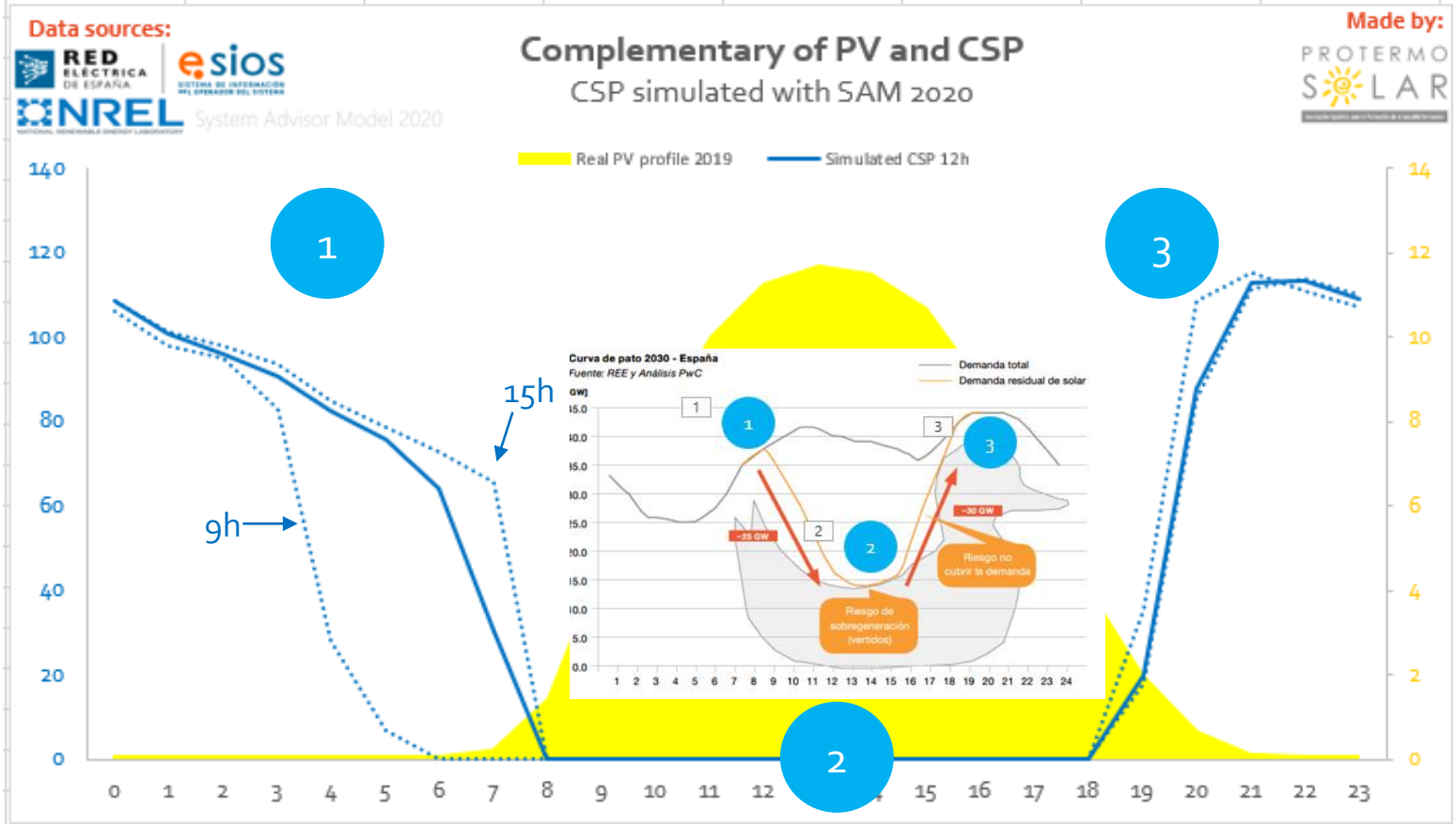
World Bank. 2021. Concentrating Solar Power: Clean Power on Demand 24/7. Washington, DC: World Bank.

A large penetration of intermittent or non-dispatchable **Renewable Energy Sources (RES)** might create a significant dysfunctionality in the electricity market:

1. Need to decouple night energy supply during the morning.
2. Risk of curtailment/excess of energy and therefore prices close to zero.
3. Difficulties to reach the demand increase at sunset.

1. CSP is the technology to complement PV

CSP with storage for night supply is the natural complement to daily PV generation



Simulation parameters:

- Location: village in Spain with most CSP
- Forced to zero from 8h to 18h
- Parabolic trough
- Solar multiple 2.5x (can be adjusted)
- Capacity 150 MW (irrelevant)
- Values in MWh

Simulated with SAM 2020 from NREL

PV real profile:

- Location: Spain
- Time series: Full year 2019
- Values in 0.1·GWh
- Actual cumulative hourly generation

Data obtained from REE

- New CSP will include large storage >9h
- Complementary Operation to PV, helping to mitigate the duck curve
- Capacity greater than 50 MW
- Lessons learnt after one decade of operation

1. Other services that CSP could provide to the system

Strategic reserve, price arbitration and thermal battery

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With the appropriate price signal:

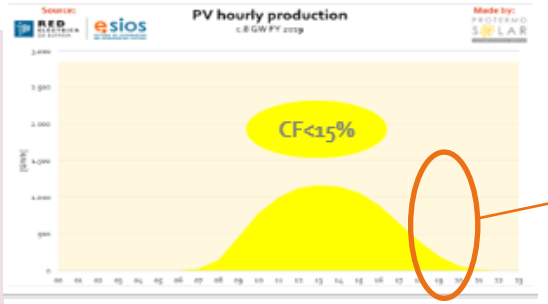
- **Reserve** for the yearly 100h peak hours
- > 3,5 GWhe currently available (could be x2) in winter to store energy for days until the system demands it

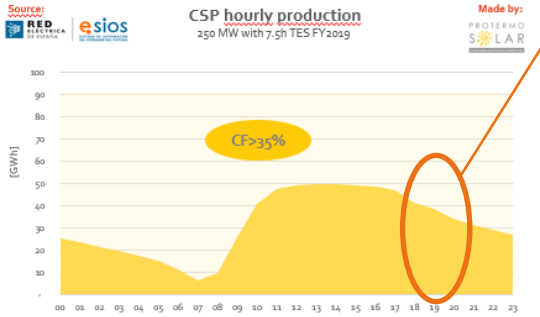
2

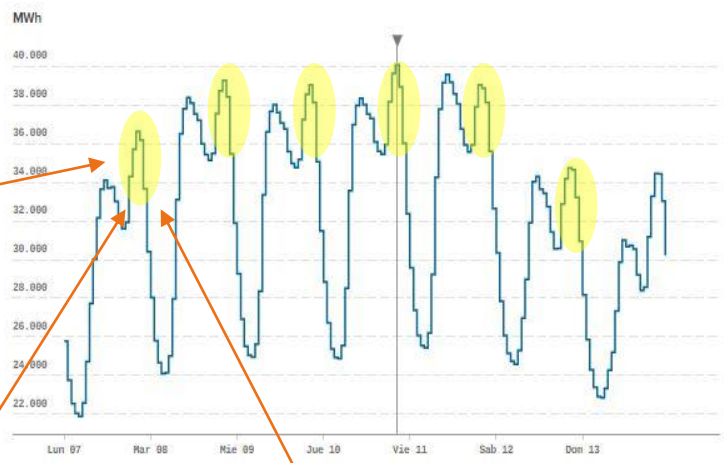
Optional:

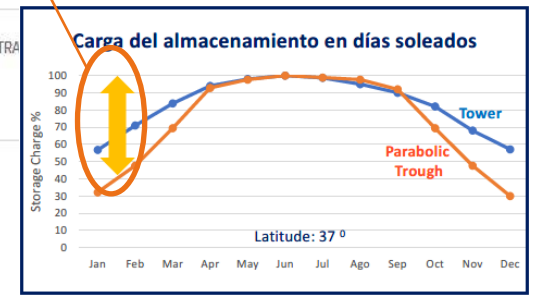
- Price arbitration
- Curtailment collection for later dispatch

(simply adding a electrical heater)









There are >7 GWhe already available, easily expandable to 12-14 GWhe and in 2030, according to the NECP, will be more than 60 GWhe. This storage can provide additional services to the system at a low cost.

1. CSP does not increase the system cost

Reduces curtailments by keeping same electricity cost

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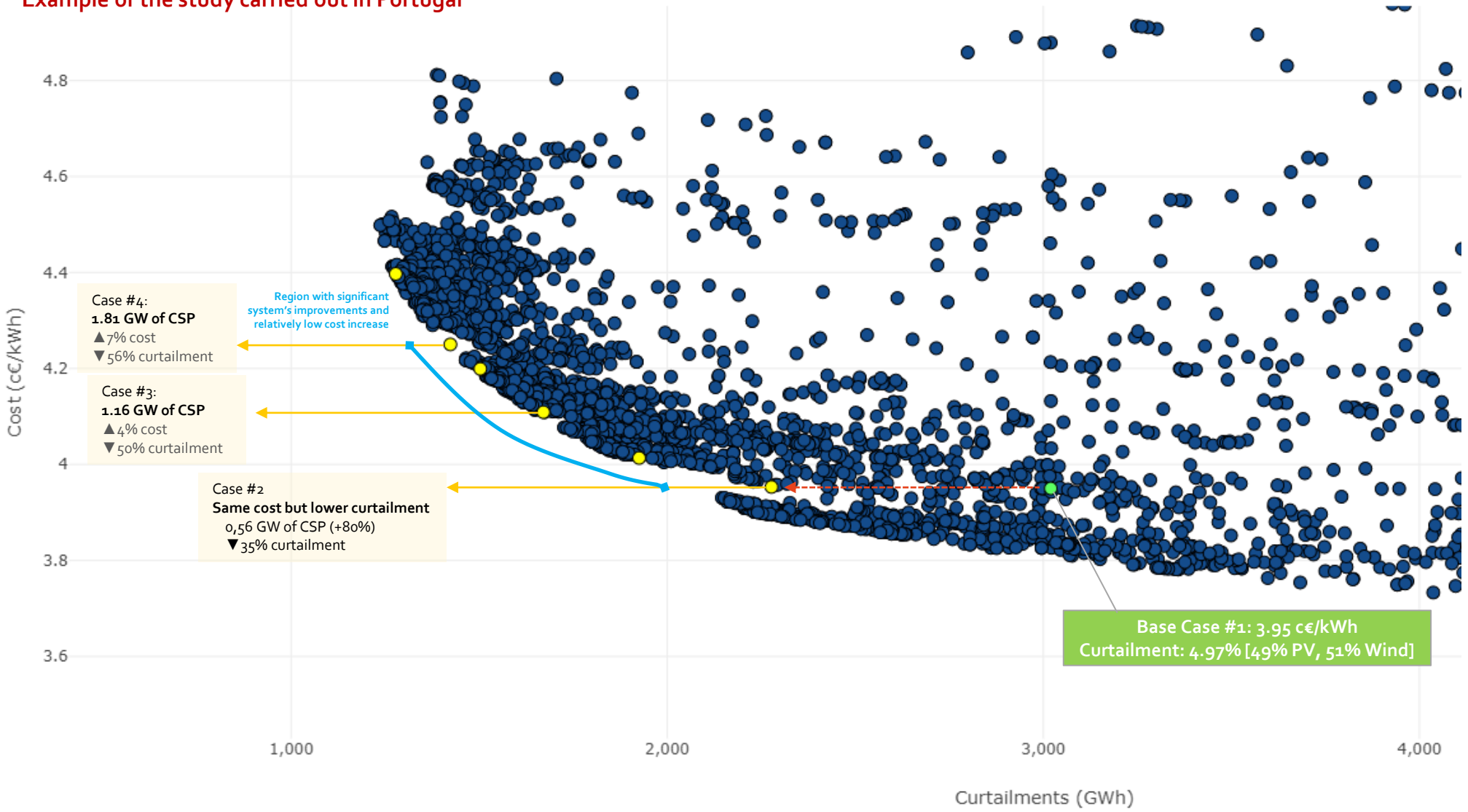
Example of the study carried out in Portugal



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1. What is, and what is not, CSP? Services of CSP
2. Worldwide outlook
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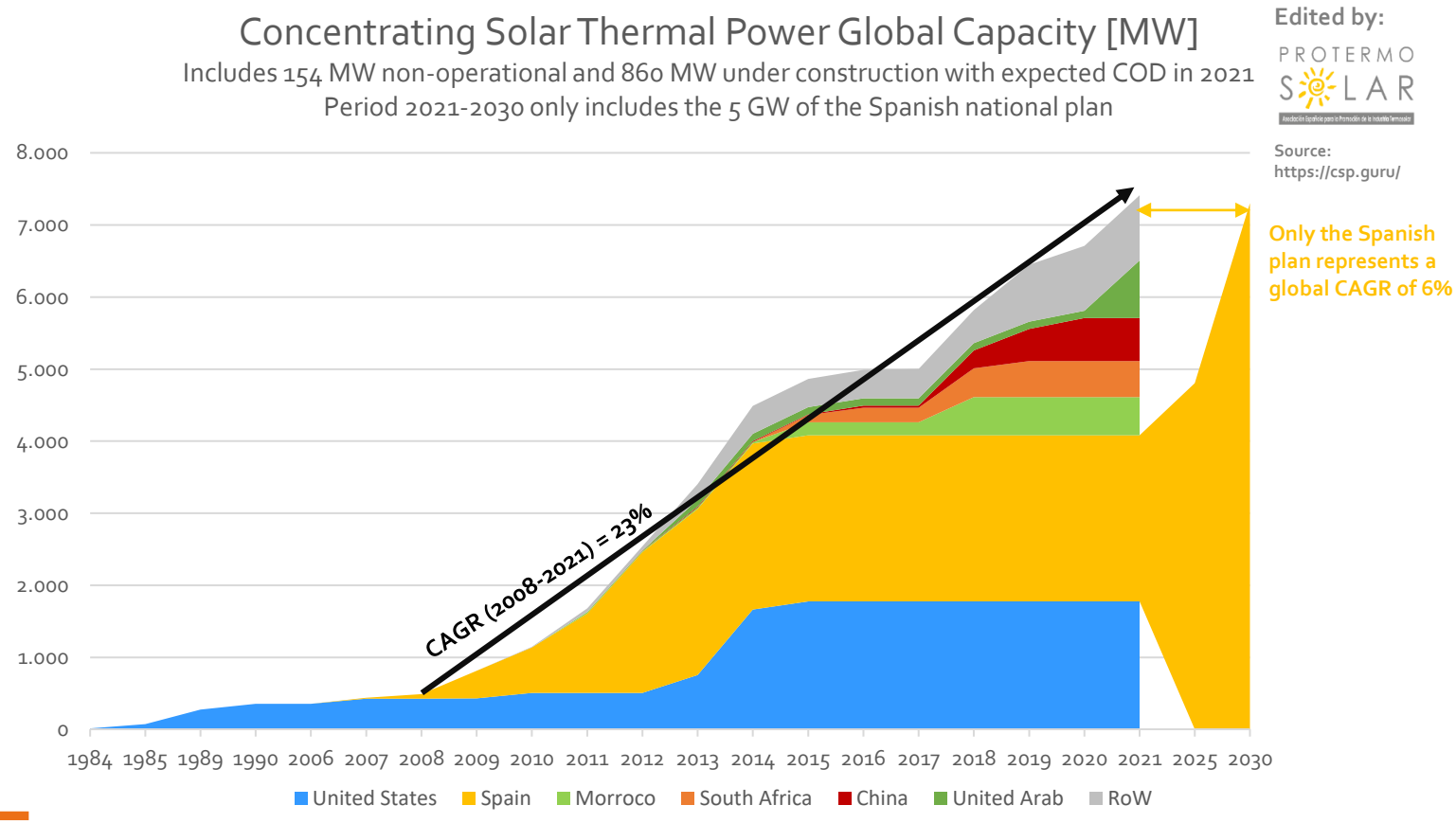
2. Recognition of the value provided by CSP storage

Spain foresees 5 GW of new CSP until 2030



Edited by: PROTERMO SOLAR

Source: https://csp.guru/

Only the Spanish plan represents a global CAGR of 6%

1. Spain led the CSP global growth in 2008-2013 with 2.3 GW

2. Despite the Spanish stoppage in 2014, other countries kept installing CSP

3. Spain has submitted to the EC* its plan to reduce CO_2 emissions in 2030; which includes 5 GW of new CSP.

4. This "new" CSP must include a significant storage to reach a number of operating hours >3.000 and up to 4.000 per year

Thanks to its massive storage, CSP is the perfect complement to PV to generate 24/7 using Solar energy at a very low price.

*European Commission

2. Spanish plan to install 5 GW of new CSP

The plan was submitted to the European Commission on the 31 March 2020

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Table 2.3. Evolution of the installed capacity of electricity (MW)

Generation system in the Target Scenario (MW)				
Year	**2015**	**2020***	**2025***	**2030***
Wind (onshore and offshore)	22,925	28,033	40,633	50,333
Solar photovoltaic	4,854	9,071	21,713	39,181
Solar thermal electric	2,300	2,303	4,803	7,303
Hydropower	14,104	14,109	14,359	14,609
Mixed Pumped	2,687	2,687	2,687	2,687
Pure Pumped	3,337	3,337	4,212	6,837
Biogas	223	211	241	241
Other renewables	0	0	40	80
Biomass	677	613	815	1,408
Coal	11,311	7,897	2,165	0
Combined cycle	26,612	26,612	26,612	26,612
Cogeneration	6,143	5,239	4,373	3,670
Fuel and Fuel/gas (non-peninsular territories)	3,708	3,708	2,781	1,854
Waste and other	893	610	470	341
Nuclear	7,399	7,399	7,399	3,181
Storage	0	0	500	2,500
Total	**107,173**	**111,829**	**133,802**	**160,837**

*The data for 2020, 2025 and 2030 are estimates of the Target Scenario of the INECP.

Source: Ministry for Ecological Transition and Demographic Challenge, 2019

Downloaded from: https://ec.europa.eu/energy/sites/default/files/documents/es_final_necp_main_en.pdf

2. Worldwide outlook

The global trend is bigger plants with presence of PV

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+

Mature

-

NooRo I, II y III (Marruecos) → 510 MW

PPA 25 years

CCP: 160 MW + 3h @ 18c$/kWh

CCP: 200 MW + 7h @ 13c$/kWh

MST: 150 MW + 7h @ 15c$/kWh

700 MW + 250 MW← Noor I (DEWA, EAU)

PPA 35 years, 15h storage

3x200 MW CCP

1x100 MW MST

250 MW PV

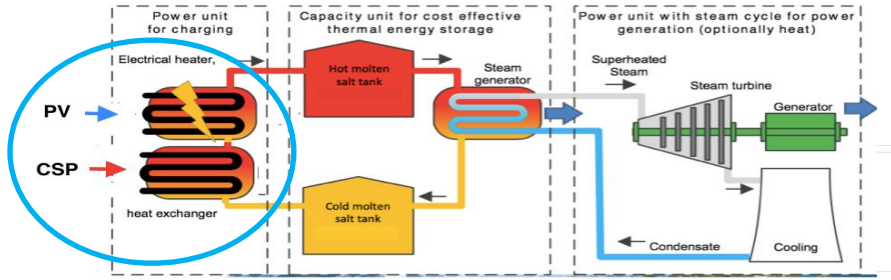
7,3c$/kWh CSP y 2,4c$/kWh PV

Midelt (Marruecos) → 800 MW

PPA 25 years

PV integrated into TES

7 c$/kWh



Redstone (Sudáfrica) → 100 MW

Torre con 12h almacenamiento

Tarifa 20 años con perfil horario

Likana (Chile)

Contrato financiero

PV diurna, CSP nocturna

China

5*100 MW

Adjudicados en octubre

2. Significant increase in size

The economies of scale are significant in the latest projects

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DEWA

Solar Field Plot

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3. CSP vs Batteries storage cost

CSP with storage is and remains cheapest for more than 4 hours storage

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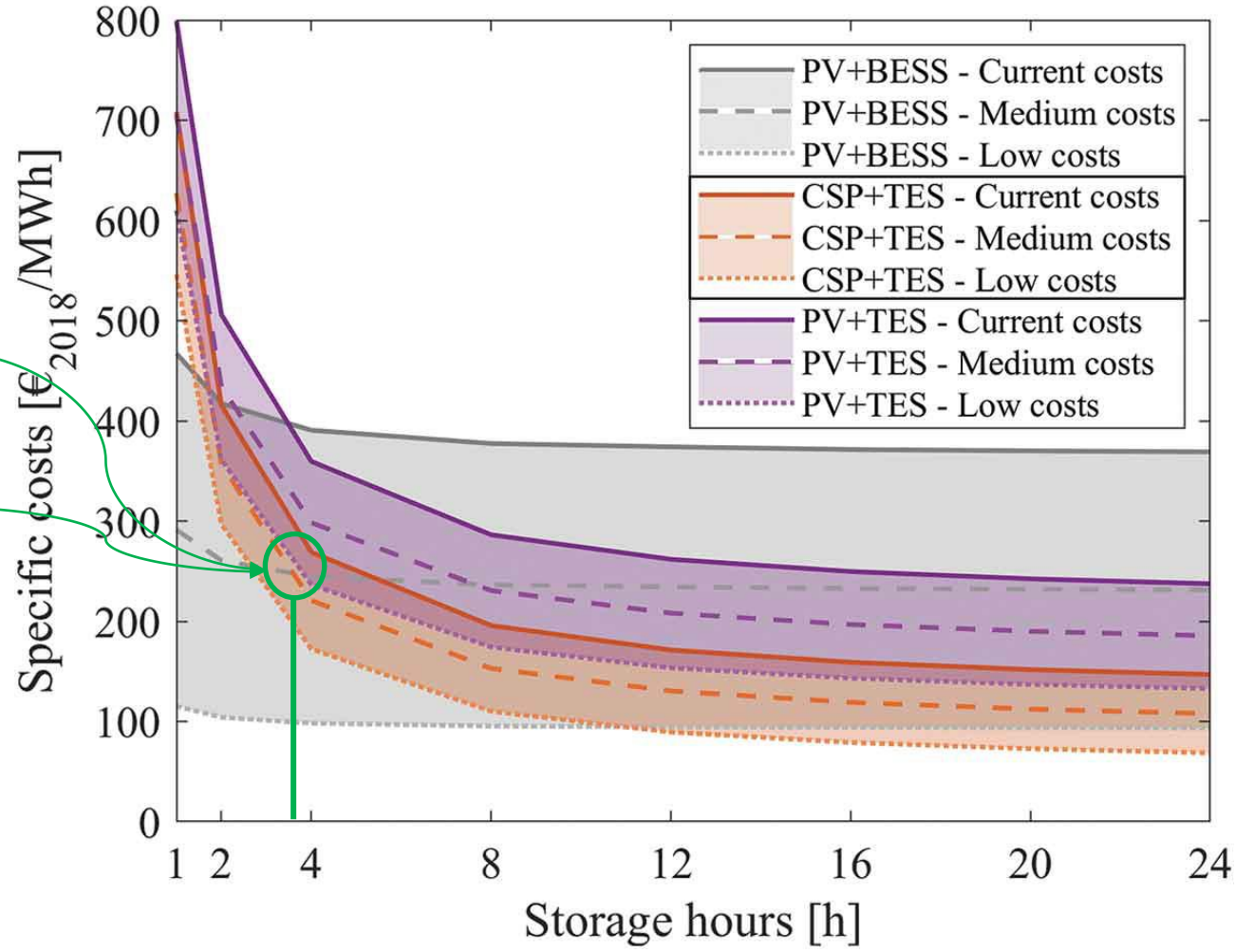
Results:

1. PV+BESS is cheaper than CSP+TES for short storage durations up to 2–3 hours.

2. CSP+TES is and remains cheapest for more than 4 hours storage except in the low-cost PV+BESS case where very strong PV+BESS learning is assumed, and the tipping point moves to 10 storage hours.



A very recent paper (2021) contrasted the cost of:

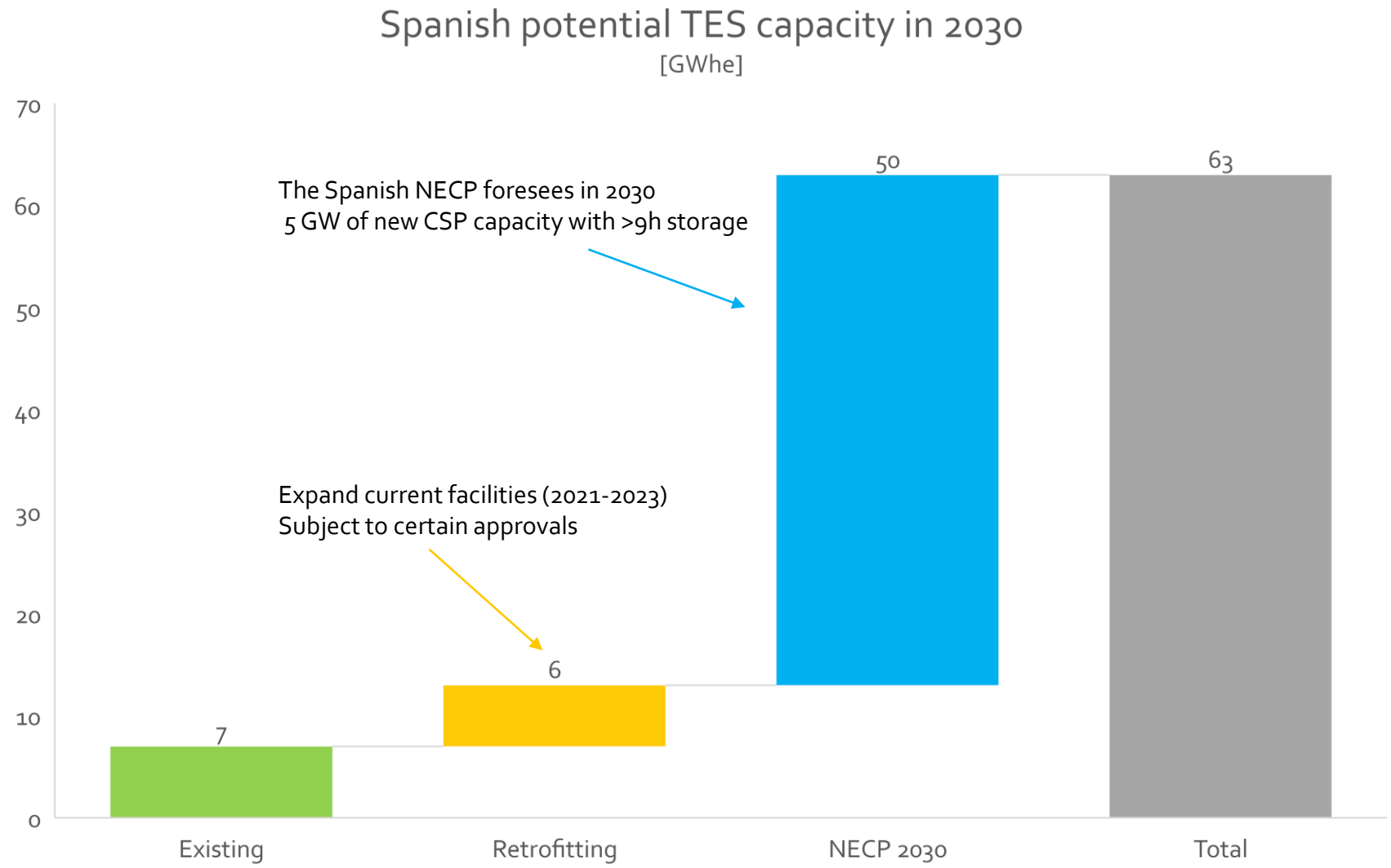
- PV + utility-scale Li-Ion batteries (PV+BESS)
- CSP + two-tank molten-salt (CSP+TES)
- TES using electric heater (PV+TES)

The reference case is a continuous load of 100MW during the pre-specified period (from 1 to 24h after sunset).

Franziska Schöniger, Richard Thonig, Gustav Resch & Johan Lilliestam (2021) Making the sun shine at night: comparing the cost of dispatchable concentrating solar power and photovoltaics with storage, Energy Sources, Part B: Economics, Planning, and Policy, DOI: 10.1080/15567249.2020.1843565
https://www.tandfonline.com/doi/full/10.1080/15567249.2020.1843565

3. TES potential in Spain

The potential TES capacity in 2030 would exceed the 60 GWhe



3. CSP is in the *España Vaciada*

The current TES capacity in Spain is 7 GWhe

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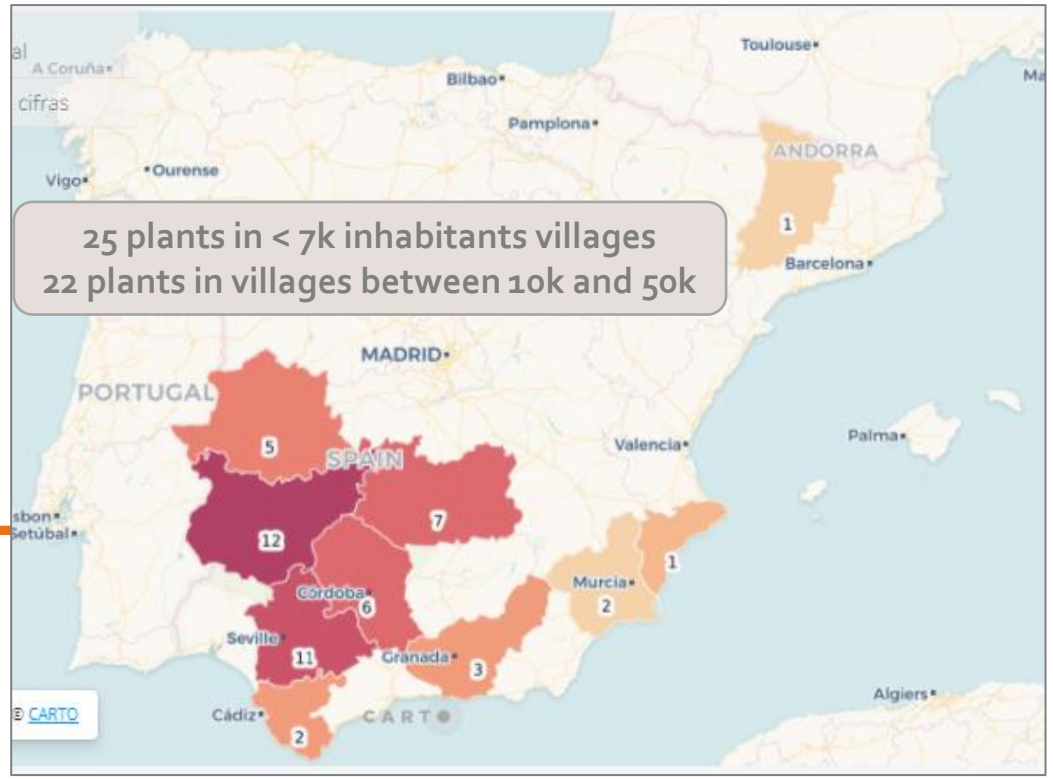
Spain

- 49 plants with a stable yearly generation of c. 5 TWh
- GDP contribution >1.450 M€ (2018) and > 5k jobs (source: APPA Renovables)
- Supply chain from the entire country (Asturias, País Vasco, Cataluña, Madrid…)
- Each plant is the economic drive of the region



Type	Plants	Power (MW)
Parabolic Trough 50 MW without Storage	27	1350
Parabolic Trough 50 MW With storage	17	850
Saturated Steam Tower	2	31
Molten Salt tower with storage	1	20
Fresnel	1	30
Hybrid Solar/Biomass	1	22
TOTAL	**49**	**2303**

3. Double the TES capacity by retrofitting

Many existing plants are designed for a TES add-on

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CSP and PV are mature as separate technologies, however there is plenty of room to implement as a single unit.

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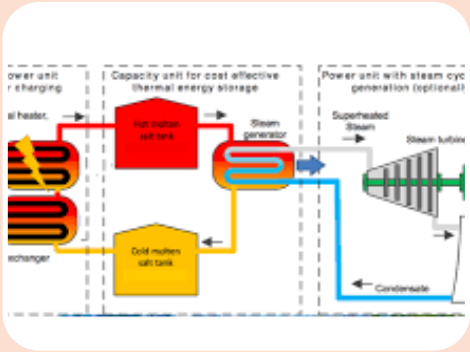

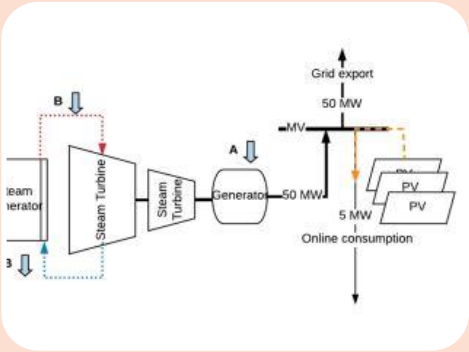

Generation to the grid

1. Improve design considering annual operating hours and capacity factors
2. Control system to keep max load to the grid
3. Improvement on the CSP fraction (new solar field designs)

Integration into the process (TES)

4. Analysis of PV integrated into the TES system – develop new systems for electrical charge
5. Research on control system to allow thermal and electrical load
6. Impact on tanks foundations

Auxiliary consumption

7. New electrical designs of the facility
8. Technology integration, use of PV, floating PV, batteries, etc. into the balance of plant.

Prototypes are needed as debt lenders and financing institutions would not facilitate a FOAK at commercial scale

Concentrating Solar Power plays a crucial role into the world electricity system to allow for a real decarbonization while decreasing the total system costs by phasing-out fossil fuels.

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1 Definition

- CSP is the alternative to the use of fossil fuels.
- CSP does not cannibalize PV but, on the contrary boost its development.
- While using comprehensive tools, CSP results into a lower system cost.

2 Services

- Night-time base load / back-up to intermittent RES
- Strategic reserve
- Price arbitration
- End user of curtailments

3 Storage maximization

- With the use of European funds, the existing storage can be doubled implying savings for the consumers.
- All new CSP plants will include at least 6h of storage.

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Thanks

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