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Analysing the barriers and drivers to concentrating solar power in the European Union. Policy implications

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ABSTRACT

The aim of this paper is to empirically identify and rank the drivers and barriers to the deployment of concentrated solar power (CSP) in the EU in the past and the future at two different levels of analysis: System/grid or macro level and project/investment or micro level. An expert elicitation and an investors' survey were carried out for this purpose. The results differ across the two levels (experts and investors), time frames and CSP designs. Specifically, deployment support, policy framework conditions and a proven technology have been major drivers of CSP deployment in the past, according to the expert elicitation. Dispatchability is regarded as the main future driver of the technology, followed by policy framework conditions and complementarity with PV. The survey of investors highlights the relevance of dispatchability, key technology and investors' features as drivers, and stress the importance of administrative processes, construction permits and grid connection as barriers. The results suggest the need to combine different policies in order to activate the drivers and/or mitigate the barriers.

1. Introduction

Concentrated solar power (CSP) is a dispatchable renewable electricity technology (RET) which might contribute substantially to a sustainable energy transition everywhere, in tandem with an increasing penetration of variable RETs. According to the IEA (2014), it could represent as much as 11% of electricity generation in 2050, with an installed capacity of 954 GW (up from 5 GW today).[1]

In contrast to intermittent RETs, but similarly to biomass, CSP with storage has a main distinguishing feature: It is able to provide dispatchable electricity. CSP plants contribute to grid balancing, spinning reserve, and ancillary services. They can also shift generation to hours when the sun is not shining and/or maximise generation at times of peak demand (World Energy Council, 2016, p. 31). However, the share of CSP in electricity generation worldwide is only 0.1% (REN21, 2018). As of 2017, Spain and the US accounted for 80% of global installed capacity (2.3 GW in Spain and 1.7 GW in the US), although expansion in those two countries stopped in 2013 and 2015, respectively.[2] Emerging economies, including South Africa, the UAE, China, India and Morocco, are playing an increasingly important role in this context (Lilliestam, 2018).

Although cumulative CSP capacity worldwide grew tenfold between 2006 and 2016, mostly due to incentive schemes in key markets (IRENA, 2018a), it lags behind other RETs.[3] Its costs have decreased in the last ten years from USD 0.3/kWh to US 0.12/kWh today (Lilliestam, 2018). IRENA (2018a) estimates that total installed costs of newly commissioned CSP projects have fallen by

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[1] De Castro and Capellán-Pérez (2018) summarise different studies with similar time horizons, with CSP shares ranging between 12 and 16% of the electricity mix, with one exception forecasting up to 42%. Lilliestam and Pitz-Paal (2018) reviews 14 global CSP expansion studies and concludes that the median expected global CSP capacity for 2018 is 23.6 GW, growing to 29 GW by 2020, 138 GW by 2030 and 400 GW by 2050.

[2] According to the CSP guru database (https://www.csp.guru), 76 plants are currently in operation, 50 in Spain and the rest in the US (16), India (3), South Africa (3), Morocco (2), China (1) and United Arab Emirates (UAE) (1). 21 projects are under construction in China (7), India (4), South Africa (3), Mexico (1), Israel (1), Chile (1), Australia (1) and USA (1).

[3] The 5 GW installed are far behind the values reached by other RETs like photovoltaics (303 GW), wind (487 GW) or hydropower (1096 GW) (IRENA, 2018b).

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27% between 2010 and 2017. Auction results for CSP projects that will be commissioned after 2020 show that costs have fallen to a range of 0.06$/kWh to 0.10$/kWh (IRENA, 2016, p. 16). However, a main reason to support CSP is that, compared to other RETs, it is still a high-cost gap maturing technology. It is in the early stages of deployment and has large cost reduction potentials.

Thus, the technology has not made a large contribution to power mixes, particularly in the EU, due to the existence of several barriers, which might continue to play a role in the future. The aim of this paper is to empirically identify the drivers and barriers (DBs) to CSP deployment in the EU and to rank their importance according to the views of investors and other relevant stakeholders. This provides useful information for appropriate policy interventions. It will allow the identification of specific policies which can either activate those drivers or mitigate the barriers. Furthermore, the research findings are deemed a valuable contribution for the industry and for researchers as they improve the knowledge about the major factors which influence the diffusion of CSP.

An in-depth literature review carried out for this paper indicates that other papers have analysed the DBs to CSP in the past in different countries and with different methodologies[4] (see supplementary material for details on each paper). However, most authors have focused only on a very narrow set of DBs. Notable exceptions are Del Rio et al. (2018), in an EU context, and Labordena et al. (2017), Mahia et al. (2014), Medina et al. (2015) and Ogunmodimu and Okoroigwe (2019) in African countries.

del Río et al. (2018) identified ten DBs for the future deployment of CSP in the EU and classified them into techno-economic, policy and social acceptability DBs. Key stakeholders in the sector were asked to rank their importance. The authors found that the higher value of CSP compared to other RETs was perceived as the most relevant driver and that the high cost of the technology compared to other RETs was the most important barrier. Medina et al. (2015) considered a broader set of investment barriers in the CSP sector in North African countries, which were grouped in three categories: business (14), political (17) and market barriers (6). They analysed their relevance for companies in a future 10-year scenario in Morocco. The results showed the importance of high capital costs (risk premium), political instability and insufficient long-term security for planning (Medina et al., 2015, p. 50). Mahia et al. (2014) conducted a survey to analyse the barriers to CSP in Morocco. Similarly to Medina et al. (2015), the barriers were included into three major groups: entrepreneurial (14 barriers), policy-related (17) and market-related (6). Barriers were ranked by experts according to their relative importance. They found out that policy-related barriers were more relevant than entrepreneurial or market barriers. The authors also asked experts about the importance of 11 drivers (or so-called “opportunities/advantages”). The two most important drivers were high solar potential (DNI) and political/institutional will to increase CSP deployment. Labordena et al. (2017) analysed the impact of political and economic barriers for CSP in Sub-Saharan Africa. They stressed the role of political, regulatory, financial and administrative barriers, long and uncertain permission processes, and other general investment risks (Labordena et al., 2017, p. 54). Finally, Ogunmodimu and Okoroigwe (2019) analysed the relevance of six barriers to CSP deployment in Nigeria (lack of strong political will, technology cost, fossil fuel contribution, lack of private investors, vandalism and insecurity and land requirements). They concluded that lack of strong political will was the most relevant barrier.

With the aforementioned exceptions, the low adoption rate of CSP in some countries has often been associated with a narrow list of DBs. Thus, a comprehensive perspective on DBs to CSP deployment needs to be adopted. The analysis of those DBs should be based on an integrated, systemic framework which takes into account all the potential factors and identifies their relative importance. The analytical framework is based on the technological innovation system (TIS) approach, and is complemented with insights from other approaches.

Compared to previous articles, this one contributes to the literature in several ways: theoretically, methodologically and empirically. First, an integrated analytical framework is built, which is used to assess the different DBs. Technology diffusion has many aspects, which need to be addressed with different theoretical approaches. Each approach stresses some relevant aspects while disregarding others. Inspired by such integrated framework, an in-depth review of the literature on CSP has been carried out, searching for all potentially relevant DBs. The outcome is a comprehensive list of possible DBs, whose relevance is identified in the empirical analysis.

To the best knowledge of the authors, a comprehensive analysis on the DBs to CSP technology in the EU in the past and the potential DBs in the future has not been published. An exception is De Castro and Capellán-Pérez (2018), which analysed the potential DBs to CSP with a focus in the future (2030) and not the past (whereas the focus in this paper is both on the past and the future). In addition, the literature review carried out in such study was circumscribed to the 2011–2015 period (and not 2008–2018, as in this article). Furthermore, this article considers a broader set of DBs, based on the aforementioned integrated analytical framework, and uses different methodologies to investigate their ranking.

From a methodological point of view, this paper shows the usefulness of the combination of a system (TIS) and a micro (investor) perspective on the DBs. Both are complementary in the sense that experts focus on barriers at the system level, but usually disregard the micro-level constraints suffered by firms (in terms of the resources, capabilities or competencies of firms). In contrast, investors focus on barriers at the micro level, but often miss the wider system level (see section 2).

The paper also contributes to the RETs and CSP literatures at the empirical level, since it combines different perspectives (system and micro), time frames (past and future) and CSP designs (parabolic trough and solar tower). Whereas previous contributions have focused on the technoeconomic features of CSP (i.e., both technological and economic aspects, see below) which act as DBs for this technology, this is not the case with other DBs. Research on the costs of the technology in terms of LCOE has been well covered. In contrast, dispatchability, local knowledge and manufacturing bases, administrative permits and investors' features have not received a comparable degree of attention. This paper empirically investigates the relative importance of these DBs.

Finally, the analysis of DBs is useful because it suggests points for policy intervention a crucial contribution of this article. Despite the emerging but abundant literature on policy mixes for sustainable energy transitions, the academic literature on policy mixes for CSP is extremely thin. Only Lilliestam et al. (2018) provide a (brief) analysis of the combination of policies which are needed in order to encourage the uptake of CSP in the future. They recommend that both deployment and innovation support are provided and that deployment support rewards dispatchability, includes firm and

[4] See, e.g., Islam et al. (2018), Bijarniya et al. (2016), Gauché et al. (2017), Haas et al. (2018), Schinko and Komendantova (2016), Polo et al. (2016), Kost et al. (2013), Frisari and Stadelmann (2015), San Miguel and Corona (2018), Naik et al. (2017), Peters et al. (2011), Purohit and Purohit (2017), Lilliestam and Pitz-Paal (2018), Dowling et al. (2017), Köberle et al. (2015), Lilliestam et al. (2012), Komendantova et al. (2012), Komendantova et al. (2011), Medina et al. (2015), Bosetti et al. (2012), Kaygusuz (2011), World Bank (2012), Trieb et al. (2011), Lingzhi et al. (2018), del Río and Mir-Artigues (2019), Mir-Artigues et al. (2019), Caldés et al. (2019) and Ogunmodimu and Okoroigwe (2019).

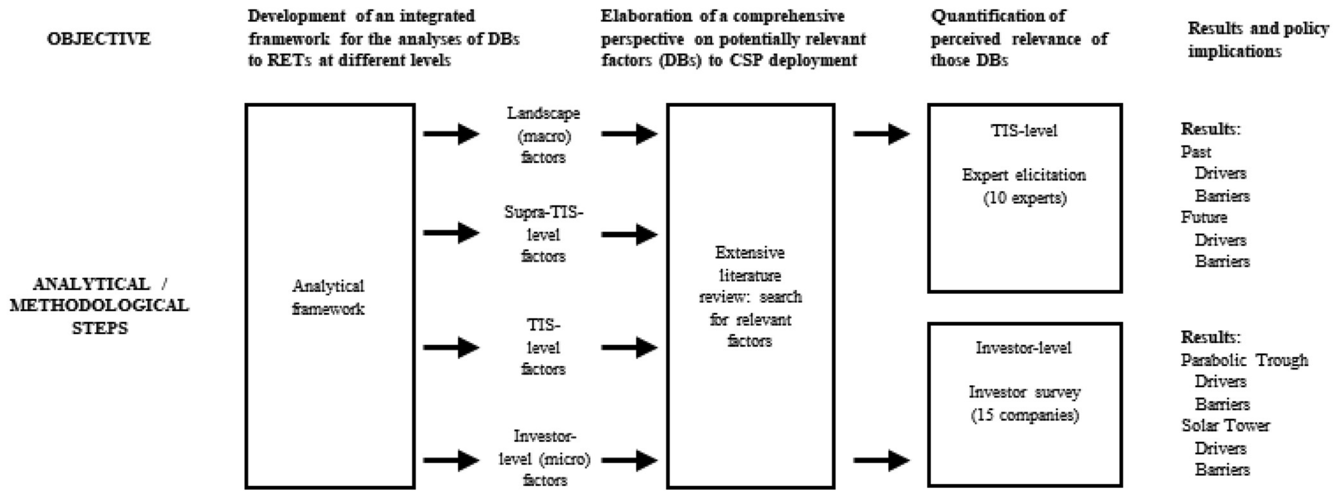

Fig. 1. Flowchart illustrating the methodological steps.
Source: own elaboration.

predictable cost pressure and allows for a steady and predictable expansion pace. By tying specific policies to the DBs identified in the empirical research, this paper proposes a policy mix for CSP and, thus, makes a relevant contribution in this context.

This article is structured as follows. Section 2 and 3 describe the analytical framework and the methodology, respectively. The results of the analysis are provided in section 4. Section 5 discusses the policy implications of the findings. Section 6 concludes. Fig. 1 illustrates the analytical and methodological steps followed in this paper.

2. Analytical framework

The analysis of DBs to CSP deployment should be based on an integrated, systemic framework which takes all the potential factors and their interrelationships into account. Several relevant approaches exist, including environmental economics, innovation studies, the multi-level perspective (MLP), the learning effects literature, diffusion modeling and innovation adoption approaches with a focus on the adopter. Each highlights crucial aspects in the diffusion process, while disregarding others (see del Río and Kiefer, 2018a, b; for a detailed explanation). The TIS approach is the essence of the analytical framework in this paper.[5]

A technological system is a "… network of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of generating, diffusing, and utilizing technology …" (Carlsson and Stankiewicz, 1991, p. 21). The TIS approach has been extensively used by scholars. It combines the analysis of technological aspects and the socio-technical processes which can influence the diffusion of technologies (Edsand, 2017, p. 2). It was developed to identify mechanisms that are either blocking or driving the development and diffusion of emerging technologies (Carlsson et al., 2002) and, thus, it is deemed the appropriate analytical approach for the purposes of this paper.

However, the TIS does not take into account crucial aspects which affect the diffusion process and, thus, it is complemented with insights from other approaches (Fig. 2)(see del Río and Kiefer 2018a for a detailed justification). The analysis of the DBs to diffusion should consider the views of those who are directly engaged in such process, i.e. the adopters (Horbach and Rammer, 2018; Mignon and Bergek, 2016).[6] There is a need to explicitly consider firm internal resources, i.e. to combine a TIS and an adopter perspective. Some authors call for more focus on the adopter level and for a better coupling of the micro and meso levels in the TIS (Hansen and Coenen (2017), Bauer et al. (2017), Mignon and Bergek (2016) and Reichardt et al. (2016)). Mignon and Bergek (2016, p.105) argue that, although the TIS has provided important insights on the system-level barriers and opportunities for diffusion, it has not explicitly taken into account the adopters of the technology and their responses to institutional drivers and pressures. In fact, it has downplayed the importance of actor-level determinants of the diffusion of RETs, despite the fact that actors on the demand side (adopters) have a main influence in this process.

The literature on eco-innovation shows that, the investment decision of investors isinfluenced by factors which are external to the firm (such as public policy) but also by internal factors (see del Río, 2009; del Río et al., 2016 for reviews of this literature). These factors generate incentives (drivers) and obstacles (barriers) for CSP investment. Several approaches focus on the internal features and behavioral aspects of the adopter, including the resource-based view of the firm (RBV) (Katkalo et al., 2010) and entrepreneurial perspectives (Planko et al., 2017). The internal factors include the resources, capabilities and competences (RCCs) of the firm. They refer to physical, financial, technological, human, organizational and reputational resources, their application in daily business practices (competences) and their strategic change over time (dynamic capabilities). The behavioural aspects include psychological, cultural, cognitive and other factors which influence adoption.

DBs are assumed to exist both at an adopter level and at higher levels (TIS, supra-TIS and landscape). Thus, the recommendation of Mignon and Bergek (2016), who combine system-level and actor-level challenges facing the adopters of RETs, is followed in this paper. This enables an analysis of the relative importance of these two levels in diffusion and the interplay between system and actor-level challenges (Mignon and Bergek, 2016, p. 107). This adopter perspective (interest and ability) is considered in this article in two manners: adopters (investors) are asked about their views on different DBs to CSP, and some RCCs of those adopters are included

[5] The full details of this framework are provided in del Río and Kiefer (2018a,b).

[6] In the context of this paper, adopters are defined as the investors in CSP technologies.

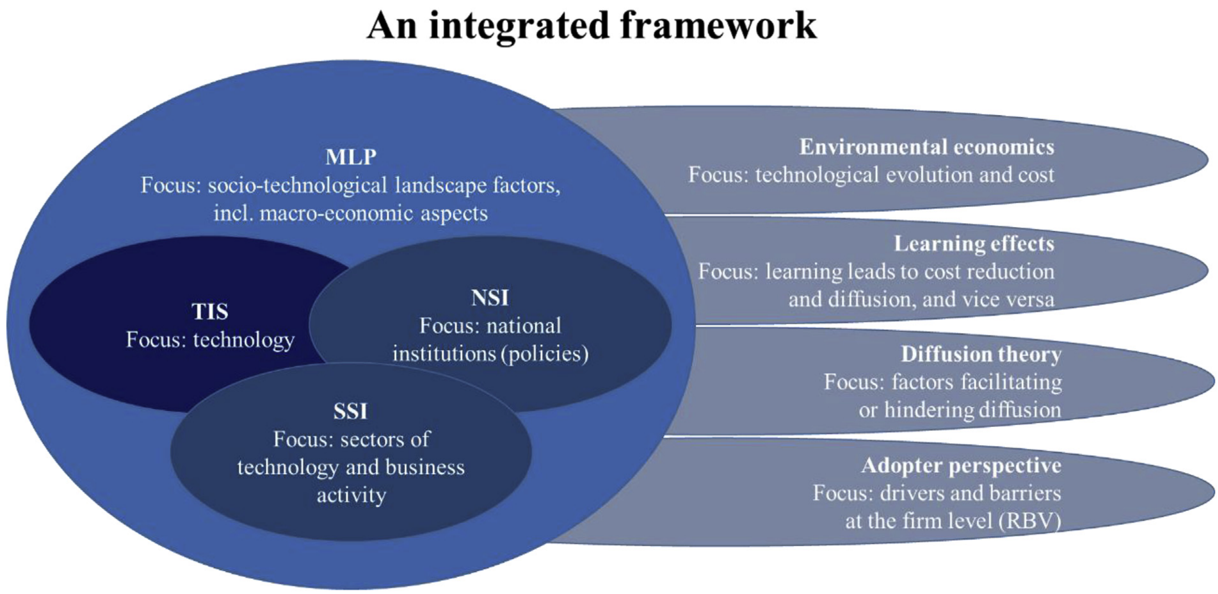

Fig. 2. Illustrating the integrated framework.
Source: del Río and Kiefer (2018a).

as relevant factors which influence CSP deployment.

On the other hand, in this article, there is an additional focus on the technological and economic (techno-economic) characteristics of the most widespread CSP technologies (parabolic trough and solar tower) because they are believed to have a considerable influence on the diffusion process. However, those techno-economic features are seldom discussed as a main driver or barrier to the diffusion of RETs in the TIS literature. As argued by Purohit and Purohit (2017), the special characteristics of CSP projects require a more elaborated approach to conduct deployment potential studies than applied for other RETs. In addition to its dispatchability and capital intensity, CSP has a main feature compared to other RETs: it is a complex technological system. Its complexity lies in the combination of different components in order to optimize the whole. Izquierdo et al. (2010, p. 6215) claim that CSP is, conceptually and economically, a more complex technology than other RETs due to the co-existence of two interrelated engineering components: the optical/collection system and the thermodynamic cycle. This brings about some distinctive attributes not present in other RETs.[7] Furthermore, tacit knowledge is very important because knowledge about this technology is firm-specific and even engineer-specific (del Río et al., 2018; Lilliestam, 2018).

A key dynamic technoeconomic feature is the cost of the technologies. While some TIS papers on RETs mention the costs of RETs and even their evolution, those costs do not play a central role in driving or hindering the diffusion of RETs in this literature. In contrast, costs have played a critical role in the accelerated diffusion of RETs (IRENA, 2016) and, thus, cost can be considered as an important DB to CSP diffusion.

To sum up, DBs to CSP can be identified at different levels of analysis (actor, TIS, supra-TIS and landscape levels) and are interrelated in the sense that DBs at a higher level are also potential DBs at lower levels (Fig. 3).

3. Methodology

The identification of barriers is usually based on a combination of a literature review, analysis of existing projects and interaction with stakeholders (Haas et al., 2018, p. 402). It aims to understand the underlying problems in order to apply measures to mitigate them. Thus, a literature review in order to identify potentially relevant drivers and barriers to CSP (section 3.1) is combined with an expert elicitation to quantify the perceived relevance of DBs on the system level (3.2) and an investor survey of the firm level (3.3). This combination allows researchers to obtain a comprehensive overview of the levels involved and overcomes the limitations of each methodology. The literature review alone can't provide a ranking of DBs; experts in the elicitation can inform about DBs at the TIS level but less so about investor-level DBs; and investors have imperfect knowledge of DBs at the TIS level (see del Río and Kiefer 2018a, b for a detailed justification and full description of these methodological aspects and choices).

3.1. Literature review

A thorough literature review of the DBs to CSP deployment in the past, with a focus on the EU, has been performed through a desktop search of documents. Main information sources included journal articles, official statistics, reports from industry associations, research organizations and other institutions (the European Commission, IRENA, Protermosolar, ESTELA and IEA,[8] among others), newspapers and government and company websites were reviewed.

According to Islam et al. (2018, p. 1008), CSP-related research has mainly progressed through journals. Thus, the most relevant energy journals as well as publications which are exclusively dedicated to this technology (CSP Today and Helio CSP) were read.[9]

[7] One of them is the relative sizing of both components, which is reflected in the so-called solar multiple. Another one is the influence of thermal storage on cost and performance (Izquierdo et al., 2010, p. 6215).

[8] International Renewable Energy Agency (IRENA), Spanish Association for the Promotion of the Thermosolar Industry (PROTERMOSOLAR), European Solar Thermal Electricity Association (ESTELA) and International Energy Agency (IEA).

[9] The following journals were consulted: the Electricity Journal, Energy Policy, Energy Procedia, Energy Journal, Energy, Renewable and Sustainable Energy Reviews, Energy Economics, Energy journal, Solar Energy, Applied Energy, Nature Climate Change and Environmental Economics and Energy Policy.

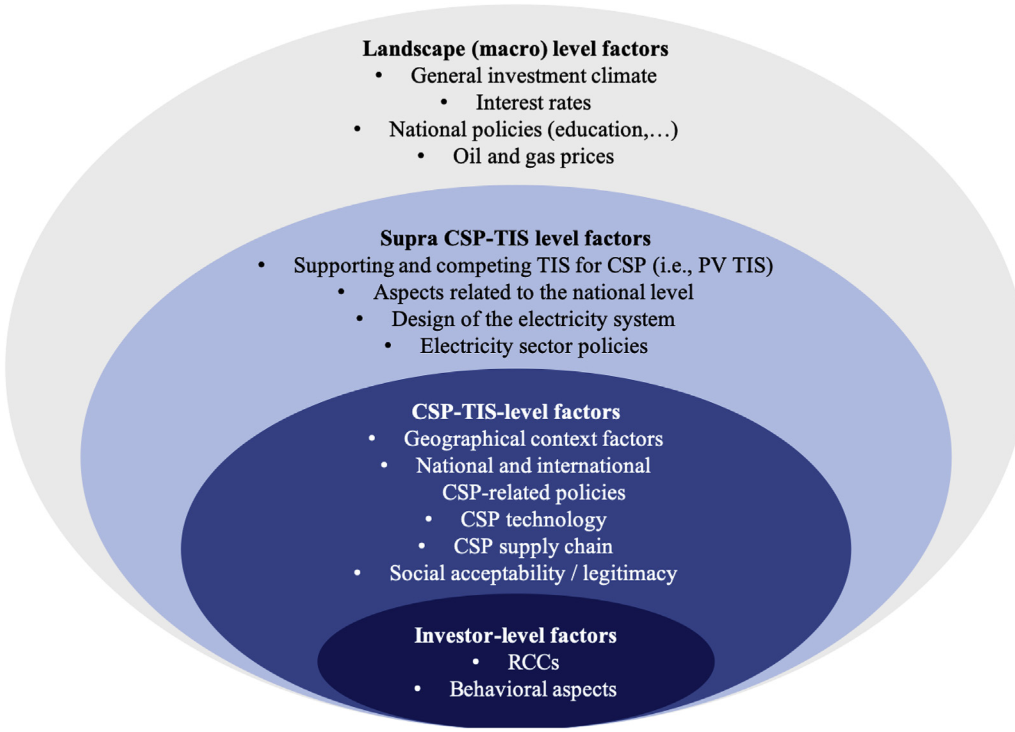

Fig. 3. Interrelationships between different analytical levels.
Source: del Río and Kiefer (2018a)

Furthermore, a search for documents in the grey literature was undertaken. The review covers the period between 2008 and 2019.

The key words "concentrated solar power", "CSP", "solar thermal electricity" were introduced in the search engines of the journals. This was complemented with a screening of each issue in the last twelve years. Contributions merely focusing on the technical aspects of CSP were removed. The rest of articles were read by the authors of this paper and those which focused on (at least) one driver or barrier to CSP were kept. Those papers with a world-wide scope, but which included relevant insights for an EU perspective on the topic, were also part of the literature review.

3.2. TIS level (experts)

Surveys have been used in the past to collect data from experts on the factors influencing technology adoption in general and adoption of RETs in particular (Nasirov and Agostini, 2018, p. 195).

The appropriate actors to interview in the analysis of the DBs to CSP at the TIS level are the "experts" on CSP. Those include researchers in the technology, manufacturers, investors and policy makers, among others. The outcome should be a ranking of the relevance of DBs to CSP deployment. An approach in which experts are asked to identify the ranking of the relevance of different DBs has been followed for other RETs by e.g., Eleftheriadis and Anagnostopoulou (2015) and Zhang et al. (2012).

Expert elicitations are a proven method when the research interest is to capture a body of knowledge which is closely related to a specific technology in a context of high technological uncertainty (Chan et al., 2011; Tversky and Kahneman, 1974). This is traditionally the case with less mature technologies, for which the "public" availability of knowledge is low. CSP can not be considered immature nowdays, but it was so until recently. Additionally, a high technological dynamism and uncertainty regarding future developments exists. Furthermore, CSP is a very specific knowledge field with a large tacit component and, thus, accessing this knowledge is difficult and public information is mostly unavailable. An expert elicitation is a suitable tool to capture this tacit knowledge.

Expert elicitations are different from other survey types because they follow a strict protocol in order to access the experts' deep information, which is not available elsewhere, while minimizing potential biases. Robust expert elicitation protocols use insights from decision theory, risk analysis, psychology, statistics and economics to counteract several biases and heuristics (Cooke, 1991; Hogarth, 1987).

In order to minimize biases, state-of-the-art debiasing strategies were applied during the elicitation (Fischhoff, 1984; Kahneman and Tversky, 1984). All experts were trained on potential biases and were asked to self-assess their level of expertise. The specific purpose of the study was explained to them and any questions or reservations that they had were considered. Confidentiality was ensured. The experts were asked to provide a numerical answer, but also to provide information and assumptions and justify their reasoning. Inconsistencies were identified and commented with the expert. Also, answers were validated and corrected for non-regressiveness. The outcome of the studies was checked for motivational bias after the elicitation.

The choice of experts is a critical issue in this approach. They should be representative actors with respect to the entire technology value chain and be active with the technology. They were selected according to hard criteria in their corresponding category: academia, industry, policy makers and other stakeholders (see del Río and Kiefer 2018a for further details).

Hard rules with respect to the optimum number of experts do not exit. Although an additional expert increases the diversity of judgment, his/her marginal usefulness decreases. An overwhelming majority of past elicitations have a range of 6–12 experts. For this study, 24 experts were identified who complied with the aforementioned criteria. 10 experts agreed to participate in the elicitations, which were carried out by telephone between May and July 2018, with an average duration of 69 minutes. After each elicitation, the analysts highlighted the most important aspects and identified statements confirming or contradicting the views of other experts.

3.3. Adopter level (investors)

The analysis of the investment barriers in a particular sector requires that the perceptions of the investors are included through a survey (Medina et al., 2015, p. 38). Thus, investors were asked about the relevance of each DB to CSP deployment previously identified in the literature review. A distinction was made between solar tower (ST) and parabolic trough (PT).

The survey on CSP investment decisions in the EU was carefully designed to take into account that the target universe of CSP investors in the EU is small, that a given factor might be a driver for some investors and a barrier for others and that some investors have repeatedly faced the above-mentioned investment decision.

Given the small target universe, raising response rates was a main concern. Personal invitations were sent in exchange for information on the CSP sector. Three reminders were sent and anonymity was warranted.

29 firms and contacts were identified with the help of the European solar thermal electricity association (ESTELA). Three identification criteria were used: (1) having directly invested in CSP plants; (2) having the plant currently in operation (not under construction or in the planning phase) and with a commercial aim (no prototypes or demonstration plants) and; (3) being currently active. 20 surveys were collected, of which 15 were complete. This represents a response rate of 55.6% on the (localizable) target universe and a “click-rate” (survey accesses) of 74.1%. Both numbers are deemed satisfactory, given the electronic set-up of the survey.

A semantic differential scale was created for all items. It includes two diametrically opposed extremes with an intermediate neutral point. The respondent was asked to quantify an impartially stated factor as either a driver or a barrier for investing in CSP[10]. For each side of the semantic differential scale (drivers or barriers), 9 levels were included (three major levels of “high”, “medium” and “low” and, within these, three sub-levels). Given that a 19-point scale (2x9+1) is difficult to manage for respondents, a user friendly graphical interface (e.g., a “slider”) was developed with a survey service provider. The pilot tests with 6 experts on environmental and energy economics and used to conduct surveys, provided useful feedbacks. Major flaws in the questionnaire were not detected, and minor changes were made. The respondents were asked to choose a representative project and stick to it throughout the survey.

4. Results and discussion

The empirical study has been based on the three aforementioned complementary methods.

4.1. Literature review

The literature review reveals that there are many potentially relevant DBs to CSP deployment. They include techno-economic and policy aspects, but also the availability of natural resources and supply-chain and knowledge-related DBs.

Techno-economic DBs include the features of the technology and its costs. Regarding the drivers, CSP is a proven technology with a dominant design (parabolic trough), which has experienced significant improvements and cost reductions in the past and is expected to do so in the future. It is dispatchable and can be a good complement to a high PV penetration. It has the opportunity to be developed in other niches, apart from electricity generation (industrial heat use and water desalination). However, other techno-economic aspects may be barriers to its deployment. These include some problems with the performance of the technology in the past, higher costs (on a levelised cost basis) than other RETs, strong competition with PV, fewer improvements and lower cost reductions than expected, negative impact of the economic and financial crisis and difficult access to credit.

The availability of natural resources can be a bottleneck for the diffusion of the technology. CSP requires appropriate levels of direct normal irradiation (DNI), land and water.

The policy aspects are a main category of DBs to CSP, and include framework conditions and specific instruments. Framework conditions refer to ambitious targets and policy stability as drivers and non-ambitious targets and retroactivity of policies as barriers. Different types of instruments may support CSP either at a European, national or regional level. They include deployment support (which can be investment-based or production-based, such as feed-in tariffs, auctions or tradable green certificates), RD&D support and prices on carbon. The cooperation mechanisms of the RES Directive could also encourage the uptake of the technology.[11] Regulatory aspects include administrative procedures (permit and planning processes and access to the grid), which have been regarded by some authors as a barrier for this technology in the past (see, i.e., del Río et al., 2018).

Several supply-chain aspects can be DBs. The existence of a well-developed local industry for components and, in general, a strong supply chain would make a country more attractive for the deployment of CSP plants. By contrast, a weak supply chain, with few actors (and, thus, low competition) in each stage, the unavailability of standardized major components and the exit of large players could be barriers in this context.

Two knowledge-related factors could be relevant drivers to CSP. One is international knowledge collaboration, since this leads to improvements in the technology, cost reductions and information flows, which may influence the speed of diffusion. Another is a strong knowledge generation base in EU with respect to non-EU countries, which may encourage the diffusion of the technology in the EU (del Río and Kiefer, 2018,b). On the contrary, low international knowledge collaboration, low competence in the CSP technology (lack of skills throughout the supply chain) and knowledge generation increasingly moving outside the EU are knowledge-related factors acting as barriers for CSP.

Finally, other DBs include social acceptability/opposition for CSP. Acceptability depends on the local benefits provided by the technology, whereas opposition might be related to its local environmental impacts.

Some of the aforementioned DBs are relevant at the TIS level, others at the investors' level, and others at both levels. In the latter case, the DBs influence both the diffusion on the TIS level and firm-level investment decisions. Regarding the investors' level, an

[10] He/she could also state that the factor was neutral (i.e., it did not influence his/her decision).

[11] The Cooperation Mechanisms of the RES Directives 2009/28/EC and 2018/2001/EC aim to encourage the collaboration of countries in RES. They contribute to the achievement of the RES targets in the EU in a cost-effective manner while providing Member States (MS) with flexibility to meet their national RES objectives. They allow MS to achieve their national RES target in cooperation with other MS and include statistical transfers, joint projects and joint support schemes (see Caldés et al., 2019 for details).

additional important aspect stands out: Previous experience accumulated in CSP within the firm and the availability of adequate RCCs may drive CSP investments.

The results of the literature review are summarized in Table 1 (for potentially relevant DBs at the TIS level) and Table 2 (for DBs at the investors' level). DBs that may be relevant at both levels are included in both tables. Although some DBs are partially included in others, they were kept separate because this allowed us to capture more specific aspects and also because this was required by the expert elicitation protocol.

Finally, as discussed above, some aspects can both be a driver and a barrier, whereas others can only be a driver or a barrier. In order to minimize biases, all DBs were stated in a neutral manner. Thus, the experts or the company decision makers stated whether a given factor was a driver or a barrier.

4.2. Expert elicitation survey

The 10 experts were asked about the relative importance of the DBs to CSP deployment in the EU in the past (up to 2018) and the future (up to 2030). Figs. 4 and 5 provide the full numerical results of our findings. They clearly stress the importance of policy factors in the past deployment of CSP. "Policy framework conditions" is the most relevant driver (with a score of 82%). These conditions include the policy ambition in the setting of long term targets and the stability of regulation. The existence of deployment support has been the second most relevant driver in the deployment of CSP in the EU (79%). A technoeconomic factor (the fact that CSP is considered a proven technology) is also a main driver (61%). Obviously, the more mature and proven a technology is, the more attractive it is for potential adopters, which do not have to face the additional risks and costs of early adopters.

Other drivers are less relevant: DNI levels (which is a precondition rather than a driver), RD&D policies, cost reductions and supply-chain and knowledge-based related factors (all below 58%). CSP has experienced substantial cost reductions (see section 1). The LCOE for PT and ST is expected to go down by 37% and 43%, respectively, in the period 2015–2025 (IRENA, 2016). A recent study by Ling-zhi et al. (2018) concludes that the LCOE of PT and ST can be reduced by 46%–57% and 47%–56% between 2018 and 2050.

The existence of a strong CSP TIS sector in the EU has been an important driver. This is related to the "strong knowledge base and knowledge generation in the EU (vs. non-EU countries)" (56%) and the existence of "local manufacturing capabilities" (57%). The latter refers to well-developed local industries for many components. CSP plants demand industrial materials. Since countries may have mature industries which manufacture components and equipment for electrothermal conversion, a substantial share of the value chain can be added locally (Vieira de Souza and Gilmanova Cavalcante, 2017). Thus, a well developed local industry for components would make it easier for plant developers to have access to those components.[12] Germany, Spain and the US have been the home of most CSP system and component providers (Peters et al., 2011).

On the other hand, the relevance of some drivers is low. These include carbon prices, complementarity with PV and the cooperation mechanisms of the RES Directive (all with a score below 20%). This could be expected, given the very low carbon prices in the past, the fact that the complementarity of CSP with PV is particularly valuable for high shares of PV (which has not been the case in the EU so far) and the barriers to the use of cooperation mechanisms (see Caldés et al., 2019).

The future drivers differ slightly from the past ones. Although policy framework conditions and policy ambition will continue to be relevant in a 2030 timeframe, the two most important drivers will be dispatchability (a score of 85%) and the related complementarity with PV (76%). Obviously, the value of CSP will increase with higher shares of PV, and, thus, both technologies may complement each other. Other drivers score high in this timeframe, including cost reductions (60%) and development in niches (64%). Regarding the latter, which had a very low score in the past (20.5%), co-generation for domestic and industrial heat use, water desalination and enhanced oil recovery are possible applications of CSP plants which are additional to electricity generation (IEA-IRENA, 2013). The development in niches is considered very relevant by a few interviewees and irrelevant by a few others. Some believe that, although there will be more attention to applications which are not related to electricity generation, this will not be a main driver of CSP and the focus will continue to be on electricity generation. In contrast, others see these niches as a promising opportunity for the technology and, in particular, for process heat

Table 1
DBs to CSP deployment at the TIS level.

Techno-economic
- Proven, mature technology/Technology risks
- Improvement of the technology
- Development in niches
- Existence of a dominant design/Existence of a dominant design (PT)
- Costs: level and trends
- Better investment opportunities elsewhere/profitability
- Dispatchability
- Complementarity/competition with PV
- Access to credit.
- Impact of the economic and financial crisis

Availability of natural resources
- DNI levels
- Land availability
- Water availability

Policy-related
- Framework conditions & policy ambition/Retroactivity, lack of stability, ambition of targets
- Design electricity market/system
- Deployment support
- RD&D support
- Regional policies
- Carbon prices
- Cooperation mechanisms of the RES Directive

Administrative procedures/processes
- Permit and planning processes
- Access to the grid

Supply-chain related
- Local manufacturing capabilities
- Strong/weak supply chain
- Thin markets for solar-specific components
- Reliability and stability of suppliers over time
- Industrial consolidation and vertical integration
- Unavailability of standardized major components
- Exit of large players

Knowledge-related factors
- International knowledge collaboration, information flows
- Strong knowledge base and knowledge generation in EU (vs. non-EU)
- Low international knowledge collaboration
- Low competence in the CSP TIS
- Knowledge generation increasingly moving outside the EU

Other
- Social acceptability/opposition
- Environmental protection/pollution

Source: Own elaboration.

[12] For example, the lack of an industrial sector for the manufacturing of CSP components, which has not been able to fulfil the demand of the CSP installations in India, has been regarded as a main barrier to CSP deployment. CSP components like absorbers and reflectors were expensive, given their low availability (Bijarniya et al., 2016, p. 601). However, many Indian manufacturers have attempted to develop a local supply chain, starting to specialize in receiver tubes, frames, curved mirrors and other key components (Purohit and Purohit, 2017, p. 663).

Table 2
DBs to CSP deployment (investors).

Technological risk
- Maturity of the technology: the technology is (not) mature enough.
- There is a considerable risk that the technology will not perform as expected
Dispatchability and storage
- The dispatchability/storage capability of CSP
The supply chain
- Thin markets for solar-specific components. Bottlenecks in the supply chain related to the existence of very few component suppliers in a specific stage
- Reliability and stability of suppliers over time
- Availability of standardized major components
Profitability
- Good/poor economics. Expected appropriate or tight profit margins as a driver or a barrier (high/low internal rate of return compared to other investment alternatives)
Financing
- Internal financing conditions (contribution of equity). Existence of good/poor internal financing conditions
- External financing conditions. Perception of good/poor external financing conditions
Public policy
- Ambition of national renewable energy policies
- Stability of renewable energy policies
- Design of the electricity market
- Deployment support for CSP
- Research, development and demonstration (RD&D) support
- Carbon price (emissions trading scheme)
Electricity grid
- Access to the grid
- Level of transmission capacity
Permits and planning processes
- Reliability of planning and schedule
- Length (time) and costs of the process
- The need for an Environmental Impact Assessment (EIA)
- Easiness or difficulty for obtaining construction permits
- Easiness or difficulty for obtaining grid connection permits
Natural resources
- High/low DNI (direct normal irradiance) with respect to other EU/non-EU countries
- Availability of land
- Availability of water
Social acceptance/opposition
- Social acceptability and opposition, such as not-in-my-backyard (NIMBY) syndrome
Resource availability
- Has the availability of these resources in your firm been a driver or a barrier to the investment in CSP?
- Financial resources
- Ownership of patents
- Availability of technological experience
- Skilled human resources
- Physical assets, such as installations, equipment and so on
- Engagement in collaboration networks
- Corporate image
Previous experience
- Has previous experience been a driver or a barrier to the investment in CSP?
- Previous technology experience
- Previous market experience
- Previous project realization experience
- Previous investment in physical assets, such as other CSP plants or components
- Knowledge accumulated by previous CSP projects

Source: Own elaboration.

applications in industry, which “represent a huge potential market” according to one interviewee.

The most relevant barriers to CSP deployment in the past are higher costs (with a score of 72%), retroactivity, lack of stability and non-ambitious targets (78%) and low levels of deployment support (62%). Despite the aforementioned cost reductions in the past, the LCOE of CSP has been comparatively higher than for fossil fuel generation and other RETs (IRENA, 2016). Retroactivity and lack of stability mostly refer to the regulatory changes in Spain in 2010/2011. The low levels of deployment support are related to the support moratorium in Spain after 2012 and the low support provided in other countries. An interesting barrier in the past is the competition with PV (61%), in contrast to the complementary relationship between CSP and PV which is expected for the future.

Technology risks are also perceived by interviewees as a relevant barrier in the past (57%). Schinko and Komendantova (2016, p. 264) argue that, contrary to other investments in low-carbon technologies and other RETs, such as wind, CSP projects do not have an extensive track record yet. This creates additional uncertainty to investors and leads to higher expectations on rates of return due to higher perceived risks, which lead to higher financing costs. As expected, the relevance of this barrier decreases in the future (36%). Finally, the economic crisis and access to credit are considered barriers with an intermediate degree of relevance in the past, probably because many CSP plants (in Spain) had already been built before the deepest stage of the economic crisis.[13]

The future barriers are mostly related to higher costs (62%), limited resource potentials (DNI) (58%) and retroactivity, lack of stability and non-ambitious targets (68%). It seems that the competitiveness of the technology will not only be related to its dispatchable feature, but to reductions in its LCOE. Both factors have substantial policy implications, as it is mentioned in the next section. DNI can reach 2000 kWh/(m^2a) in southern Spain, which is high compared to other EU countries but low compared to the 2500 kWh/(m^2a) corresponding to the MENA region (Kost et al., 2013). As a result, its highest growth potential is outside Europe, in the sun belt countries (IEA-IRENA, 2013). Interestingly, “low levels of deployment support” is not one of the five main barriers in the future, probably because cost reductions and dispatchability will reduce the need for deployment support.

In general, social acceptability/opposition, supply-chain, knowledge-based and resource-availability issues show a low degree of relevance (all below 40%), especially as barriers (both in the past and the future). A low relevance is attached to administrative procedures and permits (need to obtain a construction permit, an operation permit, an approved environmental impact assessment and a grid connection permit). This is a bit surprising, given that CSP plants need long lead times from site development to grid connection (IEA, 2014). It is also in contrast to the findings of the survey to investors (see 4.3), who are probably more aware of this barrier.

A weak supply chain (thin markets) and the exit of large players have a medium-low degree of relevance. Lilliestam (2018) provides an excellent, in-depth analysis of the different stages of the CSP supply chain and claims that, although numerous new actors have entered the CSP market very recently, “the markets have thinned considerably in the last few years, leaving each segment with one or a few experienced still active actors (…). All of these industries are concentrated in a handful of companies, in particular in the components sector” (op.cit., p.40). The elicitation also suggests that this might have been a problem. According to several experts, the few suppliers in some components (e.g., absorption tubes and turbines) have led to bottlenecks and relatively high prices and profit margins. However, they all expect that this problem will be mitigated.

On the other hand, Lilliestam et al. (2018) argue that several large experienced firms have already left the market, which has

[13] According to Teske and Leung (2016), given the lower deployment level of CSP compared to other technologies, private banks view these projects as higher risk, and project financing has been an obstacle for CSP project developers in the past. They had difficulties to obtain loans “due to the lack of long-term data on CSP deployment and the irrational perception of CSP as a risky and immature technology” (op.cit., p.93).

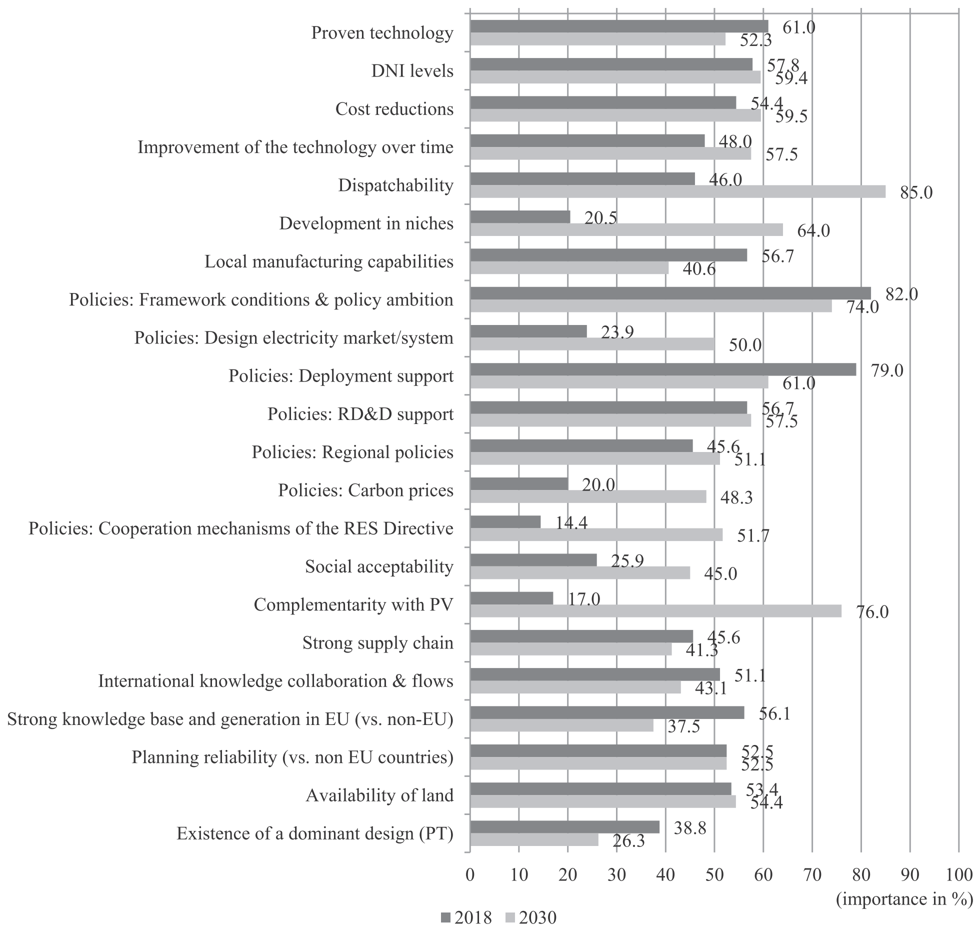

Fig. 4. Drivers to the deployment of CSP in the EU in the past and the future.
Source: Own elaboration. Note: The values represent the experts' quantification of importance on a percentage scale (0–100%). Average values are shown per category ("past until 2018 (shown as 2018)" and "future until 2030 (shown as 2030)").

implications for CSP-related knowledge. As stressed by this author, this knowledge is in the minds of engineers and workers in the CSP companies (Lilliestam, 2018, p. 42). Their departure from the industry will lead to the loss of that (tacit) knowledge on manufacturing and operation (op.cit., p.194). The author warns that this would happen if "no transfer of knowledge happens (e.g. through cooperation or engineers moving to new CSP companies)" (Lilliestam, 2018, p. 48). Several interviewees indicated that this is exactly what happened, suggesting that knowledge is not destroyed, but transferred. Many of these engineers seem to have been hired by non-EU firms, particularly Chinese ones, some of which have established branch offices and work in the EU. "Some have left, others are coming" is a widely repeated statement by the interviewees.

4.3. *Investors' survey*

This survey focused on the specific investment decisions faced by firms in the past. Fig. 6 identifies the main DBs for either PT or ST, as perceived by investors.

The main drivers for PT include aspects of the technology (maturity, expected performance and dispatchability) but also some investors' features, incuding previous technological and project realization experience and accumulated knowledge by the respective companies. The maturity of the technology and knowledge and experience accumulation are key drivers of the technology (scores of 5.9, 4.7 and 4.7, respectively), since PT is a more mature CSP design than ST and has considerably higher deployment levels. According to Lilliestam (2018, p.28) "67 of the 78 existing stations (excluding hybrids) are troughs, as are 11 of the 20 under construction." . The fact that it is mature and proven and has a good performance record is obviously very attractive for investors. In addition, there is some inertia regarding the influence of accumulated experience and knowledge in the firm when taking the decision to invest (both 4.7). This suggests pat dependencies and the important role of internal factors to the firm such as RCCs, in addition to context conditions which are external to the firm and the features of the technology.

On the other hand, the main relevant driver for ST adoption is dispatchability (5.8). This could also be expected, given its lower maturity level compared to PT and the much lower investments in this technology and accumulated experience in the past.

An interesting and a priori unexpected result is the important role played by administrative processes, construction permits and grid connection as barriers. This is the case both for ST and PT (−3.6 and −2.8, respectively).

Some major differences between PT and ST, especially regarding the drivers, are worth mentioning. Whereas technological maturity is a strong driver for PT, it is neutral for ST. The availability of standardized major components is a driver for PT and a barrier for ST. These DBs reflect the different maturity and deployment levels of each configuration. Dispatchability is a driver for both, yet a bit

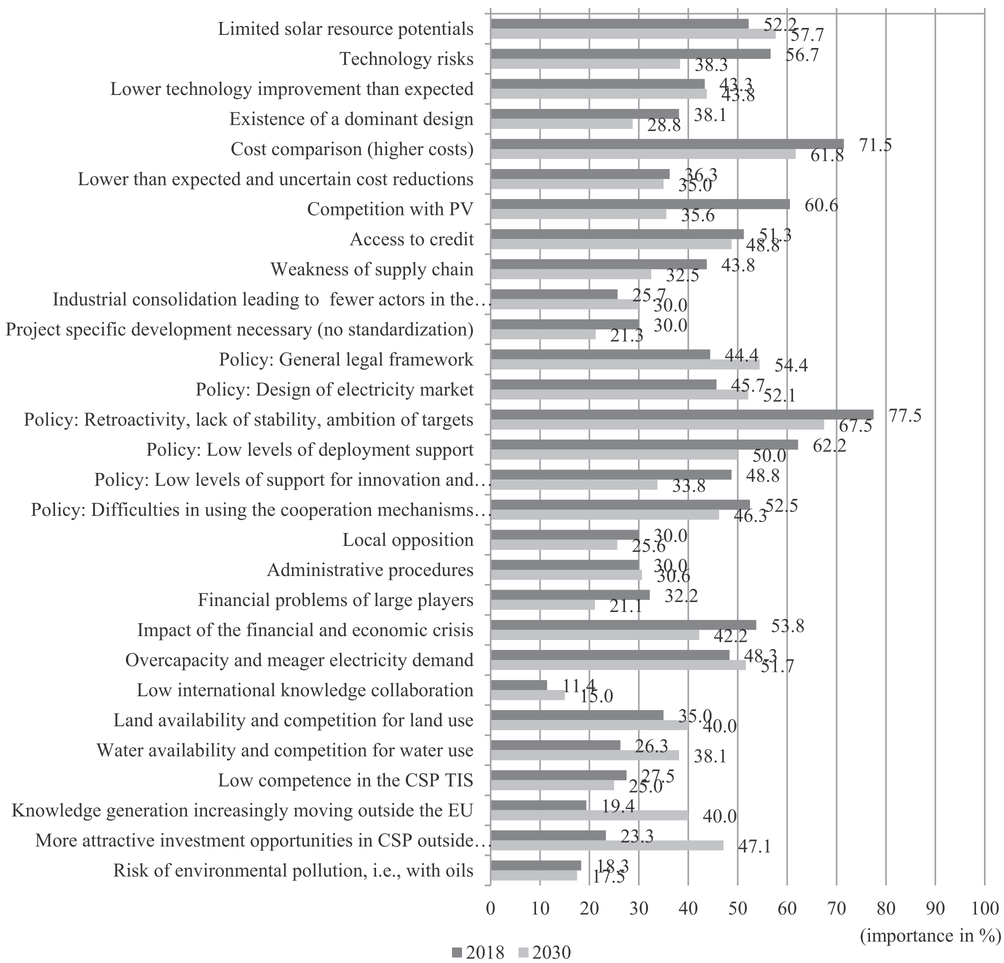

Fig. 5. Barriers for the deployment of CSP in the EU in the past and the future.
Source: Own elaboration. Note: The values represent the experts' quantification of importance on a percentage scale (0–100%). Average values are shown per category ("past until 2018 (shown as 2018)" and "future until 2030 (shown as 2030)").

more important for ST, which usually has a greater storage capacity. The previous experience accumulated by firms is a strong driver for PT but it is much less important for ST. This also reflects the longer period over which PT has been implemented. More attention is currently given to higher efficiencies and lower costs, which tends to shift the focus towards ST. However, other key DBs are similar for PT and ST and therefore can be expected to affect them equally, including framework conditions, internal financing, expected rates of return and administrative procedures.

Table 3 summarises the results of the empirical study.

5. Policy implications

The perceived relevance of different DBs suggests the need to combine different types of policy measures in order to either activate drivers or mitigate barriers to CSP deployment in the future. Therefore, a policy mix is required. Three categories of complementary policy interventions are required: Suitable framework conditions, instruments and design elements within those instruments.

Given the relevance of *framework conditions* as drivers of CSP deployment in the future, as stable and credible support as possible should be provided. This entails the adoption of long-term targets, ensuring predictable changes in the remuneration for new plants and avoiding retroactive changes for existing plants. These conditions would provide a positive signal for investors throughout the whole value chain and, thus, induce the required investments which would reduce costs through learning effects (deployment) and private R&D. Several interviewees suggested that lack of appropriate framework conditions and low levels of deployment support have negatively affected innovation. Firms substantially reduce their R&D investments in the absence of a market (del Río and Bleda, 2012).

In addition, particular *instruments* or *design elements* within instruments may remove or mitigate specific barriers and activate drivers. According to the results, RD&D and deployment support will continue to be very relevant in the future to address several barriers. They would induce improvements and cost reductions in the technology, which would directly activate two drivers ("proven technology" and "cost reductions") and mitigate two barriers ("high cost" and "technology risk"). Although the benefits of this support in terms of technology cost reductions will also be enjoyed by non-EU actors, some benefits can be locally appropriated (i.e. in the EU). RD&D support would contribute to maintain the "strong knowledge base and knowledge generation in the EU". However, in order to activate this driver, further support through other complementary instruments will be needed, as suggested by some interviewees. These include measures to strengthen local training efforts (e.g., in universities) and encourage public-private partnerships, networking, information flows as well as greater university-

Fig. 6. DBs for parabolic trough and solar tower.
Source: Own elaboration. Note: The values represent the average of the investors' quantification of importance, which are provided on a semantic differential scale ranging from −9 (strong barrier) to +9 (strong driver). In the figure, a positive (negative) value indicates that, on average, the factor is regarded as a driver (barrier).

industry-government collaboration at national and international levels. All these measures would also support "local manufacturing capabilities".

Within RD&D support, the experts in the elicitation stress the importance of support for demonstration projects. This is line with Lilliestam et al. (2018, p. 193) who argue that policies supporting demonstration plants in order to test new components could facilitate a more rapid rate of experimentation and technological learning.

Deployment support is justifiable, since CSP is not yet in a very advanced position in its learning curve compared to other RETs, and large cost reductions potentials are still left (IRENA, 2017; Lilliestam et al., 2018, Ling-zhi et al., 2018).[14] Regarding the alternatives for deployment support, either feed-in tariffs (FITs) or feed-in premiums (FIPs), with the remuneration being set in technology-specific auctions, could be good options. Auctions increase competition between firms and pressure them to reduce technology costs. Compared to FIPs, FITs entail lower risks for investors, which lead to lower financing and capital costs (Noothout et al., 2016). This is particularly positive for investments in a highly capital-intensive technology such as CSP.

The success of deployment support for RETs is not only related to specific instruments, but also to design elements within instruments (see Mitchell et al., 2011). Two design elements could

[14] According to IRENA (2017), learning effects and technological improvements have not yet been the main driver of cost reductions for CSP, leaving significant cost reduction potentials to be unlocked.

Table 3
Main DBs in the empirical analysis.

	Expert elicitation		Investors' survey	
	Past	Future	PT	ST
Drivers	- Deployment support, - Policy framework conditions - policy ambition. - Proven, low-risk technology	- Dispatchability (higher value) - Policy framework conditions and policy ambition - Complementarity with PV	- Maturity. - Expected performance. - Dispatchability. - Previous technological experience. - Previous project realization experience. - Accumulated knowledge.	- Dispatchability
Barriers	- Higher costs - Retroactivity, lack of stability - Non-ambitious targets - Low levels of deployment support	- Higher costs - Limited resource potentials (DNI) - Retroactivity, lack of stability - Ambition of targets.	- Administrative processes - Construction permits - Grid connection	- Thin markets for solar-specific components - Administrative processes - Construction permits - Grid connection

Source: del Río and Kiefer (2018a).

reduce the technology costs and/or the support costs.[15] A maximum project size in order to be eligible for support should not be required (as it was the case in Spain with the 50 MW limit). This is so because CSP projects need to be relatively large in order to function properly and because upsizing is a relevant source of cost reductions (IEA, 2014). On the other hand, Lilliestam and Pitz-Paal (2018, p. 19) argue that the long PPA duration in the recent CSP auction in Dubai has given a long-term perspective for investors, reducing the costs of capital and the LCOE by 2 cents per kWh.

In addition to cost reductions, dispatchability is the most important driver which needs to be activated. The value added that CSP combined with thermal storage can deliver to the stability and reliability of energy systems, especially with a high penetration of fluctuating power from other RETs, should be recognised by policy makers (Frisari and Stadelmann, 2015, p. 21). This can be done through the implementation of specific instruments or with design elements within these instruments. In this context, the economic opportunities of FITs versus FIPs were analysed in detail in several contributions (Dowling et al., 2017; Kost et al., 2013; Usaola, 2012; Wittmann et al., 2011). These studies concluded that FIPs offer greater revenue potential for CSP systems because they capture time-varying effects. FITs are less market-compatible than FIPs and do not encourage the electricity generator to sell the electricity when it is more valuable (market exposure).

Nevertheless, the dispatchability of CSP could be rewarded through the adoption of specific design elements in FITs, whether set administratively or in auctions (del Río and Mir-Artigues, 2019). This can be done by requiring a minimum number of hours of storage (as in Dubai), by granting higher remuneration levels in hours with higher electricity demand (as in South Africa) or through time-diverse auctions. In the latter case, different auctions can be organized according to the generation profile, e.g. base-load, non-peaking and peaking, as in California (del Río, 2017).

Soft loans could facilitate access to credit and may be particularly useful to reduce the financing costs for a capital-intensive technology such as CSP. The U.S. loan guarantee programme contributed to overcome financing difficulties for CSP (IEA, 2014). Note that favourable framework conditions (long-term targets and regulatory stability) would also improve the financing conditions for investors. Although access to credit was a barrier in the past, it is not expected to be so in the future.

Furthermore, the findings suggest that barriers related to administrative processes and grid connection should be mitigated, although only general recommendations can be made in this regard. Clear and streamlined authorization procedures across the EU should be implemented.

Social opposition is not regarded as a relevant barrier. However, not-in-my-back-yard (NIMBY) issues may be a problem with much higher CSP deployment levels in the future. This is due to the land use required by the technology and the land availability problems in certain areas, especially for central receivers (which also have a greater visual impact). Awareness-raising campaigns on the global, national and local benefits of CSP may mitigate this barrier.

Finally, it is unclear whether some DBs should be addressed with public interventions and which specific measures could be effective in this regard. This is the case for "deployment in niches", "thin markets" and "relatively low DNI levels". Incentives for deployment (appropriate framework conditions and deployment support) could be expected to mitigate the "thin markets" problem, as they would encourage investments throughout the whole supply chain. A stable market would encourage existing firms to invest and would make it attractive for new ones to enter the market. This may also mitigate the problem of large players leaving the sector. According to one interviewee, "firms disappeared due to lack of a market. The knowledge disappears because some people with the knowledge go to other sectors, or to non-EU firms".

Previous technology experience and previous project realization experience are very relevant drivers. European firms have a solid accumulated knowledge base in CSP for both ST and PT, which they perceive as a strong driver. Policies aimed at RD&D support (as provided by EU RD&D programs) and constant additions of new CSP projects can maintain and increase the existing experience and knowledge base in European firms.

6. Conclusions

As a dispatchable renewable energy technology with large cost reduction potentials, CSP has an important role to play in the EU energy transition if the drivers to its deployment are activated and the barriers are mitigated. This article has provided an assessment of the relevance of DBs to CSP deployment in the EU in the past and the future, as perceived by experts as well as investors in the technology. The degree of importance of the DBs differs to some extent for distinct time frames , types of stakeholders and CSP technologies, although some DBs are common to several of those categories.

Dispatchability, costs and policies are the three key DBs. However, their relative importance clearly changes over time. The main feature of CSP with respect to intermittent RETs (dispatchability) is

[15] However, it is beyond the scope of this article to provide a detailed assessment of the pros and cons of different design elements for CSP promotion. See del Río and Mir-Artigues (2019) for further details.

the main determinant for the uptake of the technology in the future. In the context of decarbonisation in many EU countries, intermittent RETs will reach a large penetration. This will require GHG-free technologies which are able to provide power on demand. CSP can play this role, especially in the South of Europe. In contrast, dispatchability has not been regarded as a main driver in the past, when the relatively low penetration of intermittent RES was not a challenge for electricity systems. The high relevance of "complementarity with PV" in the future and its low value in the past supports this interpretation.

In addition, the high LCOE of CSP (compared to other RETs) made this technology unattractive for potential investors. Indeed, it is regarded as an important barrier in the future, although less so than in the past. This is consistent with the fact that there is still a significant potential for cost reductions in the future, depending on advances along its learning curve (IRENA, 2017, 2016). Thus, its relevance as a barrier can also be expected to decrease.

If the relevance of dispatchability as a driver increases and the importance of costs as a barrier decreases in the future, then policy, which was a main driver and barrier in the past, would be less important in the future. The empirical analysis partly confirms this policy-relevant interpretation. Two main policy drivers (appropriate framework conditions and deployment support) and two main policy barriers in the past (retroactivity/lack of stability and low deployment support) are regarded as less important in the future.

However, policy will continue to be a main driver/barrier for the technology at least in four respects. First, investment certainty over the remuneration period will be needed because CSP is a highly capital-intensive technology with long pay-back periods. Thus, policy stability, lack of retroactivity and ambitious targets will be a crucial driver for the technology. Second, deployment and RD&D support will still be required, given the cost gap of the technology and the potential improvements and cost reductions that can be achieved with increased deployment and demonstration. Third, valuation of the dispatchability of CSP requires that some instruments or design elements are adopted. Fourth, since investors stress the importance of administrative processes and grid connection as barriers, measures to streamline administrative procedures are recommendable.

The findings in this article imply that a policy mix should be implemented in order to activate drivers or mitigate barriers. However, a policy mix entails considerable challenges, which suggest fruitful avenues for future research. These include the analysis of trade-offs between different policy goals, adequate balances between complementary types of support (RD&D and deployment) and interactions (synergies and conflicts) between instruments for CSP support. As argued by Labordena et al. (2017), the multiple policy objectives of carbon-neutrality, dispatchability and affordability are not easily compatible. On the other hand, finding an adequate balance between RD&D and deployment support is a great challenge for policy makers in the case of public support for CSP. While deployment support is more relevant in the short-term, RD&D support should also receive attention, given its importance in the long term and the time gap between RD&D investments and RD&D outcomes.

Finally, the interactions between different DBs have not been analysed in this paper. Some DBs are probably interrelated, i.e., one driver may have a direct impact on deployment but also an indirect effect (either positive or negative) through its impact on other driver(s). Future research should analyse these interlinkages.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2019.119400.

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