

Representative CSP Case Studies and Assessment of the Pros and Cons

Lessons learned from the past

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ABOUT THE PROJECT

In the light of the EU 2030 Climate and Energy framework, *MUSTEC- Market uptake of Solar Thermal Electricity through Cooperation* aims to explore and propose concrete solutions to overcome the various factors that hinder the *deployment* of concentrated solar power (*CSP*) projects in Southern Europe capable of supplying renewable electricity on demand to Central and Northern European countries. To do so, the project will analyse the *drivers and barriers* to CSP deployment and renewable energy (RE) cooperation in Europe, identify future CSP *cooperation opportunities* and will propose a set of concrete *measures* to *unlock the existing potential*. To achieve these objectives, MUSTEC will build on the experience and knowledge generated around the cooperation mechanisms and CSP industry developments building on concrete CSP *case studies*. Thereby we will consider the present and future European energy market design and policies as well as the value of CSP at electricity markets and related economic and environmental benefits. In this respect, MUSTEC combines a dedicated, comprehensive and multi-disciplinary analysis of past, present and future CSP cooperation opportunities with a constant *engagement* and *consultation* with *policy makers* and *market participants*. This will be achieved through an intense and continuous *stakeholder dialogue* and by establishing a tailor-made *knowledge sharing network*.

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This report should be cited as:

Andrés Souza (ESTELA), Pablo Del Río & Christoph P. Kiefer (CSIC), Representative CSP Case Studies and Assessment of the Pros and Cons, MUSTEC Working Document Issue 2

The current report summarises key findings under the following MUSTEC publications:

Souza A. (2018): Selection of representative and strategic STE projects potentially suitable for cooperation. Deliverable 5.1, MUSTEC project, ESTELA, Brussels

Del Río, P. and Kiefer, Christoph P. (2019): Evaluation of the Pros and Cons of Different Alternative CSP Projects and Policy Implications. Deliverable 5.2, MUSTEC project, IPP-CSIC, Madrid, Spain

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1 INTRODUCTION

MUSTEC aims to assess the opportunities that renewable energy cooperation may bring to the future market uptake of CSP in Europe. In this context, the focus of this report is providing a bottom-up comprehensive analysis of alternative existing CSP projects with heterogeneous techno-economic configurations, locations and sizes. A preliminary evaluation of the pros and cons of each one in the framework of European cooperation is carried out.

A set of project typologies that could be deployed at commercial scale and are considered by industry as “representative” for what can be marketed today were identified by MUSTEC. The corresponding results are included in (Souza, 2018). The selection led to 6 project types, which reflect different operational profiles (off-taker needs) and are considered today that they will be the basic conceptual building blocks for any bankable CSP-based solution in the future, suitable to fit under the EU cooperation mechanisms. Their main parameters define the basic configurations and operational profiles to be used for investigating market uptake opportunities for CSP in Europe.

The objective of the above-mentioned analysis is to support the development of a methodological framework to assess selected CSP project types and to evaluate the pros and cons of different alternatives for CSP projects. A tailor-made methodological framework to assess and compare those projects is developed. Several key techno-economic variables which underlie the structure of different types of projects are identified. Starting from an initial selection of a broad range of variables that characterize the selected CSP projects, the most relevant variables have been selected based on a literature review, a partner expertise in CSP projects and consultations with main stakeholders in the sector. Afterwards, an assessment of the pros and cons of different alternatives for CSP projects has been carried out. In this frame, the assessment is based on the gathering of hard data on the assessment variables as well as intermediate factors (drivers and barriers to the use of cooperation mechanisms for CSP, policy goals and context factors) and in-depth stakeholder interviews. The assessment of those pros and cons allows us to provide some general policy recommendations.

The elicited results are wrapped up into a simple set of project typologies that could be deployed at commercial scale and are considered by industry as “representative” for what can be marketed today. This means that these typologies are today and will be from now on the basic conceptual building blocks for any bankable CSP-based solution, suitable to fit under the EU cooperation mechanisms. Their main parameters define the basic configurations and operational profiles to be used for investigating market uptake opportunities for STE (Solar Thermal Electricity) in Europe.

In addition, corresponding contextual industry and market information is provided together with further considerations about the potential development of the stated options related to the current framework for procurement of manageable RES power in Europe and other contingencies derived from the market experience of ESTELA industrial members.

The intended reach of this work is therefore to set out a comprehensive set of STE projects that today can be considered representative of the current real needs of off-takers and/or could be a

solution for tackling future needs as identified today; doing so, this should lead to a relaunch of the European STE “home market” and make use of the cooperation mechanisms provided by European legislation, making possible to sell electricity e.g. from a southern to northern country.

Besides the best available market knowledge and experience of the industry members of ESTELA, the regular consultations with relevant stakeholders, this work stems also from an analytical process (described further on) based on desk research.

2 SELECTION OF REPRESENTATIVE CSP PROJECTS

2.1 Methodological approach

In the frame of the MUSTEC project, a selection of representative and strategic CSP projects potentially suitable for cooperation was carried out. Their main parameters define the basic configurations and operational profiles to be used for investigating market uptake opportunities for CSP in Europe. This section summarizes the respective work, which is included in (Souza, 2018), developed in the framework of the MUSTEC project.

The intended reach of this analysis is to set out a comprehensive set of CSP projects that today can be considered representative of the current real needs of off-takers and/or could be a solution for tackling future needs as identified today. However, it was not intended to define and point out a specific, “most likely” configuration with exact parameters of the next plant that “should” be built in Europe. The main scope was rather to narrow down the options to projects that “make sense” today for further detailed study. On the market frontlines, these are the project typologies that would be used for further conceptual work and/or tailored commercial offers to concrete clients, among which a successful case for cooperation could arise.

The first step taken was to define how the feature “representativeness” would be considered throughout the development of the task. Defining what is “representative” is critical because this feature can be defined according to different possible criteria, which would yield diverging results. Therefore, it was necessary to identify the criteria which would lead a project to be considered as “representative” and thus, be selected as a case to be further analyzed and used as a base for the proposal of potential business cases. The main criteria for identifying the typologies of projects that would make commercial sense are considered to be related to:

1. Appropriateness to match an off-taker’s needs.

The selection of plants to analyze aims to exemplify the different most typical operational profiles, to select those that could represent successful operating cases and to provide options answering present and future market needs in Europe. The operational profiles include: stand alone, stand-alone (baseload profile), peaker profiles (time-of-day premium), complementary dispatch to PV, “commercial hybrid” or co-located CSP+PV units and full-firmness through hybrid configurations.

2. Configuration variables.

The technical configuration of a given plant is essentially the consequence of the requested or intended output profile, with some distinctions that can be made between different types of technology used for two plants that operate in a similar way. This second criterion integrates different features of the plants that are also considered as sub-criteria:

- i. Size (generation capacity)

ii. Type of technologies used and hybridization options

- a. Hybridization options
- b. Seasonal balance.
- c. Storage.
- d. Complementary criterion: location.

Table 1 summarizes the selection criteria.

Table 1: Summary of selection criteria.

Criteria	Categorization	Proposed Values
i. Appropriateness to match an off-taker's needs	– Operational profile responding to a specific need	1. Standalone (tower/PT, medium/big storage) 2. Standalone (baseload) 3. Peaker (<i>time of day</i> premium tariff) 4. Full firmness (hybrid configuration) 5. "Commercial" hybrids or co-located plants (hybrid configuration (PV+CSP)) 6. Complementary dispatch to PV
ii. Configuration variables		
a. Size/Power output (capacity)		– Between 100 and 200 MW
b. Type of technologies used	– Hybridization options – Seasonal balance	– Gas (HySol), Biomass – Central Receiver (Tower) – Parabolic trough
c. Storage		– 8 to 15 hours
iii. Complementary criteria		
a. Location	– Direct Normal Irradiation (DNI) – Access to land/land-use permits – Access to the transport or distribution system network – Water use concessions – Political will	– Sites with a DNI of at least 2,000 [kW/m²/year] – In Spain, Portugal, Italy, Greece, Cyprus or Morocco

Source: Souza, 2018.

2.2 Summary of selected projects

In Table 2 the operational profiles related to off-taker needs are described and a set of plants which exemplify the operational profiles identified as representative is presented and data on the configuration variables is provided.

Table 2: Selection of power plants that exemplify representative operational profiles and their configuration variables.

Operational profile	Relation to off-taker needs	Plant selected as example	Configuration variables			
			Size/ Power output	Technology	Storage capacity [hours]	Location
Standalone	Fulfilling national RES targets in the energy mix (disregarding other conditions or constraints, such as cost), established by the recipient country in its annual Integrated Plan submitted to the EU Commission for compliance with the percentages of cross-border exchanges between countries to be established by the new 2020-2030 Renewables Directive (REDII).	“La Africana” (Spain - parabolic trough)	50 MW	Parabolic trough	7.5	Córdoba, Spain
		Noor III (Morocco – central tower receiver)	150 MW	Central tower receiver	7.5	Ouarzazate, Morocco
Standalone (Baseload profile)	Having a baseload operation as many hours as possible on sunny days, in the face of the planned shutdown/decommissioning of conventional power plants.	Gemasolar (Spain)	20 MW	Central tower receiver	15	Sevilla, Spain
Peaker profile (time-of-day premium)	Increasing the contribution of renewables to the electrical system in the hours of highest consumption, to compensate for the lack of flexibility of the variable renewable sources (VarRES) of their system.	Xina Solar One (South Africa)	100 MW	Parabolic trough	5.5	Pofadder, South Africa
Complementary dispatch to PV	Reducing the back-up required in the hours in which PV, after sunset, would not be able to generate electricity, to achieve a greater contribution of solar energy without exceeding the thresholds of PV power that could lead to curtailments (i.e. having off-takers with a specific interest in covering the night demand peaks with RES at a reasonable cost, thus recognizing the value of CSP).	DEWA (Dubai, UAE)	100 MW (tower) plus 3x 200 MW (PT) units	Central tower receiver & Parabolic trough	15 (for tower unit) & 11 (for PT units)	Mohammed bin Rashid al-Maktoum Solar Park, Dubai, UAE
“Commercial hybrid” or co-located CSP+PV units	Importing manageable (solar) renewable energy at the lowest possible cost, considering hybrid PV-CSP power plants (“commercial hybrids” or “co-located”), integrating the manageability that the storage capability of the solar-thermal power station provides and the reduction of the global price	Cerro Dominador – Atacama-1 Project (Chile)	110 MW CSP (plus 100 MW PV)	Central tower receiver plus PV	17.5	Atacama Desert, Chile
		Noor Midelt (Morocco)	2 units of 150-190	Parabolic trough or tower* plus	Minimum 5 hours*	Midelt, Morocco

	that the photovoltaic system can bring.		MW	PV		
Full firmness through hybrid configuration	Ensuring the contribution of CSP plants to power supply with absolute firmness in a certain number of hours per year, by hybridizing the solar-thermal power plant with natural gas (but demanding a major percentage of the solar contribution throughout the year).	HySol concept	N/A	Parabolic trough & gas turbine hybridised through TES	N/A	Spain

Source: Souza, 2018.

3 PRESENTATION OF SELECTED PROJECTS

3.1 “La Africana” Plant – *Standalone (parabolic trough)*

The Africana Energía plant, or “La Africana”, is a 50 MW, parabolic trough STE plant, that spans over 270 hectares, and has 550,000 m² of mirrors and 168 loops. It is located between the municipalities of Fuente Palmera, Guadalcazar, Almodóvar del Río and Posadas, in the province of Córdoba, Spain. It was promoted by the group formed by Magtel, TSK and Grupo Ortiz. The plant incorporates a thermal energy storage system based on molten salts that can provide up to 7.5 hours of heat storage for electricity production. The complex can be seen in Figures 1 and 2 below, whereas Figure 3 shows the storage tanks and Figure 4 shows the parabolic trough collectors. It produces around 170,000 MWh/year, which is equivalent to the consumption of about 100,000 homes.



Figure 1: Africana Energía Complex (aerial view 1)



Figure 2: Africana Energía Complex (aerial view 2)



Figure 3: Africana Energía - Molten salts storage tanks



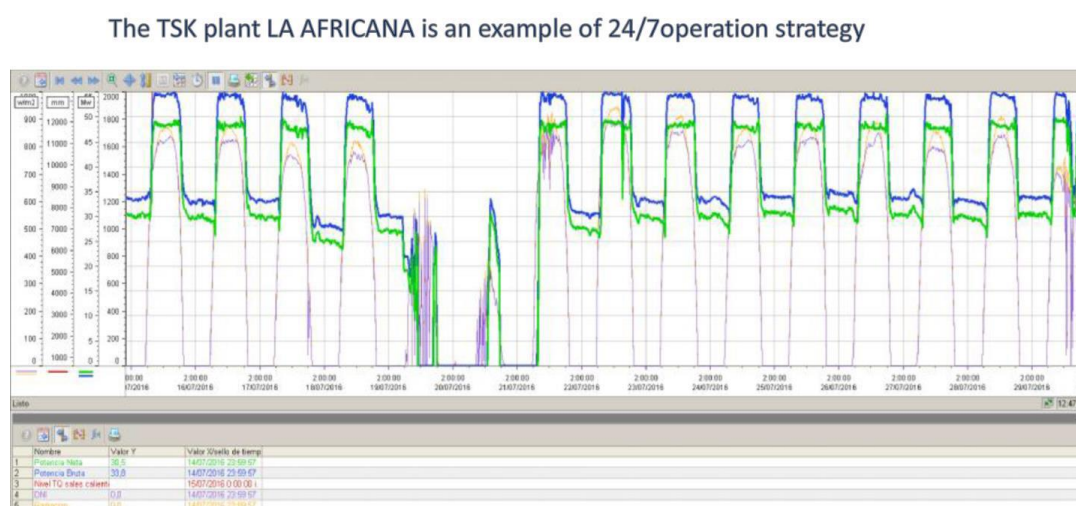
Figure 4: Africana Energía - Parabolic trough collectors

To incorporate electricity produced by STE power plants and increase the percentage of renewables without specific dispatch criteria, while taking advantage of the grid stability that these plants provide to areas with instability risks due to the large presence of asynchronous renewable plants (e.g. PV or Wind), the plants could be designed with intermediate storage

volumes (6 - 8 hours) and a size of solar field that practically does not require having to fold mirrors at any time during summer.

The plants would produce in spring, autumn and winter, at nominal power as soon as possible in the morning and would extend their operation, also at nominal power until the minimum safety level of the hot tank is reached. In the case of the Spanish power plants, for example, the power output, when operating from the tanks, is usually not the nominal one but somewhat lower, due to the design of the tank discharge exchangers. However, during the summer months, these plants would prefer to operate continuously (24/7) even if they must reduce the nominal power after sunset. In this way they avoid having to stop and start the turbine every day, which has a significant economic impact on maintenance costs.

The following chart (Figure 5) shows the operating profile of the “La Africana” plant in a typical series of consecutive days in summer.



The green line represents the typical net dispatch profile of La Africana during the summer season.

Figure 5: Dispatch profile of the Africana Energía plant

Tables 3 and 4 below summarise the values for the configuration variables, together with additional information regarding the tariff, off-taker, cost and jobs created.

Table 3: Configuration variables

La Africana	
Location	Posadas (Córdoba), Spain
Average DNI of site	1,950 kWh/m ² /y
Power output capacity and energy production	Turbine Capacity: 50.0 MW & 180,000 MWh/y (approx.)
Storage Capacity	Storage Type: 2-tank indirect, Storage Capacity: 7.5 hours, Thermal Storage Description: 60% Sodium Nitrate, 40% Potassium Nitrate.
Types of technologies (including hybridization options used)	Parabolic trough, Turbine Output Type: Steam Rankine, Cooling Method: Wet cooling

Table 4: Additional information

La Africana	
Generation Off-taker(s):	Endesa
Cost (approx.)	387,000,000 Euros
Project Type	Commercial
PPA/Tariff Type	"Real Decreto 661/2007" initially
PPA/Tariff Rate	27.0 Euro cents per kWh
PPA/Tariff Period	25 years
PPA/Tariff Information	Feed-in Tariff
Annual O&M Jobs	40

3.2 Noor III Project – Standalone (Central receiver on tower)

The Noor III project (central receiver on tower with molten salts in receiver and storage) completes Moroccan Noor Solar Complex and is considered as the second utility-scale, commercial CSP tower with molten salt storage in the world. The realization cost is approximately 807 million Euros and at the time of writing (Souza 2018) was in the finalization phase, scheduled to start commercial operations in October 2018. In December 2018, Noor III completed a 10-day reliability test demonstrating that the project can provide continuous rated power even in the absence of sunlight¹. The plant is currently in operation.

Noor III uses tower technology with a gross power of 150 MW and a storage capacity of 7.5 hours, it covers an area of 750 hectares, and it is expected to supply 500 GWh per year, under the Direct Normal Irradiation conditions in Ouarzazate of 2,635 kWh/m²/year. Its solar field features 7,400 heliostats of 178 m² each that follow the sun and direct its rays into the central receiver at the top of a tower of 250 m. This plant is owned and operated by MASEN. However, the participants involved are ACWA POWER as the developer, SENER as main technology provider (solar field, solar receiver, storage system and the power block) and China's SEPCOIII (shares EPC duties with SENER), which is mainly involved in all the components and subsystems of the Power Island.

Noor III will deliver 140 MW of net capacity during Morocco's Peak Hours' Time Slot. The remaining 10 MW supplies power for the site itself (parasitic load). With 7.5 hours of storage, Noor III was optimized to meet the demand during five peak hours daily, in which the electricity price is 18% higher. The first two STE plants at Ouarzazate, Noor I and Noor II, both parabolic troughs, have 3 and 6 hours of storage respectively.

This solar complex is part of the strategy to increase the share of renewable energies in the national energy mix, from around 30% in 2009 to 42% in 2020. Morocco's 2009 Solar Plan calls for the development of 2,000 megawatts of solar energy by 2020. With the approximately 570 MW of solar power of the complex (including the future Noor IV, 70 MW PV plant), it will be the largest solar complex in the world (until the completion of the DEWA project in Dubai). Additionally, it will contribute to the creation of a new green industry, which is in line with Morocco's objectives of a more secure energy supply, energy diversification, CO₂ emission reductions and increased employment. It is estimated that the complex will produce the equivalent of the annual electricity consumption of around 1,157,000 Moroccan households.

¹ <https://www.powermag.com/moroccan-molten-salt-tower-project-clears-reliability-test/>

Figures 6 and 7 below show the Noor III site and the heliostats.



Figure 6: Aerial view of the Noor complex



Figure 7: Ground view of a Noor III heliostat

Tables 5 and 6 below summarise the values for the configuration variables, together with additional information regarding the tariff, off-taker, cost and jobs created.

Table 5: Configuration variables

Noor III	
Location	Ouarzazate, Morocco
Average DNI of site	2635 kWh/m ² /y
Power output capacity and energy production	Turbine Capacity: 150 MW (134 MWe Net) & Estimated Energy production: 550 GWh/year
Storage Capacity	Storage Type: 2-tank direct, Storage Capacity: 7.5 hours, Molten salt
Types of technologies (including hybridization options used)	Power tower (central receiver), Turbine Output Type: Steam Rankine, Cooling Method: Dry cooling

Table 6: Additional information

Noor III	
Generation Off-taker(s):	ONEE (National Office for Electricity and Potable Water)
Cost (approx.)	807 Million Euros
Project Type	Commercial
PPA/Tariff Type	PPA
PPA/Tariff Rate	27.0 Euro cents per kWh
PPA/Tariff Period	25 years
Annual O&M Jobs	60

3.3 “Xina Solar One” Plant (Abengoa) – Peaker with “time of day” premium

The “Xina Solar One” plant is located close to Pofadder, in the Northern Cape Province in South Africa, and next to KaXu Solar One plant. The plant features parabolic trough technology, with a 5-hour thermal energy storage system using molten salts. Xina Solar One is Abengoa’s third solar project in South Africa and has a total installed capacity of 100 MW. The construction of this plant started at the end of 2014 and became operational (commercially) by mid-2017.

It belongs to a consortium of which 40% is controlled by Abengoa, with 20% of the holdings for each of the other members: Industrial Development Corporation, the Public Investment Corporation and KaXu Community Trust. Abengoa developed the project on behalf of the consortium.

The project supplies clean electricity to Eskom, South Africa's power utility, under a 20-year power purchase agreement and it is expected produce energy to serve more than 90,000 households and prevent the emission of more than 398,000 tons of CO₂ per year when compared to a natural-gas plant. These two 100 MW plants will jointly shape one of the largest solar complexes in Africa.

In addition, its job creation peaked at over 1,300 positions during construction, and it is expected to create 45 permanent positions during plant O&M. This project contributes to South Africa’s goals of introducing up to 17,800 MW of renewable energy by 2030 and reducing its dependence on oil and natural gas.

The deployment of solar thermal power plants in South Africa has had different support frameworks, which justifies the specific design of each of them. In rounds 1 and 2, there was a feed-in-tariff, so plants with reduced investment volume and specific designs were designed to facilitate their financing, as well as others with a high load factor and large storage volume. However, in rounds 3 and 3.5 the remuneration was established based on the “time of day”

scheme, with a premium of 270% of the tariff for the generation between 16:30 and 21:30 hours, and not remunerating generation at all between 22:00 and 5:00 of the next day.

Pictures of the site can be found below (Figures 8 & 9).



Figure 8: Aerial view of Xina Solar One Plant (South Africa).



Figure 9: Xina's Parabolic trough collectors.

The Xina plant is a good example of a design typology that responds to a need of maximizing income with those conditions. The storage of these type of plants is usually relatively small (5 hours), but the solar field is oversized to generate the maximum possible during all the days of the

year, including in winter. However, during summer, they have to shut down a certain percentage of the solar field, which at certain times could reach 10%. The Xina storage system has been designed to run the plant for about 5 hours at full load during the PPA's peak time, between 16:30 and 21:30h.

Tables 7 and 8 below summarise the values for the configuration variables, together with additional information regarding the tariff, off-taker, cost and jobs created.

Table 7: Configuration variables

Xina Solar One	
Location	Pofadder, Northern Cape Province, South Africa
Average DNI of site	2,816 kWh/m ² /y
Power output capacity and energy production	Output: 100 MW, Expected energy generation 380GWh/year.
Storage Capacity	Storage Type: 2-tank indirect, Storage Capacity: 5.5 hours, Thermal Storage Description: Molten salt
Types of technologies (including hybridization options used)	Parabolic trough, Output Type: Steam Rankine, Cooling Method: Dry cooling

Table 8: Additional information

Xina Solar One	
Generation Off-taker(s):	Eskom (South Africa's power utility)
Cost (approx.)	880 million USD
Project Type	Commercial
PPA/Tariff Type	"Time of day – Peak time tariff"
PPA/Tariff Rate	270 % over normal rate
PPA/Tariff Period	20-year power purchase agreement
PPA/Tariff Information	Peak time (270% of Standard tariff)
Annual O&M Jobs	45

3.4 Gemasolar (Torresol Energy) – Standalone baseload

The "Gemasolar" plant is located in the area of Fuentes de Andalucía in the region of Andalucía, Spain. It was developed by Torresol Energy, a joint venture owned in 40% by MASDAR and 60% by SENER. It is currently operated by Torresol O&M.

The plant spans over 195 hectares and features a power tower technology (central receiver, 140 m height), has 2,650 heliostats and a 15-hour storage system (2 tank direct, 5,000 annual equivalent hours, molten salts), which allowed it to become the world's first utility-scale plant to apply a tower receiver with storage for all night operation. It has a net power output of approximately 19.9 MW (17 MW registered) and it supplies to the network approximately 80 GWh of energy, serves about 27,500 homes and helps to avoid the emission of 28,000 tons of CO₂/year.

Due to its efficient operation, accurate predictability, and capacity to produce energy around the clock (achieving a record of 36 days uninterrupted), it was selected as a representative project from Spain for the COP21 conference in Paris.

Figures 10-12 below provide an overview of the plant, the solar tower and the heliostat field.



Figure 10: Aerial view of Gemasolar plant.



Figure 11: View of Gemasolar power tower from the centre road of the plant



Figure 12: View of the heliostat field with the first rings in "defense" (flat) position.

The Gemasolar plant is an example of a design that, although it was built within the general support regime in Spain, it was intended to be presented as a prototype of a solar thermal baseload plant.

The storage system has a large volume (for 15 hours) and the solar field is oversized in order to produce the nominal load both during daylight hours and after sunset. From May and until the end of September, Gemasolar can chain consecutive days of operation at nominal power, 24 hours a day. Moreover, it can produce 24 hours a day during the winter months, provided that it lowers the power output for a few hours.

Tables 9 and 10 below summarise the values for the configuration variables, together with additional information regarding the tariff, off-taker, cost and jobs created.

Table 9: Configuration variables

Gemasolar	
Location	Fuentes de Andalucía, Sevilla, Spain
Average DNI of site	2,100 kWh/m ² /y
Power output capacity and energy production	Power output: 19.9 MW (17 MW registered) & 80,000 MWh/y
Storage Capacity	Storage Type: 2-tank direct, Storage Capacity: 15 hours, Thermal Storage Description: One cold-salts tank (290°C) from where salts are pumped to the tower receiver and heated up to 565°C, to be stored in one hot-salts tank (565°C). Molten salts.
Types of technologies (including hybridization options used)	Output Type: Steam Rankine, Cooling Method: Wet cooling

Table 10: Additional information

Gemasolar	
Generation Off-taker(s):	Spanish Electrical System
Cost (approx.)	230,000,000 Euro
Project Type	Commercial
PPA/Tariff Type	Feed-in-Tariff
PPA/Tariff Rate	0.27 EUR/kWh initially
PPA/Tariff Period	25
PPA/Tariff Information	"R.D. 661/2007" initially
Annual O&M Jobs	40

3.5 DEWA-IV Project (ACWA Power) – Complementary operation to PV

The DEWA IV (fourth phase of the development) project is a pioneer in realizing the vision of solar thermal and photovoltaic energy working in a complementary manner, which may constitute the most rational approach to move towards a CO₂-free electricity generation in the countries of the solar belt.

In fact, the solar thermal units are the key part that will allow the incorporation of relevant volumes of photovoltaic and wind power plants without the need for gas backup on sunny days. What is more, the prices at which solar thermal generation has been offered with this operational/dispatch profile are lower than those offered by new combined cycles working a reduced number of hours per year.

The project is located in the Mohammed bin Rashid al-Maktoum Solar Park, which is approximately 80 km south from Dubai, and is the largest single-site solar park in the world, with a planned capacity of 1,000MW by 2020, and 5,000MW by 2030, with a total investment of AED 50 billion.

This fourth phase of development of the energy production in the park is the largest investment in a STE project in the world (AED 14.2 billion or some 3.3 billion EUR). The project will bring 700MWe of power and it is being implemented by Saudi Arabia's ACWA Power, the "Silk Road Fund" and China's Shanghai Electric. The consortium bid the lowest Levelised Cost of Electricity (LCOE) of 7.3 USD cents per kWh (although it is expected that the upcoming development in Midelt, Morocco, could be lower than this). The project will feature the world's tallest solar tower, at 260 metres and will be commissioned in stages, starting from Q4 of 2020 (according to official sources, DEWA).

It will be comprised of 3 Parabolic Trough units of 200 MW with 11 hours of thermal storage and 1 Power Tower unit of 100MW with 15 hours of thermal storage.

However, the most relevant feature of this project, and one of the reasons why it was selected as representative of the relevant operational profiles for potential business cases, is that it was conceived to collect the solar heat during the day and only start producing electricity between 4 pm and 10 am, which means that the operator can make the most of PV during the day and then switch to STE to supply demand after sunset. Typically, night-time energy supply was the preserve of fossil fuels, but STE has resulted to be the best renewable alternative. The DEWA 700 STE project is part of Dubai's plans to increase its share of renewable power generation to 25% by 2030 and 75% percent by 2050.

Tables 11 and 12 below summarise the values for the configuration variables, together with additional information regarding the tariff, off-taker, cost and jobs created.

Table 11: Configuration variables

DEWA-IV	
Location	Mohammed bin Rashid al-Maktoum Solar Park, Dubai
Average DNI of site	1,850 kWh/m ² /y
Power output capacity and energy production	700 MWe
Types of technologies (including hybridization options used)	100 MW power tower with 15 hours of thermal storage plus three 200 MW Parabolic Trough plants with 11 hours of TES (7.5GWh), Dry cooling

Table 12: Additional information

DEWA-IV	
Generation Off-taker(s):	Dubai Electricity and Water Authority
Cost (approx.)	3.9 billion USD
Project Type	Commercial
PPA/Tariff Type	PPA
PPA/Tariff Rate	\$7.3 USD cents per kWh
PPA/Tariff Period	35 years
PPA/Tariff Information	Contract
Annual O&M Jobs	TBD

3.6 Atacama-1 project (Cerro Dominador complex, ABENGOA) / NOOR Midelt Project (ACWA) – “Commercial hybrid” (CSP+PV)

The “Atacama 1” and the “Noor Midelt” project correspond to the same principle of complementarity between photovoltaic and solar thermal generation with storage and dispatch after sunset as that of the DEWA project, but conceived at the level of a single business unit in which the average generation price of the two plants - PV and solar thermal installed on the same site - can be very competitive.

For instance, the Atacama project has successfully competed against combined cycles for 24/7 continuous production and the Midelt project, also featuring a combined production unit, will soon reveal its costs (expected to be lower than the DEWA project), that will also compete against fossil generation.

The large-scale deployment, both in combined business units or in separate business units (as the DEWA project), is the way to drastically reduce gas back-up. The Atacama-1 STE plant is the first concentrated solar plant in Latin America. Altogether, the project’s solar field will cover 1,000 hectares (including PV), will have 10,600 heliostats and it will prevent the emission of approximately 870,000 tons of CO₂ per year, producing base load energy (24 hours a day). It will help Chile achieve its aim of producing 20% of its electricity from clean energy sources by 2025.

The Noor Midelt project is part of the Moroccan Noor Solar Plan, which envisions a total capacity of 2,000 MW by 2020. Two ~400MW hybrid concentrated solar power (CSP) and photovoltaic (PV) plants will make up the first phase and for each project, 150 to 190 MW would be provided by STE with a minimum of 5 hours storage. The tender process was launched in July 2016 and until now, 5 consortia have pre-qualified for further evaluations, including those led by: ACWA Power, EDF Energies Nouvelles, ENGIE, Innogy SE and JGC, which were invited to answer a Request for Proposal (RFP), whose result will be published by the end of 2018. This plant, as a part of the Noor solar Plan, will be critical for achieving the country’s goal of producing 52% of its electricity through renewable energy by 2030.

Table 13: Configuration variables

Atacama 1 & Midelt		
Location	Antanofagasta, Chile	Midelt, Morocco
Average DNI of site	3,300 kWh/m ² /y	2,360 kWh/m ² /y
Power output capacity and energy production	100 MW PV plus 110 MW CSP	600 – 800 MW
Storage Capacity	Storage Type: 2-tank direct, Storage Capacity: 17.5 hours, Thermal Storage Description: Molten salt	Thermal Storage of minimum 5 hours
Types of technologies (including hybridization options used)	Power tower and PV units	Power tower and PV units; 2 units of 150-190 MW of STE and the remained of PV (to be defined by the developer)

Table 14: Additional information

Atacama 1 & Midelt		
Generation Off-taker(s):	Sistema Interconectado del Norte Grande (SING)	ONEE (National Office for Electricity and Potable Water)
Cost (approx.)	\$1.4 billion USD (for the whole complex) with \$758 million USD financing	N/A

3.7 The HySol concept – Decoupled solar-gas combined cycle with TES

The HYSOL Configuration aims at delivering “dispatchable and firm energy during the whole year regardless the climate conditions, while using 100% renewable energy sources for electricity production through is innovative hybrid system”. The biomass-derived gas fuel production can be decoupled from the plant location and produced thousands of kilometres away from the plant, being transported through the conventional gas network if properly upgraded.

The flexibility of the configuration allows the HYSOL technology to cover peaks in demand as well as base load generation, tailoring the hybridization percentage of the plant to match the needs of the electrical system. The configuration includes two turbines: a Steam Turbine and a Gas Turbine that recovers the exhaust heat in the Thermal Storage; this solution allows the independent sizing and operation of the turbines, thus forming a “decoupled” combined cycle.

The HYSOL Project was developed by a consortium formed by 8 partners from four different European Union member countries (Spain, Italy, Denmark and The Netherlands) and it was developed with funds from the 7th Framework Programme (FP7). It consists of research partners: CIEMAT - Plataforma Solar de Almería (Spain), the Italian National Agency for New Technologies, Energy and the Sustainable Economic Development (ENEA, Italy), DTU Department of Management Engineering (Technical University of Denmark), Universidad Politécnica de Madrid (UPM, Spain) and SDLO-PRI (The Netherlands) as well as industrial partners: Investigación, Desarrollo e Innovación Energética SL (IDIE, Spain), Air Industrie Thermique Spain SL (Aitesa, Spain), and GRUPO COBRA (Spain).

Although there is no commercial power plant yet that fully operates with this configuration, the project focused on the study, the design, and the optimisation of an innovative configuration based on a new Heat Recovery System (gas-molten salt) and biogas-fuelled Aero-derivative Gas Turbine, including a pre-industrial scale demonstration of around 2.5 MWth.

Figure 13 below shows the demonstrator facility developed:



Figure 13: HYSOL Manchasol demonstrator

4 EVALUATION OF ALTERNATIVE CSP PROJECTS AND POLICY IMPLICATIONS

4.1 Analytical and methodological framework

The end goal of this analysis is to identify the pros and cons of different CSP project types which may benefit from the use of the cooperation mechanisms in the future. Assessing whether a CSP project might be more or less suitable to be used as part of the cooperation mechanisms is a complex, multi-faceted task. This is so because, on one hand, CSP projects have many different attributes, in terms of technological configurations, economic aspects, meeting electricity demand profiles, local socio-economic and environmental impacts etc. On the other hand, the assessment of the aforementioned suitability is contingent upon different features of the context in which they can be implemented. There are several aspects which need to be considered: geographical (perspectives of the importing and exporting countries), temporal (whether the present, i.e., a 2020 timeframe, or the future, i.e., 2030 or 2050 horizons are considered) and other (i.e., whether only statistical transfers or also physical transfers of electricity are envisaged).

Therefore, in order to provide a complete picture and assessment of such suitability, many elements have to be considered. Key project features should be taken into account. Some “assessment variables” can be used to evaluate those features, including technical, cost, system value, environmental and socio-economic variables.

However, the impact of these “assessment variables” on the aforementioned pros and cons of different project types cannot and should not be analysed in a vacuum, i.e. directly, but it is

mediated by their effect on three types of “intermediate factors”, some of which have been researched in other work of the MUSTEC project: drivers and barriers to CSP cooperation², policy goals/priorities of the potentially importing and exporting countries and country context factors³.

Drivers and barriers to CSP cooperation.

Whether a given CSP project type is attractive for its use as part of the cooperation mechanisms partially depends on the extent to which this project activates the drivers or mitigates the barriers to cooperation.

Whereas the review of the literature and the findings from the initial work conducted suggest the relevance of several drivers and barriers, the empirical analysis based on a survey to different types of stakeholders showed that there were 10 drivers and 10 barriers (see Del Río et al (2018) for full details). A questionnaire was developed in order to identify the most relevant drivers and barriers for the CSP cooperation mechanisms in the future. According to the responses to the questionnaire, the most relevant drivers included the dispatchability nature of CSP, new domestic jobs and industrial opportunities, complementarity with PV and policy ambition (renewable energy targets) (in descending order of importance). Regarding the barriers, the higher costs of CSP compared to other renewables (on an LCOE basis), heterogeneous regulated energy prices and support schemes, resistance to lose sovereignty over the energy market and existing interconnections capacities were regarded as the most relevant barriers (also in descending order of importance). Public acceptance related factors in the different countries (transit, exporting and importer) were regarded as the least relevant barriers.

Policy goals/priorities of the potentially importing and exporting countries

On the other hand, policy goals represent a powerful driver for the uptake of given technologies and may influence the type of projects that are adopted since they may emphasize particular features of these projects. In the past, these goals have been identified in order to assess specific renewable energy policies (e.g., Del Río, et al., 2012; IRENA, 2014).

The policy goals of the exporting and importing countries should be considered since, depending on the policy priorities, those countries will encourage the use of the cooperation mechanisms for CSP and, probably, the types of CSP projects they may regard as most attractive as part of such cooperation. In this sense, a distinction between those two types of countries should be made. Policy goals in the exporting country may include effectiveness (RES target compliance), minimization of support costs for RES, low system costs (addition of direct and indirect generation costs), positive local socio-economic benefits and low local environmental impacts. Policy goals in the importing country may include dispatchability, compliance with RES targets, low costs (if statistical transfers are used to meet those goals) and positive local socio-economic benefits.

Depending on the weight attached to those policy goals, a given project type may be more attractive for CSP cooperation. From the perspective of the exporting country, those CSP projects which minimize support costs, contribute to dispatchability, have positive local socio-economic

² See Caldés Gómez et al., 2018 and Del Río et al., 2018

³ See Welisch, 2019 and Lilliestam et al., 2018.

impacts and low negative environmental impacts in the exporting country are more likely to be used as part of CSP cooperation. From the perspective of the importing country, those which contribute most to RES target attainment and to flexible dispatch (in case of physical transfers) and have a lower cost would be more attractive in this regard.

Country context factors

Finally, some country context factors are deemed highly influential on the potential use of cooperation mechanisms for CSP. These context factors have been addressed in other tasks of the MUSTEC project.

In particular, Welisch (2019) identifies the main market conditions for CSP in Europe in both potential importer countries such as Germany and France and potential exporter countries such as Spain and Italy. In the former, they look at seasonality of demand, development of import volumes and the degree of achievements for their RES targets to assess a potential need and business case for importing CSP. In the latter, the energy mix and RES options in the country, the type of support that could be expected for CSP projects (and opportunities for cross-border support), and other specific characteristics were assessed to determine these countries' qualification for export. The author looks at the current as well as the future situation, i.e. into the current and future supply of (intermittent) renewable electricity and increase in (peak) electricity demand (importing country), which determine the need for dispatchable, flexible generation capacity. It also considers (wholesale) electricity prices in the exporting and importing countries and interconnection capacity. Three key aspects (barriers) stand out in this regard: there is not an urgent need for importing countries to import electricity in order to fulfill their RES targets, wholesale electricity prices in the importing countries are lower than in the exporting countries and electricity interconnections are limited.

However, two main aspects of importing countries may make cooperation attractive: physical cooperation (in order to take advantage of the dispatchability of CSP) and virtual cooperation (target fulfillment). In Germany, the current need for dispatchable (renewable) electricity seems to be relatively moderate, but future needs for dispatchable electricity are likely to rise. Given the phase-out of nuclear and coal-fired power plants, importing CSP could be one option to fulfill these needs (Welisch, 2019). On the other hand, target fulfillment may provide an incentive for (virtual) cooperation in 2030.

Therefore, taking into account those results, CSP projects which contribute most to the provision of dispatchable power and facilitate target fulfillment will more likely be used as part of CSP cooperation.

Obviously, the last two sets of intermediate factors (goals and country context factors) are somehow related. For example, the exporting or the importing governments may emphasize the goal of dispatchability, given the prospects of a high penetration of intermittent RES. However, those two sets of factors have been kept separate for reasons of transparency (i.e., in order to make each factor more visible).

To sum up, different assessment variables influence the different DBs, are in line with specific policy goals and relate to context factors in either the exporting or the importing country to a

greater or lesser extent, in turn influencing the pros and cons of specific project types. The following figure provides a simplified picture of this analytical framework.

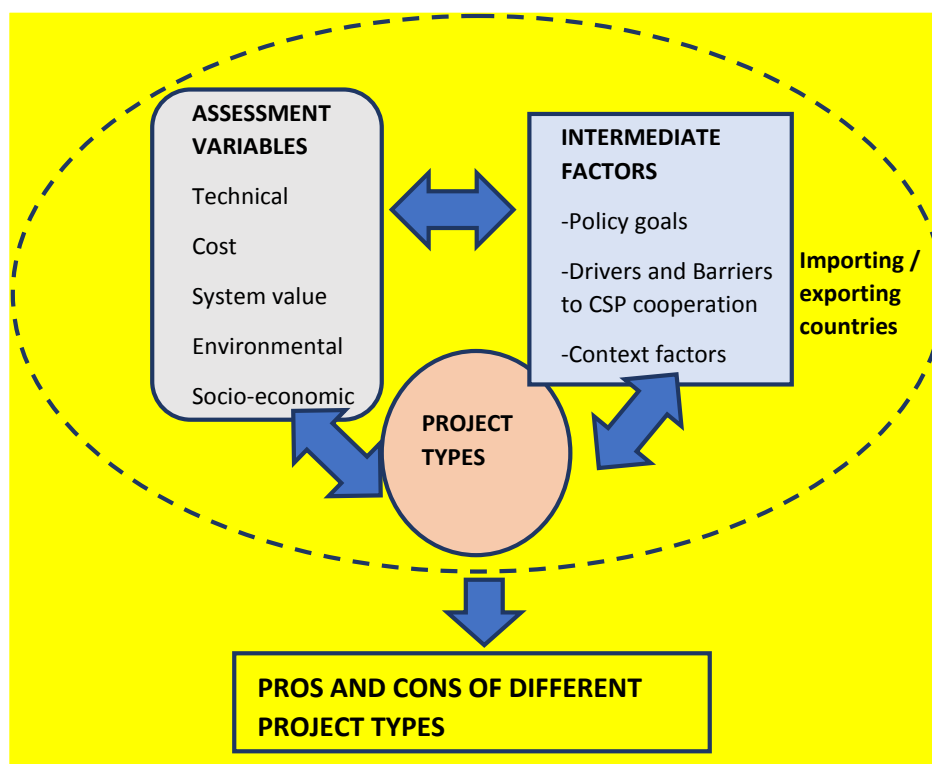


Figure 14: Analytical framework to assess pros & cons of different CSP projects for CSP cooperation in EU.

On the other hand, a set of distinctions are deemed relevant and some methodological and analytical choices have been made, since they have an impact on the aforementioned assessment. These are related to: the choice of the importing and exporting country, the consideration of both statistical and physical transfers of electricity, the types of cooperation mechanisms and the time horizons considered in the analysis.

Why Germany and Spain have been selected as the importing and exporting countries, respectively?

Given the involvement of two countries in the cooperation mechanisms, both the perspective of the potential importer and exporter countries should obviously be taken into account. Therefore, a Southern and a non-Southern European country have been chosen. In this context, the focus will be on Spain as the exporter country and Germany as the importer country, in line with other analyses carried out in MUSTEC (e.g., Welisch, 2019). The choice of Spain seems to be a logical one in this context. Spain is the main country in which CSP expansion at scale is possible⁴ and it is currently the only country which has supplied a substantial amount of CSP and where ambitions aim to expand this deployment further (Welisch, 2019).

⁴ CSP can, in principle, be built in Italy and the southern Balkans, but the potential is much more limited (Lilliestam et al., 2018).

At the same time, Germany and Spain have a predisposition and a higher likelihood to engage in CSP exchange in the nearer future than other countries⁵. This is due to two main factors: a) Spain has already deployed a substantial amount of CSP and is considering expansion in the mid-term future (up to 2025 and 2030)⁶; b) Germany is open to cooperation and has considered importing electricity in the past. In the mid-term future, a business case might arise there due to changes in the electricity system (increased demand, higher fluctuations etc.) (Welisch, 2019). These two countries also continue to fund CSP research activities and have done so for a while now.

Why are both statistical and physical transfers considered?

Countries may choose to meet their RES targets by importing, physically or statistically (via transfer of Guarantees of Origin, or similar), renewable electricity produced in another EU country (Lilliestam et al., 2018, p. 20). Therefore, both types of cooperation are considered. However, given the limited interconnection capacities (in both Spain and Italy), it seems likely that this cooperation would be statistical rather than physical (Welisch, 2019).

What types of cooperation mechanisms are considered?

There exist four possible cooperation mechanisms that Member States (MS) can choose from. These were described in articles 6, 7, 9 and 11 of the Directive 2009/28/EC, which broadly correspond to articles 8, 9, 11 and 13 of the new RES Directive (Directive 2018/2001/EU), respectively.

While statistical transfers, Joint Projects between EU MS and Joint Support Schemes are suitable for cooperation agreements within the European territory, Joint Projects with third countries are only suitable for cooperation agreements between EU MS and neighboring countries. The main difference between the European cooperation mechanisms and Joint Projects with third countries is that, while the later requires the electricity to be physically imported to the European territory, such requirement does not exist in Europe and is left to the decision of the involved MS (for example, a joint project defined under the new article 9 (Joint Projects with third countries) may or may not have physical transfers of electricity). Following Caldés and Díaz-Vázquez (2018), from now onwards, we will only consider “statistical transfers” and “joint projects” (with or without physical transfer of the electricity), given the geographical scope of MUSTEC⁷.

What time horizons have been considered and why?

In this report, as well as in other tasks of the MUSTEC project, we take into account the present (up to 2020), but also focus on the future (up to 2030). This is a particularly relevant distinction in the context of this task, mostly because the relevance of one of the main policy goals and context factors (need for flexibility/dispatchability) is likely to differ across both time horizons. The need for dispatchability is likely to increase over time, i.e. it will be relatively more important in 2030

⁵ The likelihood of Italy and France for engaging in CSP exchange is a lot smaller for these case countries (Welisch, 2019).

⁶ In the National Integrated Energy and Climate Plan, Spain expects to deploy an additional 5 GW by 2030, to be added to the 2.3 GW currently deployed in this country (Ministerio para la Transición Ecológica (MINECO), 2019).

⁷ For more information on the opportunities and barriers to renewable energy cooperation with neighboring countries, see the work conducted within the BETTER project (www.better-project.net).

(given the large expected penetration of low-cost intermittent RES-E generation (wind and PV) in the medium term) than it is now and, thus, one specific CSP configuration may be more valuable in this context in one time period than in the other. Changes can also occur in another policy goal (target attainment). For example, statistical transfers could be needed in order to comply with RES targets in 2020, but not in 2030 (or the other way around). Finally, the selection of several representative CSP project types, as previously described, has been conducted following two main criteria (off-taker needs and configuration variables).

Summing up, those CSP projects deployed in Southern European countries which are able to provide electricity on demand (dispatchable), have a lower LCOE, provide the greatest amount of electricity, have high positive local socio-economic impacts and low local environmental impacts are in theory more suitable for cooperation. However, these positive features of projects may not be equally valued. In fact, it can be expected that the main positive feature of this renewable energy technology (dispatchability) will be the main aspect driving the deployment of CSP projects.

A survey (expert elicitation) to identify the perception of key stakeholders on the most relevant features that CSP projects should have in order to be attractive to be used as part of the cooperation mechanisms of the RES Directive (for both potential importer and exporter countries) has been carried out. Expert elicitation is a special survey tool designed to extract deep knowledge not available elsewhere (i.e., no public data available, only very few people knowledgeable in the subject and highly complex subjects with uncertain future developments) and have frequently been used in (renewable) energy research (i.e., Bosetti et al., 2012; Verdolini et al., 2018). Expert elicitation provides a structured approach for obtaining expert judgments from scientists, engineers, and other analysts who are knowledgeable about particular issues and variables of interest. Expert elicitation is an important source of information concerning the future costs, technical performance, and associated uncertainties of technologies (Verdolini et al., 2018, p. 134). For these reasons, expert elicitation is deemed adequate for this investigation. In this context, an expert elicitation was targeted at experts knowledgeable in both the fields of CSP and EU cooperation mechanisms.

A total of 16 suitable experts were identified, 7 thereof forming part of the MUSTEC project (although only 2 of this 7 finally responded). Given the nature and focus of the project, it is not surprising to find a relatively large share of experts in the project consortium. As expert elicitation is based on a strict elicitation protocol aimed at minimizing biases and ensuring highest robustness, the method allows the inclusion of “internal” experts. Nevertheless, in order to ensure highest scientific standards, special attention was given to the design of the protocol. For example, all experts were given a short introduction and formation in order to generate a common point of departure. Confidentiality and anonymity were assured, targeted at reducing overconfidence and motivational biases. Also, experts were asked to access their broad knowledge and not just a recent or memorable event, targeted at availability heuristic and base-rate fallacy. Also, experts were asked to self-assess themselves. Therewith, motivational bias could be checked for. In the end, there were no differences between external and internal experts and in the following the results of the expert elicitation are treated as a common body of data.

Regarding the process, 11 experts were invited to participate in the study and 9 finally responded. The elicitations took place in May 2019 on a written basis via e-mail. Specifically, experts were asked about the main features that a future CSP project should have so that it would be attractive for potential importer and exporter countries to be used as part of the cooperation mechanisms of the RES Directive (articles 8 and 9) in two different situations (physical electricity transfers and only virtual transfers).

Since it is advisable to have the views of different types of experts (Verdolini et al., 2018), 3 groups of experts were contacted: policy makers (1 respondent), industry (2) and academics (6). Experts were asked to indicate, in a scale of 0 to 10, how familiar they were with Concentrated Solar Power and with the Cooperation Mechanisms of the RES Directive (10=top expertise; 8=high expertise; 5=average expertise; 2=low expertise; 0=no expertise). The average scores were 8.3 and 6.5, respectively.

4.2 Results

As suggested by the above analysis, the assessment variables are deemed instrumental in the analysis of the pros and cons of different CSP project types for cooperation. They are not intended to be used to directly compare projects, but their influence is mediated by their effects on drivers and barriers (DBs) to CSP cooperation, context factors and policy goals. Given the DBs and policy goals, a specific project type, i.e. with certain features, may be deemed more suitable for cooperation, given that it is more likely to: 1) meet policy goals; 2) activate drivers to CSP cooperation; 3) mitigate barriers to CSP cooperation.

The aim is to identify which types of projects will be more attractive for CSP cooperation in the future, and our empirical analysis illustrates this with data for specific projects. However, the aim is not to identify which projects are “best”. Indeed, our results show that the CSP projects are very similar in terms of the assessment variables that have been chosen and for which we have data. This is so because a whole set of projects which are currently operating have not been included as potentially suitable for cooperation (parabolic trough without storage). These are the projects which do not have storage, i.e., those first parabolic trough projects which were deployed in Spain in the 2000s, and were not considered suitable for cooperation from the initial selection presented in the first sections of the report, although these projects are the large majority of those which are currently operating (44 out of 84, according to CSP Guru). The Spanish CSP fleet currently amounts to 2.3 GW, broken down in 1/3 of plants with at least 7 hours of storage and 2/3 of plants without storage.

When identifying the pros and cons of different CSP project types for cooperation, the policy goals in the importing and exporting countries, which partially depend on the context conditions in these countries, should be taken into account. These include dispatchability (minimization of system costs or security of supply), compliance with RES targets at the lowest costs and high socio-economic benefits and low environmental impacts (in the exporting country).

When combined with thermal storage, solar electricity exports can contribute to the stability of the electricity system and reduce the need for fossil fuels as back-up technologies to balance the increasing intermittent sources of electricity. Therefore, if dispatchability is the goal in both potential exporter and importer countries (in this case, under the existence of physical transfers), then those projects with a greater storage capacity would be more attractive. It is not only an issue of “number of hours of storage” but rather of the offtaker needs in both types of countries.

In Spain, a high penetration of intermittent RES, and particularly PV, makes it recommendable to have low-carbon dispatchable power when the sun starts setting and until the morning of the next day, which indicates a main role to be played by CSP. With a high penetration of non-dispatchable renewables, there will always be a missing part of the demand curve (between sunset and sunrise next day) that will require back-up. By dispatching STE/CSP plants when the sun is starting to set until the capacity of the storage tank is exhausted, a dramatic displacement of fossil fuel back-up (CCGTs) can be achieved. This dispatch profile complements PV production in sunny days and avoids the need to respond to the evening ramp, when the production of PV plants quickly goes down. Therefore, the project typologies with the largest storage capacities would be particularly suitable.

Dispatchable power would also be needed in the importing country, pointing out in the same direction: the greater the storage capabilities, the better. Although, in Germany, the current need for dispatchable (renewable) electricity seems to be relatively moderate, at least from a cost perspective, future needs for dispatchable electricity are likely to rise. Importing CSP could be one option to fulfill these needs (in case proper interconnection capacity exists, making physical transfers possible). A high-renewables scenario requires a high amount of balancing in the importing country, which might indicate a potential market/need for CSP. In contrast, if the aim is to fulfill the RES targets at the lowest costs in the importing countries (in the absence of physical transfers, i.e., only virtual cooperation), then the importer country would more likely look for those projects which generate more energy and do so at the lowest costs (in terms of LCOE). In this context, higher plant sizes would be better and parabolic trough technologies, which are able to achieve larger plant sizes, might be more advantageous in this regard.

Having CSP at lower costs can be attractive for both the host and the off-taker countries since this could entail a lower support level for both countries as well as for the EU. Higher investment costs require support to make the projects bankable (Caldés & Díaz-Vázquez, 2018), given that some projects have higher investment costs and LCOEs than others. However, those projects are not necessarily less suitable for cooperation when the overall picture (i.e., all policy goals, all DBs and all context factors) is taken into account. The capacity to generate electricity irrespective of its value to the system would be a searched feature by the importing country under the mechanisms of article 8 and 9 of the new RES Directive 2018/2001/EU (statistical transfers and joint projects between MS). However, the exporter country should also take into account such value, because this is different depending on the time of the day when the electricity is produced. In principle, if only an amount of electricity is searched for, these projects would not necessarily minimize system costs in the exporter country. The reality is that, given the types of projects considered in this report, in which all have a considerable storage capacity and are thus able to dispatch electricity in a flexible manner, large differences between them are unlikely. High-cost projects (in terms of LCOE) would be particularly unattractive in this regard. Some of the projects considered in this report are CSP/PV hybrids. The hybridization of CSP with PV can entail a reduction in production costs compared to CSP-only.

In addition, note that projects with high storage capabilities may also be the ones with the lowest costs, since CSP generation costs may decrease with the size of storage given that, despite a greater solar field, the power block would be the same and a greater number of operation hours would result (Dowling et al., 2017; Gauché et al., 2017). This suggests that there might be synergies regarding the choice of certain project configurations to fulfill two policy goals at the same time.

If the aim is to encourage local socio-economic development in the exporting country, then those projects which contribute more to employment creation and to the industrial supply chain would be more attractive. Only data on O&M jobs for some projects have been obtained. Obviously, the greater the amount of O&M jobs, the better for the local economy where the plant is located. Unfortunately, we have not been able to obtain reliable data on the rest of socio-economic variables and, thus, we cannot state that a given project type or specific project scores better than others in this respect. This will need to be the focus of future research. However, given the absence of hard data, we anticipate that it will be a hard task.

Innovative projects are essential to demonstrate the technical and commercial viability at industrial scale of new generations of energy technologies and solutions to achieve a cost-competitive, sustainable and secure energy sector by 2050 (Caldés & Díaz-Vázquez, 2018). EU and Spanish CSP industries could greatly benefit from innovative projects, allowing them to maintain CSP leadership.

An interesting issue is whether more innovative projects are more suitable for cooperation. This might depend on whether the perspectives of exporting or importing countries are taken into account. From the point of view of the importing country, mature, tested, proven project configurations might be more attractive than innovative ones, especially if the main goals of the importing country are to fulfill RES targets and do so at the lowest costs. However, from the point of view of exporting countries, more innovative projects contribute more to its technological capacity, generating spillovers and, maybe, opportunities to export the technology in the future. Caldés and Díaz-Vázquez (2018) find out that Extremadura (a less developed region in Spain) could, under the right framework conditions, host a European cross-border solar electricity First-Of-A-Kind (FOAK) project. Some of the immediate benefits for the exporting country (Spain) include the possibility to maintain Spanish CSP industry and research leadership. Southern European countries and Spain in particular host the majority of research facilities and capabilities in Europe. Furthermore, it would be possible to contribute to reduce costs and increase the performance of a technology that is expected to play a key role in the future Spanish system without compromising public funds or affecting the final electricity consumer prices. Similarly, investments in R&D may trigger new investments opportunities in other sectors. At the regional level, the authors argue that such a FOAK project would entail R&D investments that increase R&D capacity and is a driver for new investments.

On the other hand, the exporting country might be interested in minimizing the environmental impacts from CSP generation. Despite being renewable and, thus, not emitting CO₂ or other GHG during electricity production, CSP projects have three main local environmental impacts: land occupation, water consumption and visual intrusion (only for solar tower). Scoring well in the “environmental impacts” variable is not only an end in itself, but it is also a main factor driving the social acceptability of any energy project (i.e., the NIMBY). Therefore, those project types and specific projects which have more environmental impacts, would be less attractive with respect to this particular criterion.

In addition to policy goals, there are some barriers to the use of the cooperation mechanisms to which different features of the projects may contribute more or less, i.e., which can be mitigated. Therefore, those CSP projects which activate drivers or remove barriers to cooperation are more likely to be suitable for cooperation. In this regard, as mentioned deliverable D4.4 (Pablo Del Río et al., 2018), the most relevant drivers to the use of the cooperation mechanisms for CSP in the future include the dispatchable nature of CSP, complementarity with PV, new domestic jobs and

industrial opportunities, and policy ambition (renewable energy targets) (in descending order of importance).

The above discussion on policy goals has already explained how different project types could contribute to dispatchability. The complementarity with PV is a driver which is directly related to the aforementioned dispatchability of CSP and off-taker needs, in the context of a high penetration of this intermittent renewable energy technology. Regarding the contribution to domestic jobs and industrial opportunities, lack of appropriate data prevents us from carrying out an assessment of how different project types and specific projects contribute to this driver. On the other hand, it is difficult to foresee how the features of specific project types may activate some drivers. This is the case with policy ambition, which is an exogenous factor to which different project designs are unlikely to contribute.

While the above are the most relevant drivers, there are others which are also relevant (although less so) and to which different project types can make a difference. For example, two of them are “contribution to improve technological performance and cost reductions in CSP” and “costs savings in MS target achievement”. The latter is closely related to the policy goal of lower costs. The project types considered in this report can have an influence on the former. In particular, highly innovative designs like the “commercial hybrids or co-located plants (CSP+PV units)” project type (such as the Noor Midelt project) and the “full firmness (hybrid configuration)” type (such as the HySol concept) can make a significant contribution in this context. In contrast, it is unclear how different project types affect other relevant drivers, which seem to be rather exogenous to project design, including “EU guidance in implementing the cooperation mechanisms”, “move towards creation of internal energy market”, “obligation to open support schemes” and “alignment with the Paris objectives”.

Regarding the barriers to CSP cooperation, Pablo Del Río et al. (2018), “the higher costs of CSP compared to other renewables (on an LCOE basis)”, “heterogeneous regulated energy prices and support schemes”, “resistance to lose sovereignty over the energy market” and “existing interconnections capacities” are regarded as the most relevant barriers. However, some of these barriers are of a general nature and unrelated to project design (heterogeneous regulated energy prices and support schemes, resistance to lose sovereignty over the energy market and existing interconnections capacities).

The most relevant barrier (higher costs of CSP on an LCOE basis compared with other renewable electricity generation technologies) indicates that, as it has been discussed in the case of the “low cost” policy goal, those projects with lower costs would be more attractive for cooperation. Although less relevant, other barriers to CSP cooperation suggest that some project types might be more attractive for cooperation. For example, there might be a public reaction in importer countries due to investing taxpayers’ money abroad. This reaction can be mitigated if the importing country spends less money per unit of electricity generated (€/MWh), which makes low-cost projects more attractive in this regard. The same conclusion can be inferred from the barrier “low levels of deployment support in the exporting country”, which would encourage the deployment of low-cost projects.

On the other hand, there might be a public reaction in exporting countries due to the NIMBY syndrome which is caused by renewable energy projects in general and CSP projects in particular. This problem would be mitigated by projects which lead to higher local socio-economic contributions and lower environmental impacts. Finally, other barriers are not meaningful in the context of this study, since in addition to being less relevant cannot be easily influenced by the

design of the project (“difficulties in communicating benefits, “first mover risk” and “public reaction in transit country”).

The answers of experts to the questionnaire are broadly in line with this analysis. Interviewees were asked about the features of a CSP project that would be more attractive for Spain as an exporting country and Germany as an importing country to be involved in the cooperation mechanisms in two different types of situations, one in which transfers of electricity between Spain and Germany are not possible due to lack of sufficient interconnection capacity and only the virtual transfers of articles 8 and 9 of the Directive are possible (situation 1) and, another in which physical transfers of electricity between Spain and Germany, in addition to the virtual transfers of articles 8 and 9, are possible (situation 2). The results are shown in the following Figures.

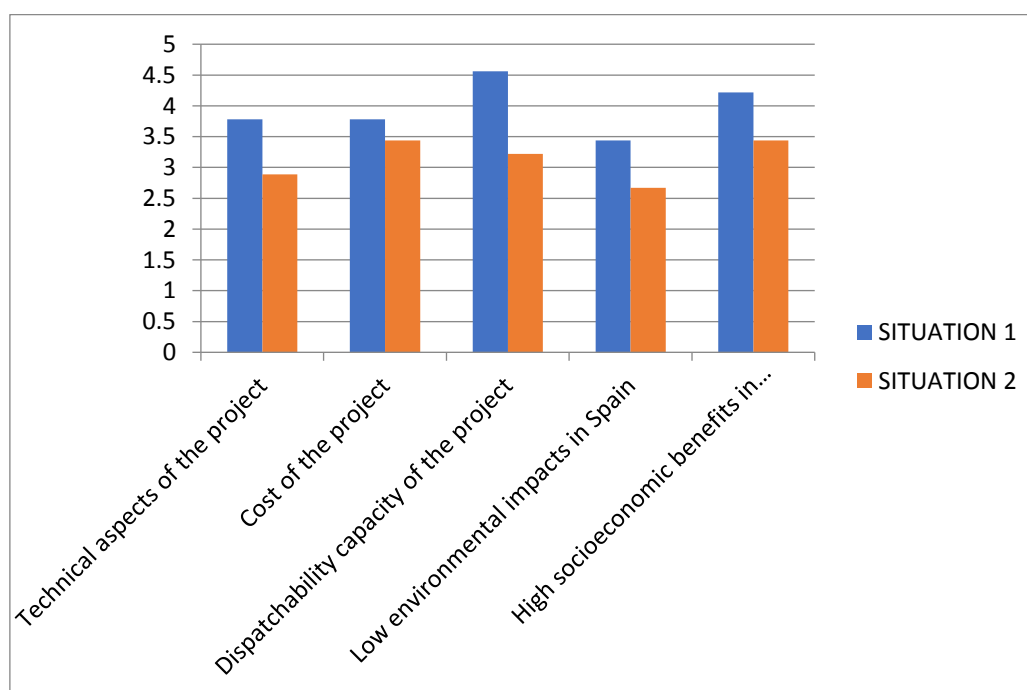


Figure 15: Scores on the features of a CSP project that would be more attractive for Spain as an exporting country to be involved in the cooperation mechanisms in two different situations.

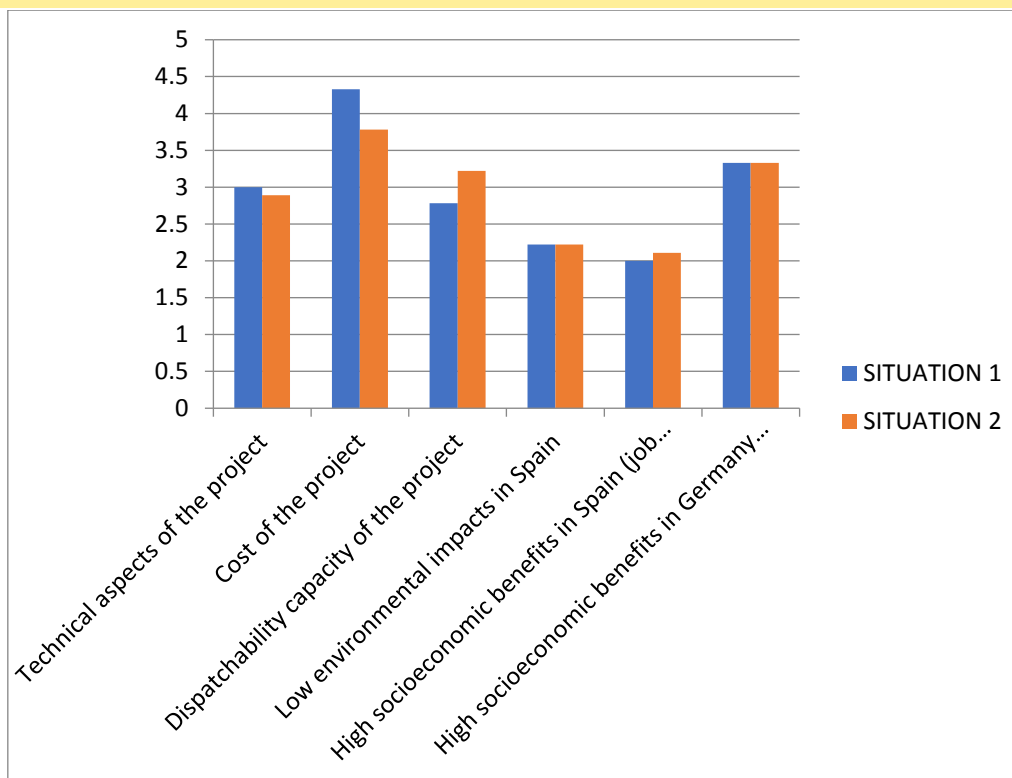


Figure 16: Scores on the features of a CSP project that would be more attractive for Germany as an importing country to be involved in the cooperation mechanisms in two different situations.

According to the interviewees, dispatchability would be the most relevant feature of a CSP project for the exporter country (Spain). One interviewee mentions that, “since the plant would be in Spain, the better its dispatchability, the easier its management by the Spanish grid operator will be and the less perturbation the plant will introduce in the Spanish grid”. Another interviewee argues that “dispatchability is very important because the electricity will be produced and consumed in Spain. Since there is overcapacity and there will be an even large deployment of variable RES generation in Spain, it is important to provide stability/flexibility to the Spanish system”. Finally, one respondent claims that “projects should be adapted to the requirements of off-takers. Dispatchability is the differentiating feature that CSP provides against other cheaper RES, for instances CSP can complement PV production”. One respondent raises an important issue: “low interconnection causes higher flexibility needs of power plants. This will increase the market value and reduce support costs”. This is probably the reason behind the higher score attached to dispatchability in situation 1 compared to situation 2.

The relevance of dispatchability for the exporting country is closely followed by high socio-economic benefits in Spain. One respondent notes that “(CSP cooperation) will help to preserve current employment and to create new employment near the sites”. For another, “the more jobs and industry creation are induced by the project, the more beneficial it is for Spain’s local economy, and therefore the project will be more interesting for Spain due to the currently high unemployment rate”. A third one claims that “this is very relevant because besides the dispatchability advantage over other RES technologies, CSP is, as of today, one of the RES technologies that has an industrial interest for Spain and creates many jobs”. Finally, another argues that “the impulse of socio-economic benefits (especially in the exporter, but also in the importer country) is, in my opinion, a basic reason to promote cooperation mechanisms around a renewable technology such as CSP”.

According to the interviewees, “low environmental impacts in Spain” would be the least relevant characteristic that CSP projects should have in order to be attractive for Spain as part of the cooperation mechanisms. This result does not change much in situation 2 compared to situation 1.

In situation 2, dispatchability continues to be relevant, but only second to the “cost of the project” (see above). One interviewee believes that “(the cost of the project) would be the most important factor for statistical transfers”. Two other mention that “cost is an important factor in any cooperation project” and that “projects should be competitive to alternative RES projects in other countries”. Finally, one argues that “reduced CAPEX and OPEX are very relevant. Even if the LCOE is not competitive for the long term levelized costs, CSP should provide competitive prices at peak demand hours”. Interestingly, one respondent points out a relationship between both features in the future: “If physical transfer is possible. CSP could play an essential role in Europe to increase RE share and to enhance grid operation. The CSP market will significantly increase and therefore the cost will be reduced because of economies of scale”. “Low environmental impacts in Spain” is also the least relevant CSP project feature.

Concerning the features that a future CSP project should have in order to be attractive for Germany as part of the cooperation mechanisms, the cost of the project receives the highest score (most relevant). As argued by one interviewee, “since Germany will have to pay for the plant in order to get the rights for virtual import of electricity, the cost will be a major parameter”, whereas “costs maybe the determinant criteria for the importer” for another. In contrast, dispatchability is not so relevant in this context. According to one interviewee, “in an interconnected system dispatchability is less relevant for the market value of the project and therefore less relevant for support costs”. One respondent argues that “since the electricity import will be only virtual, the plant dispatchability will not affect the management of the German grid”. The second most relevant feature is “high socio-economic benefits in Germany”. One respondent claims that “some companies in Germany could have benefits by being involved in the project”. As it could be expected, “high socio-economic benefits in Spain” are the least relevant feature in this case. This ranking does not change in situation 1 compared to situation 2.

Apart from these scores, one interviewee questions whether the existence of physical transfers makes a difference (situation 1 with respect to situation 2), i.e., whether this distinction is relevant. “Honestly, I do not think that it is feasible that anyone will undertake a physical transfer of electricity but, if it happened, it is so irrelevant that a small quantity of electricity would not have an impact neither on the Spanish nor the German power mix. Therefore, I do not see any difference between physical or only virtual transfers”. In contrast, another interviewee suggests that such distinction might be important, arguing that “I think the existence of the interconnection will not create a major difference, except for the lower value of dispatchability for the market. The interconnection reduces the value of dispatchability as it is a competing flexibility source”.

5 CONCLUSIONS

The goal of MUSTEC is to assess the opportunities that renewable energy cooperation may bring to the future market uptake of CSP in Europe. The aim of this report is to provide a bottom-up comprehensive analysis of alternative types of CSP projects which are potentially suitable for cooperation. A preliminary evaluation of the pros and cons of different types of CSP projects in the framework of European cooperation is carried out.

This Working Document provides an analytical/methodological framework to assess the pros and cons of different types of CSP projects which are potentially suitable for cooperation, as mediated by their impact on a set of assessment variables and intermediate factors (drivers and barriers to CSP cooperation, policy goals and context factors). It analyses the pros and cons of different types of CSP projects potentially suitable for cooperation and identifies some policy implications. The analysis is based on the gathering of hard data on the assessment variables as well as intermediate factors (drivers and barriers, policy goals and context factors) and stakeholder interviews.

The respective findings allow the identification of those project features which may make them more attractive for CSP cooperation in the future, illustrating this with data for specific projects. The aim is not to identify which projects are “best”. Indeed, our results show that the CSP projects are very similar in terms of the assessment variables that have been chosen and for which we have data.

When identifying the pros and cons of different CSP project types for cooperation, the policy goals in the importing and exporting countries, which partially depend on the context conditions in these countries, should be taken into account. In addition to policy goals, there are some barriers to the use of the cooperation mechanisms to which different features of the projects may contribute more or less, i.e., which can be mitigated. Therefore, those CSP projects which activate drivers or remove barriers to cooperation are more likely to be suitable for cooperation.

Taking those aspects into account, projects which are particularly suitable for cooperation are those which provide dispatchable electricity, i.e., are equipped with considerable storage capacities. This is the case for exporting and (in case of physical electricity transfers) importing countries, taking into account future electricity systems in Europe with a significant share of variable renewable electricity generation. However, which project types are more suitable for cooperation, i.e., the features that they should have in order to be attractive for importing and exporting countries in this context also depends on the policy priorities of these countries. For example, if the aim is to fulfill the RES targets at the lowest costs in the importing countries (in the absence of physical transfers, i.e., only virtual cooperation), then the importer country would more likely look for those projects which generate more energy and do so at the lowest costs (in terms of LCOE). If the aim is to encourage local socio-economic development in the exporting country, then those projects contributing more to employment creation and to the industrial supply chain would be more attractive. Unfortunately, we have not been able to obtain reliable data on this variable and, thus, we cannot state that a given project type or specific project scores better than others in this respect. If the exporting country is interested in minimizing the local environmental impacts from CSP generation (land occupation, water consumption and visual intrusion), then those project types and specific projects with more environmental impacts would be less attractive for the exporting country to be part of CSP cooperation.

On the other hand, although those CSP projects which activate drivers or remove barriers to cooperation are more likely to be suitable for cooperation, it is difficult to foresee how the features of specific project types may activate some drivers or mitigate barriers which are rather exogenous factors to which different project designs are unlikely to contribute or can only do so marginally.

The answers to the expert survey broadly confirm those results. According to the interviewees, dispatchability would be the most relevant feature of a CSP project for the exporter country (Spain), closely followed by high socio-economic benefits in Spain. Concerning the features that a

future CSP project should have in order to be attractive for Germany as part of the cooperation mechanisms, the cost of the project receives the highest score (most relevant).

Although the focus has been on features of CSP projects which activate drivers or remove barriers to cooperation and, thus, are more likely to be suitable for cooperation, our results allow to identify some policy implications which derive from this analysis: valuation of dispatchability, policy interventions to encourage costs reductions through deployment support and a technology/industrial policy which provides demonstration and R&D support for CSP, and specific policy initiatives which mitigate barriers to the use of the cooperation mechanisms (i.e., not specifically for CSP).

If the aim is to encourage the participation of CSP projects in the cooperation mechanisms, our findings indicate that the dispatchability of projects should be a main feature of these projects, but this is not enough and the dispatchability of renewable electricity from CSP should also be appropriately valued in public support measures as well as electricity systems. Therefore, the promotion of these projects should focus on the dispatchability of the energy generated, with an appropriate valuation of the added services provided by CSP to the power system. Indeed, a main feature of CSP plants with storage is that they can produce high-value, dispatchable power on demand. The value added that CSP combined with thermal storage is to strengthen the reliability⁸ of energy systems, especially with high penetration of fluctuating power from certain RETs, should be recognized by policy makers (Frisari & Stadelmann, 2015, p. 21). This can be done with particular instruments or with design elements within these instruments. This issue will be addressed in subsequent work conducted under the MUSTEC project⁹.

Our results suggest that if low compliance cost is a main policy goal in RES cooperation, then the higher costs of CSP on an LCOE basis compared to other renewable energy technologies (e.g., PV or onshore wind) may be a barrier for using these projects in RES cooperation¹⁰. Further cost reductions for all CSP project types will thus be required. CSP expansion will only materialize if deployment of the technology is publicly supported with appropriate framework conditions and instruments and costs are substantially reduced. And costs will be reduced with increased deployment. There is still some leeway for cost reductions as a result of learning effects with increased deployment for this technology. Although cumulative CSP capacity grew tenfold worldwide between 2006 and 2016 due to incentive schemes in key markets (IRENA, 2018), it lags behind other renewable electricity technology (RETs) in terms of installed capacity. Its costs have been substantially reduced in the last ten years from USD 0.3/kWh ten years ago to US 0.12/kWh

⁸ The *reliability* of bulk electrical systems consists of two fundamental concepts: a) *system adequacy*, i.e. the ability of the electric system to supply the aggregate electric power and energy requirements of the electricity consumers at all times, taking into account scheduled and reasonably expected unscheduled outages of system components b) *operating reliability (security)*, i.e. the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system components (NERC, 2007, p.234).

⁹ The policy interventions may need to go beyond adopting specific instruments, and may encompass more critical aspects, e.g., a redesign of electricity markets which takes the dispatchability of the technology into account. However, discussing these designs is beyond the scope of this paper.

¹⁰ As mentioned above, it should be taken into account that CSP may be more expensive in terms of LCOE, but not necessarily in terms of system costs, which are more relevant from a social perspective).

today (Lilliestam & Pitz-Paal, 2018), but it is still a higher-cost gap technology (in terms of LCOE) which needs to be supported¹¹.

On the other hand, it is well-known that investments in research, development and demonstration (RD&D) represent a relevant source of improvement and cost reductions in the technologies. Beyond specific instruments, the definition of long-term political frameworks supported by regulatory schemes is a crucial element to encourage private R&D investments. Within RD&D support, support for demonstration projects stands out. Lilliestam et al. (2018, p. 193) argue that policy supporting demonstration plants in order to test new components could facilitate a more rapid rate of to-scale experimentation and technological learning. Indeed, the EU research programs have financed demonstration projects in the Mediterranean region. On the other hand, finding an adequate balance between RD&D and deployment support is still a great challenge for policy makers. Therefore, a combined technology and industrial policy, aimed at those improvements and cost reductions, can be recommended.

Finally, some policy interventions may mitigate barriers to the use of the cooperation mechanisms (i.e., not specifically for CSP) and, thus, to CSP cooperation. In this context, policies will probably need to be implemented at two different policy levels, i.e., they should include appropriate framework conditions and specific instruments. Different government levels (EU, national and regional) may be relevant to tackle specific drivers and barriers. Taking into account the drivers and barriers to the use of the Cooperation Mechanisms, specific instruments can be considered. They can be grouped in five main categories: (1) Information provision, (2) Legislative initiatives, (3) Access to finance, (4) Public awareness campaigns and (5) International cooperation. In addition, there are broader types of policies which are taken for other reasons, or are part of general policy decisions, but which would indirectly have a positive effect on the use of the Cooperation Mechanisms, because they either activate a driver or mitigate a barrier¹².

¹¹ Recent prices offered by CSP bidders in auctions are well below such figure, however, including Dubai (\$ 0,073 / kWh), Australia (\$ 0,060 / kWh) and Chile (\$ 0,050 / kWh).

¹² These include, among others, better interconnections between MS, more ambitious post-2020 RES targets, climate leadership, move towards the creation of an internal energy market, alignment with Paris Agreement objectives and more certainty about the post 2020 regulatory framework - see (Caldés et al., 2018) for further details.

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