Market Uptake of Solar Thermal
Electricity through Cooperation

Deliverable 4.3 of the MUSTEC project - "Analysis of the Drivers and Barriers to the Market Uptake of CSP in the EU"

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Market Uptake of Solar Thermal Electricity

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 document provides an integrated analytical framework to identify the drivers and barriers to CSP deployment, empirically identifies those drivers and barriers to CSP deployment in the EU in the past and the future with the help of a literature review and ranks those drivers and barriers according to the views of investors and other relevant stakeholders involved in CSP.

Whereas our review of the literature suggests the relevance of a wide array of drivers and barriers, our empirical analysis based on an expert elicitation and an investors' survey suggests that the degree of importance of each driver/barrier differs for different types of stakeholders (industry, researchers, policy makers and others), different time frames (past and future) and different CSP designs (parabolic trough and solar tower).

Regarding the past drivers of CSP deployment, the expert interviews have suggested the importance of deployment support, policy framework conditions and policy ambition and the technology being regarded as proven (technology risks). Dispatchability is regarded as the main future driver of the technology, followed by policy framework conditions and policy ambition and complementarity with PV. The investors' survey confirms the relevance of dispatchability as a driver, together with key technology features (maturity and good performance of the technology) and investors' features (accumulated knowledge and experience) specifically for the case of parabolic trough.

Regarding CSP deployment in the past, several barriers stand out. These include higher costs, retroactivity, lack of stability and ambition of targets and low levels of deployment support. Higher costs, limited resource potentials (DNI) and retroactivity, lack of stability and ambition of targets are perceived as the most relevant future barriers for experts. The view of investors on those barriers is significantly different. They stress the importance of administrative processes, construction permits and grid connection. In short, the views of investors and experts regarding both drivers and barriers are deemed complementary, since they focus on different levels of analysis.

1. INTRODUCTION.

The development and deployment of new, low-carbon technologies is an essential part of efforts to mitigate climate change. However, historical trends are clear: energy technologies do not emerge and diffuse quickly due to a wide array of barriers to invention, development and diffusion (Grübler et al. 1999; Fouquet 2010). Policymakers need to identify ways in which the process can be accelerated (McDowall et al. 2013). Indeed, experiences in different countries show that diffusion can be a very slow and tedious process (Negro et al. 2012). This occurs in general and particularly in the energy sector. As Rosenberg (1976) puts it, at the beginning the new technology is crude, expensive, inefficient, and badly adapted to the existing institutional setting and the ultimate use, which leads to slow diffusion. Therefore identifying the drivers and barriers to renewable energy technologies (RETs) in general and CSP deployment in particular is a relevant exercise in order to propose policy measures which activate those drivers or remove those barriers. Compared to intermittent RETs, CSP has a main distinguishing feature: it can be equipped with low-cost thermal energy storage, which allows it to provide distpatchable renewable power. Generation can thus be shifted to times when the sun is not shining or to maximizing generation at peak demand times. It can then be a cost-effective, flexible option in different places, especially with increasing shares of variable renewable electricity (Mehos et al. 2015; IRENA et al. 2018).

This document provides an integrated analytical framework to identify the drivers and barriers to CSP deployment, empirically identifies those drivers and barriers to CSP deployment in the EU in the past and future with the help of a literature review and ranks those drivers and barriers according to the views of investors and other relevant stakeholders involved in CSP.

To our best knowledge a comprehensive analysis on the drivers and barriers to CSP technology in the EU in the past has not been published. Del Río & Kiefer (2018) analyses the potential drivers and barriers to CSP with a focus in the future (2030) and not the past. The literature review carried out in such study is circumscribed to the 2011-2015 period, whereas the analysis in this document takes the period until 2018 into account. Furthermore, while this study draws to some extent on that contribution, it considers a broader set of drivers and barriers, based on an integrated analytical framework which combines several approaches, and uses different methodologies to investigate the ranking of those drivers and barriers to CSP in the EU in the past and the future as perceived by different types of stakeholders.

Many previous studies have identified drivers and obstacles to RETs in a piecemeal fashion without comprehensively examining the topic. The low adoption rate of some RETs or in some countries has often been associated with a random list of drivers and barriers to diffusion (Kebede & Mitsufuji 2017). We believe that the analysis of those drivers/barriers should be based on an integrated, systemic framework which takes into account all the potential factors and their interrelationships. Our choice is for an analytical framework which is based on the technological innovation system (TIS) approach, complemented with insights from other approaches and, in particular: 1) an adopter's perspective; 2) context factors; 3) technological features and costs (see section 2). The strength of the TIS approach is that it provides a detailed structure for understanding the interplay between policies and cultural, technical and economic developments.

The rest of this document is structured as follows. The next section provides the analytical framework. It discusses several analytical approaches to analyse the drivers and barriers to CSP. An integrated framework based on the technological innovation system (TIS) approach, which integrates insights from other approaches is provided. Section 3 describes the methodology used for the empirical analysis of those drivers and barriers. The results of such analysis are provided and discussed in section 4. Section 5 concludes.

2. ANALYTICAL FRAMEWORK.

This section briefly discusses our integrated analytical framework to identify the drivers and barriers to CSP deployment. The full details of this framework are described in Del Río & Kiefer (2018).

Our starting point is that the analysis of those drivers/barriers should be based on an integrated, systemic framework which takes into account all the potential factors and their interrelationships. Several theoretical approaches to diffusion exist in the literature, including environmental economics, innovation studies, the multi-level perspective (MLP), the literature on learning effects, diffusion modelling approaches and innovation adoption approaches with a focus on the adopter. Each stresses crucial aspects in the diffusion process, while neglecting or downplaying others (see Del Río & Kiefer 2018, for a detailed explanation). The TIS approach is at the core of our analytical framework which is also complemented with insights from other approaches.

The systemic perspective views innovation as the outcome of system interactions, involving "the network of institutions in public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman 1987). This systemic perspective argues that low-carbon industrial development may be obstructed by system failures (Woolthuis et al. 2005), and that the narrowly defined market failure approach is an inadequate framework for informing innovation policy (McDowall et al. 2013, p.164).

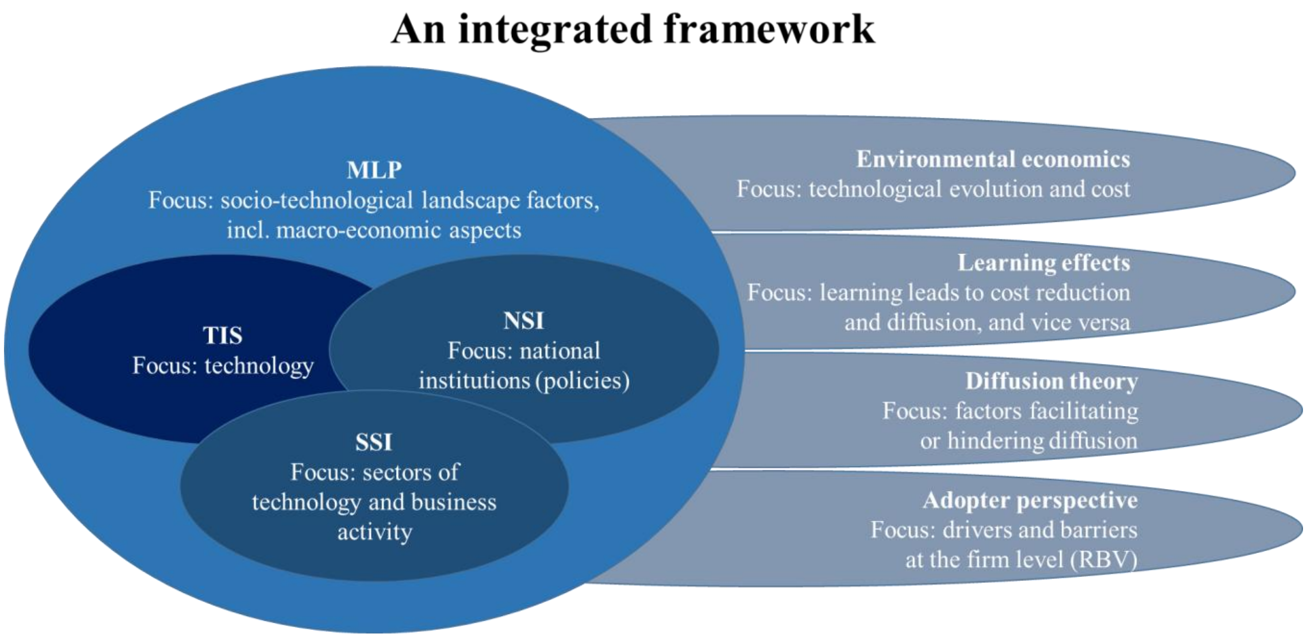
Within the systemic perspective, there are several alternatives. The TIS has been chosen in work package 4 of the MUSTEC project as the core approach to analyse the drivers and barriers to CSP deployment in the past. The TIS approach, which was introduced by Carlsson and Stankiewicz (1991), has been extensively adopted by scholars, as it combines the study of technological aspects with the socio-technical processes which can influence the diffusion of technologies (Edsand 2017, p.2). The strength of the TIS approach is that it provides a detailed structure for understanding the interplay between policies and cultural, technical and economic developments. The innovation system approach is conceptually fully consistent with the evolutionary theory of technology policy, the key features of which are probably best articulated in Metcalfe (1994) and are: focus of policy on variety and selection, and on diffusion as well as on generation of knowledge; adaptive policy making; the importance of the wider institutional context; and the facilitation of the self-organisation of the innovation system (McDowall et al. 2013, p.165).

An integrated framework based on the TIS, which combines it with other approaches is provided below (section 2.1). The specific elements of an integrated framework for the analysis of CSP drivers and barriers are provided in section 2.2, and their relationships in the analytical framework are discussed in section 2.3.

2.1 The need to combine approaches: an integrated framework.

The TIS approach and its conceptualization of different drivers and barriers to diffusion is deemed the appropriate analytical approach to identify the drivers and barriers to the deployment of CSP. However, it does not take into account crucial aspects which affect such diffusion process and, thus, needs to be complemented with other approaches (Figure 1). In the following paragraphs the need to complement the TIS with other approaches is justified.

Figure 1. Illustrating our integrated framework.



-Need to combine the TIS with the SSI and the NSI: the role of sectoral features and national institutions.

As argued by Bergek et al. (2015, p. 52), analysts have from its inception, tried to find ways to take into account interactions with other types of systems encompassing or transcending the TIS, such as sectoral systems of innovation (SSI) and national systems of innovation (NSI). Hanson (2017) illustrates the fruitfulness of distinguishing between a sectoral and a technological context. This combination of sector and technology perspectives is particularly relevant for multi-component technologies, such as CSP, since their underlying innovation dynamics involve multiple sectors (Stephan et al. 2017), suggesting that the sectoral configuration deserves more attention in TIS analyses. Bergek et al (2015) argue that an explicit analysis of relevant sectoral context structures and their interactions with a focal TIS through external links and structural couplings is needed in order to fully capture TIS (and sector) dynamics. On the other hand, the TIS should be combined with a national innovation perspective since many institutions (including policies) which are relevant for the CSP TIS have a national character.

-Need to combine the TIS and the MLP: the landscape factors.

One of the most common criticisms to the TIS approach has been the lack of consideration of "context factors". Some of these relate to macro or "landscape" factors, which are stressed in the MLP. Thus, a particularly fruitful combination might be that between the TIS and the MLP. This has also been attempted in the past, for example, by Markard et al. (2009) and Markard and Truffer

(2008)[1]. The MLP framework, which can be used in the analysis of technological transitions, places more emphasis on the wider context than the TIS (Geels 2002). The ability of the MLP to take into account the incumbent actors (the "socio-technical regime") and the wider context (the "socio-technical landscape") has been considered an asset of the framework, while lacking in the TIS framework, according to Markard and Truffer (2008). Our analytical framework addresses this criticism by systematically including factors of the landscape which could affect CSP deployment (e.g. macroeconomic aspects).

-Relevant insights from environmental economics: the importance of the costs of the technologies in the diffusion process.

The costs of the technology (e.g., CSP) compared to competing technologies (e.g., PV) as well as their respective evolutions over time are arguably main drivers of the diffusion process. Costs are stressed by the environmental economics perspective.

-Relevant insights from the learning effects literature.

Learning effects as a result of diffusion lead to cost reductions, i.e., learning effects are sources of cost reductions. Therefore, insights from the learning effects literature should be included in the analysis. Note that cost reductions and diffusion positively interact: cost reductions lead to diffusion which, in turn, reduces costs by activating learning effects. Several contributions suggest that there have been and will be substantial cost reductions for CSP (IRENA 2016; IRENA 2018). Recent analytical work by Lilliestam et al. (2017) suggests learning rates above 20%. Lilliestam (2018) shows that, for parabolic trough configurations with storage (the currently predominant configuration in the market), cost reductions and its diffusion go hand in hand. In addition, preliminary data indicators seem to confirm this for currently-under-construction or planning solar tower technologies with large storage capacities. Based on project and auction data, IRENA (2018) estimates a learning rate of 30% for the 2010-2020 period.

-Relevant insights from diffusion theory: the importance of the techno-economic features of the technologies in the diffusion process.

Some characteristics of the technologies may influence the speed of their diffusion. A very relevant one is the drastic changes that adoption may cause in firms (changes in the organization of the firm, in production routines, in production processes, in training of the workforce). The existence of an installed base and the problem of switching costs have been regarded in the past as a key barrier to adoption (see, i.e., Del Río 2005 for a discussion). The existence of lasting physical assets is a constraint to the investments in new equipment. Such assets are replaced in the long term, but in the short term they may slow down the diffusion of new technologies,

[1] However, other authors are critical of such combination because the TIS and MLP perspectives are "ontologically different" (Vasseur et al. 2013; Stirling 2011).

especially in capital-intensive sectors. In this case, the introduction of more radical changes takes place when it is time to replace the capital goods because it is cheaper and easier to introduce technological changes then. Firms prefer to adopt technologies which can easily be embedded in the existing production process with only minor adaptations (drop-ins) or which require lower capital expenditures. Besides firm-level considerations, additionally, it has to be considered that CSP competes with a pre-existing infrastructure and other technologies on a system-level, which may also hinder its diffusion (Adams et al. 2012; Boons & Lüdeke-Freund 2013). A critical aspect of CSP in this context is its dispatchable nature, which makes it increasingly attractive for potential adopters in decarbonised electricity systems with a higher penetration of variable renewables.

-Need to combine TIS and an adopter perspective: firm internal resources.

The analysis of the drivers and barriers (DBs) to diffusion should take into account the views of those who are directly engaged in such process, i.e., adopters (investors)(Mignon & Bergek 2016). The literature on eco-innovation show that, when taking the decision to invest, investors are affected by factors which are internal to the firm (resources, capabilities and competences) as well as by “external” factors, of which the role of public policy has usually been stressed (see Del Río 2009; Del Río et al. 2016 for reviews of this literature). These internal and external factors create incentives (drivers) and obstacles (barriers) for the investment. Several approaches focus on the internal features (such as resources, competences and dynamic capabilities, RCCs) and behavioural aspects of the adopter, including the resource-based view of the firm (RBV)(Katkalo et al. 2010) or entrepreneur perspectives (Planko et al. 2017). The former include the firm’s bundle of available or accessible RCCs such as physical, financial, technological, human and intellectual capital, organizational and reputational/cooperation resources, both tangible and intangible, their application in the daily business practices (competences) and their strategic and deliberate change over time (dynamic capabilities). The latter consider that all economic agents are boundedly rational, with psychological, cultural, cognitive and other factors having an influence on decisions, highlighting the importance of individual firm’s culture, climate, future- and sustainability orientation, organizational aspects and the like.

2.2 Elements of an integrated framework for the analysis of CSP drivers and barriers

2.2.1 *Basis on the TIS approach.*

The TIS approach is the point of departure for the conceptual framework. It was developed to analyse emerging technologies in order to identify mechanisms that are either blocking or driving their development and diffusion and suggest how policy could intervene (Carlsson et al. 2002).

2.2.2 *Focus on the growth stage and bridging/mass markets.*

In the TIS approach, it is recognised that the development and diffusion of a novel technology is a complex process plagued by uncertainty. The initial formative phase of a TIS can last for several decades and includes R&D, demonstration and early commercialisation (Wilson 2012). The formative phase may be followed by a growth phase, during which the technology starts to be diffused on a larger scale and, eventually, a saturation phase (Karltorp 2016, p.97).

For the case of CSP, the technology has gone through a formative phase, and an up-scaling has been initiated with an associated development of an industry around the technology. Turbine manufacturers, component manufacturers and utilities are the main technology developers.

We consider two technological modalities of CSP (parabolic trough and solar tower). Parabolic trough has been the dominant technology in the past, followed at a long distance by solar towers and the other two alternatives (Fresnel and Stirling), although solar towers have recently gained ground. Parabolic trough is a more mature technology than the other alternatives, including solar towers, for which there isn’t any dominant design yet and not even a discernible one on the horizon. Since parabolic trough systems and solar towers are expected to continue to be the dominant commercial technology in the next years, i.e. at least up to 2025 according to (IRENA 2016), they will be the focus of this document.

2.2.3 *Focus on the EU and national levels.*

Both EU and national institutions play a crucial role in the development of a TIS and, particularly, in the case of the CSP TIS (e.g. EU targets, EU R&D policies, national deployment policies, national electricity markets etc…). While this focus on the EU and national level has its merits, it is probably not enough for some RETs, where the TIS is rather global and not national, as with CSP. Of course, there is always a trade-off between manageability and completeness. Furthermore, although a limitation, the focus of this report is on deployment in the past, and the relevance of the EU in global CSP deployment has been very high.

2.2.4 *Including context factors*

A main criticism of the TIS approach in the past has been the absence of consideration of contextual factors (geographically and non-geographically related ones). There are “internal versus external forces of change (…). The internal dynamics is only part of the picture” (Jacobsson 2008, p.1498). However, as argued by Markard et al. (2015), the TIS approach has been used to account for both system specific as well as so-called exogenous structural elements that impact system dynamics. Context structures thus also affect a TIS by influencing the development of its key processes (Hanson 2017, p.4).

Bergek et al. (2015) propose a coherent framework that makes explicit how the interactions between a TIS and its contexts can be conceptualized. In particular, they elaborate on TIS-context interactions for four exemplary context structures which would be relevant for the analysis of the drivers and barriers to CSP deployment:

1) *Surrounding and related TIS*, whether vertically in the supply chain (e.g. mirrors TIS) or horizontally-related TIS (e.g., PV TIS, battery TIS…). This interaction can be supportive or competitive.

2) *Interaction between a focal TIS and related sectors*. A sector comprises multiple TISs supplying technologies and products needed to serve a certain function for prospective users. Interaction takes place due to sector specific regulations, norms and cognitive frames, and physical infrastructures. In the case of CSP, this directly refers to the energy sector (e.g., electricity market design). A sector provides a quite stable context which individual TIS either has to adapt to or to try to change to its own benefit. Interactions occur between a focal TIS and sector-level actors, networks, technologies and institutions.

3) *A geographical dimension* of TIS context structures. Technological developments are not evenly distributed over space and regional structures impact technology development and diffusion in different ways.

4) *A political dimension* in which a "battle over institutions" takes place.

The authors also stress the importance of the provision of specific system-level assets (e.g., political support for CSP deployment, CSP-policies, trained personnel, educational and financial system…). Each of these may exhibit very particular constraints and dynamics, which impact the further development of a TIS. These TIS-context interactions tend to change over time. We thus include several context factors:

1) International aspects. Schmidt and Dabur (2014) proposed a division of TIS into two: national TIS and international TIS. The technological system in one specific technology such as CSP might indeed be international, even global. As mentioned above, we focus on the EU and MS level. Therefore, we include the international aspects in our framework but only in a limited manner for reasons of manageability.

2) Other competing and supporting TIS. The interactions between the TIS and a relevant neighbouring sector lead to drivers and barriers to the TIS-CSP. Here, the role of established industries and supply-chain influences should be included. It might indeed be very fruitful to distinguish between a sectoral and technological context, although these contexts overlap. As mentioned by Bergek et al. (2015, p. 55), "much of the TIS–TIS interaction occurs along vertically related technology value chains. A focal TIS typically requires raw materials, components, sub-systems and services that are provided by other TISs, which implies that the development of the focal TIS could be affected, positively or negatively, by the development in upstream TISs".

Therefore, the supply chain of CSP, made up of different stages and sectors, should be taken into account to some extent.

3) The electricity sector. According to Mignon and Bergek (2016), a type of context factors includes broader structures in which the specific TIS-RETs (e.g., CSP TIS) constitutes a sub-system, such as the “electricity sector”, or national structures, not specific to any sector, forming a “national innovation system”. The later are included in the national-level focus (see previous point). The electricity sector (and system) is indeed a critical aspect, since CSP obviously produces electricity, and the institutional arrangements in the electricity sector may encourage or deter CSP deployment.

4) Other context (landscape) factors. These include sudden price shifts in essential production factors, major technical disasters, changes in political priorities in a society, interest rates, oil and gas prices etc…, among many others. However, it may indeed be very difficult in practice to include all the possible influences from the context (or exogenous factors). If so, the empirical analysis would be unmanageable. Karltorp et al. (2017) propose to leave the exogenous factors aside. An intermediate, pragmatic solution would be TIS-specific: interviews to experts would help elucidate which exogenous factors are worth including in the analysis. Similarly, we restrict the consideration of some aspects in order to reduce the complexity of the analysis. As in Hanson (2017), we focus upon those parts of the context that have structural overlaps or have impacted the key processes of the focal CSP TIS.

2.2.5 *Focus on the adopter and the TIS level.*

This analysis focuses on the diffusion of the technology. It is assumed that drivers and barriers exist at an adopter level as well as higher levels (TIS, supra-TIS and landscape). In the context of this document, adopters are defined as the investors in CSP technologies[2]

The analysis of the DBs to diffusion should take into account the views of those who are directly engaged in such process, i.e., adopters (investors)(Mignon & Bergek 2016). Unfortunately, there has been a lack of focus on the companies, adopters, investors etc… in the past in the TIS RETs literature, despite the fact that as it is argued in the broader literature on innovation systems, that the innovation and diffusion process is both an individual and collective act (Jacobsson & Bergek 2004).

Some authors call for more focus on the adopter level and for a better coupling of the micro and meso levels in the TIS. Mignon and Bergek (2016, p. 105) argue that, although the TIS has provided important insights into the system-level barriers and opportunities for development and early diffusion, it has not explicitly taken into account demand-side actors (e.g. adopters of the

[2] Here, an adopter is defined the following way: An adopter (or technology adopter) is a firm that engages in the search for and evaluation of technologies and realizes an investment decision in favor of one of them. The investment may be financial, physical, etc. The firm is considered to be an adopter of the technology it invested in.

technology) and their responses to institutional drivers and pressures. Similarly, Hansen and Coenen (2017), Bauer et al. (2017) and Reichardt et al. (2016) call for such coupling,

However, only Mignon and Bergek (2016) and Hansen and Coenen (2017) have explicitly complemented the TIS with the adopter perspective (Mignon & Bergek 2016), while this is only implicit in other papers (Hanson 2017; Malonzo & Posadas 2016; Karltorp 2016; Gosens & Lu 2014). Our analytical framework considers this adopter perspective (interest and ability) in two manners: we ask adopters (investors) about their views of different drivers and barriers to CSP and we also include some RCCs of those adopters as relevant factors influencing CSP deployment.

We follow in this context the recommendation of Mignon and Bergek (2016) who call to combine different approaches in order to better understand the behaviour of system actors, the dynamics of innovation systems and their joint consequences for the diffusion of innovations. They combine system- and actor-level challenges facing those who adopt renewable electricity generation technologies. This enables an analysis both of the relative importance of these two levels for later-stage diffusion and of the interplay (if any) between system and actor-level challenges (Mignon & Bergek 2016, p.107). They explicitly include the actor-level in their analysis and derive two main categories of factors that can influence what innovations adopters become aware of, what value they attribute to particular innovations and their ability to adopt them: adopter resources and behavioural factors (see above).

2.2.6 *Additional focus on the techno-economic characteristics of CSP.*

The techno-economic features of the technologies are seldom discussed as a main driver or barrier to the diffusion of the specific RET in the TIS-RETs literature. It is a bit surprising that technology, which is a structural component of TIS, is undervalued in TIS-RETs analyses. Most authors do not address the purely technical aspects of RETs. Instead, we argue that the characteristics of the technologies do have a considerable influence on the diffusion process. We thus take into account the particular technoeconomic features of the most widespread CSP designs (parabolic trough and solar tower) when analysing the drivers and barriers to CSP.

2.2.7 *Consideration of the costs of CSP.*

Related to the previous point, a key dynamic technoeconomic feature is the costs of the technologies. While some papers on TIS-RETs mention the costs of RETs and even the evolution of those costs, they mostly neglect the interactions between the other TIS elements and the evolution of those costs as a driver or barrier to the diffusion of the RET under study (see Del Río & Kiefer 2018, for further details). The underrepresentation of costs in the diffusion of RETs in a TIS perspective is striking, given the critical role played by those costs in the accelerated diffusion of RETs, as shown by non-TIS approaches and the cost reductions of mature RETs (solar PV and wind on-shore), which have led to very competitive cost levels for these technologies and their widespread diffusion. We take a more nuanced, intermediate approach in this study, whereas both costs and non-costs aspects drive the diffusion of RETs.

Costs and diffusion are mutually interrelated, leading to a reinforcing cycle. Lower costs induce diffusion, since they make the technology attractive from an adopter point of view. But, on the other hand, a greater diffusion rate leads to lower costs, given dynamics economies of scale and learning effects. Indeed, the learning effects approach applied to CSP has shown that there have been significant cost reductions in the past (see, e.g., Lilliestam et al. 2017).

Note that the focus on costs and on the adopter are related to some extent, since the costs of the technologies are a main variable in the decision to invest, i.e., the investment return depends on cost and revenues. For the investment decision, both the total cost of the investment and the cost per unit of output are important (Karltorp 2016).

2.3 Relating the elements and levels of analysis.

Drivers and barriers to CSP can be identified at different levels of analysis. They are interrelated, in the sense that drivers and barriers at a higher aggregation level are potential drivers and barriers at lower aggregation levels.

ACTOR-LEVEL: These are the microconditions relevant for CSP investment. These relate to the RCCs of potential investors (and non-investors) as well as their behavioural aspects. In addition to their own aspects, investors are affected by factors which are outside of their realm and which are rather exogenous to them. These belong to the CSP-TIS, the supra-CSP TIS and to the landscape levels.

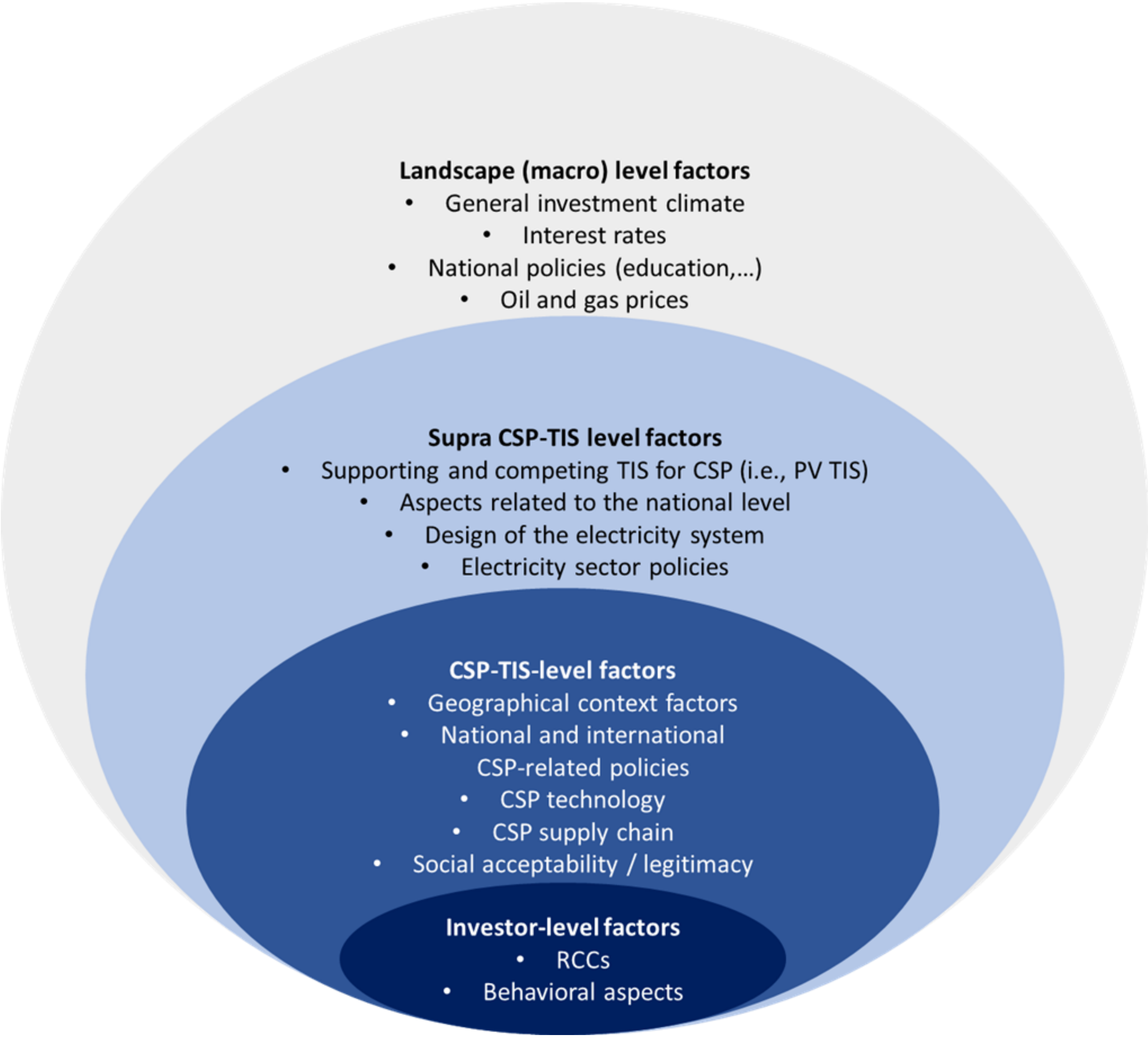
TIS-LEVEL: Factors belonging to this level include geographical context factors (transnational linkages in CSP technology), non-geographical context factors (national and international policies related to CSP) as well as the characteristics of CSP technology (dispatchability, high initial investment costs, importance of tacit knowledge…). Aspects related to the CSP supply chain should be included in this level as well as issues of social acceptability of CSP technology (legitimacy).

SUPRA-TIS LEVEL: These include several aspects. Some are related to supporting or competing TIS to CSP, i.e., the PV TIS, the battery TIS etc… Others are related to the national level and include the design of the electricity system and electricity-sector policies.

LANDSCAPE: Finally, factors included here represent the highest level of aggregation (macro level). Examples include the general investment climate in the country, interest rates, general national policies (education), oil and gas prices etc…

The following figure provides a representation of the different analytical levels and their interrelationships (overlaps).

Figure 2 Interrelationships between different analytical levels.



Therefore, an integrated, systemic analysis of the drivers and barriers to CSP should take into account all those factors and identify their relative importance. Nevertheless, as mentioned before, for reasons of manageability of the analysis, this study can not cover all the possible factors affecting the CSP TIS, but only the most important drivers and barriers to CSP deployment. The unit of analysis has to be at the lowest level possible in order to be able to grasp all potentially relevant influences, i.e., at the actor or TIS level. The following section explains what methodological options exist in order to appropriately capture such relevance.

3. METHODOLOGY.

The application of the aforementioned analytical framework requires the consideration of several methodological guidelines (section 3.1). This makes it recommendable to combine a literature review (3.2) with an expert interview (3.3) and an investor survey (3.4).

3.1 Methodological guidelines for the application of the analytical framework

The aim of this research is to identify the drivers and barriers (DBs) to CSP deployment using a TIS approach complemented with other aspects. Two main complementary levels of analysis can be discerned: the system level (level of the TIS) and the adopter (investor) level. It should be acknowledged that the distinction between the two is somewhat artificial, since some DBs at the adopter level represent systemic barriers (i.e., belonging to the TIS level). Therefore, there will be two focuses of the analysis: the TIS level and the adopter (investor) level. The identification of DBs at these two levels requires a different research strategy, although both share some aspects in common.

ADOPTER LEVEL

The starting point is that the analysis of the DBs to diffusion should take into account the views of those who are directly engaged in such process, i.e., adopters (investors)(Mignon & Bergek 2016). As mentioned above, when taking the decision to invest, investors are affected by factors which are internal to the firm (RCCs) as well as by "external" factors, of which the role of public policy has usually been stressed. These internal and external factors create incentives (drivers) and obstacles (barriers) for the investment. The external factors can be conceptualized as DBs at the TIS level. In addition, the techno-economic features of the technology (most notably, its costs) are a crucial third element in this analysis. The focus has been on solar tower and parabolic through technologies.

A list of possible DBs has been identified. These are based on: 1) the literature review performed in Del Río et al. (2018), which includes contributions up to 2015; 2) an additional review of the literature covering the last three years and other sources not considered in Del Río et al (2018)(see 3.2); 3) other possible DBs which stem from the literature which uses the TIS approach to analyse DBs in RETs (performed by the authors, see Del Río & Kiefer 2018); 4) Other possible DBs which stem from the literature on the adopter level, focusing on the RCCs of the investors (performed by the authors, see Kiefer et al. 2018).

This list on possible DBs to CSP deployment thus combines aspects at the TIS level (e.g., the role of policy) with aspects at the level of the adopter. Investors are then asked about the relevance of each of those DBs. The outcome of the survey provides a clear picture on the relevance of the perceived DBs to CSP deployment (distinguishing between solar tower ST and parabolic trough PT).

TIS LEVEL

The analysis of the DBs to CSP at the TIS level is complementary to the previous one. It requires a different empirical approach since the focus is on a higher level than the adopter. In this case, the appropriate actor to interview is the "expert" on CSP. Experts include researchers in the technology, manufacturers, investors, policy makers etc… But, similarly to the above case, the outcome is the ranking of the relevance of DBs to CSP deployment. Note that there are some unavoidable overlaps between both types of analysis, since factors at the TIS level also play a role at the adopter level.

The identification of DBs and their relevance follows a similar logic as in the case of the adopter level, i.e., a literature review allows the identification of DBs at the TIS level, and then this is followed by an expert elicitation survey which allows the ranking of the relevance of each DB. This approach has been followed by e.g., Eleftheriadis and Anagnostopoulou (2015) and Zhang et al., (2012). In Zhang et al. (2012) and Eleftheriadis and Anagnostopoulou (2015), survey participants were asked to assess the importance of barriers to RETs using a Likert scale from 1 to 5, with 1 denoting unimportant and 5 most important.

In order to apply the analytical framework and to identify the drivers and barriers to CSP deployment in the EU in the past, three complementary types of activities have been performed: a literature review (3.2), an expert elicitation (3.3) and an investor survey (3.4). The latter two are based on the findings of the former and try to identify the relevance of each DB, in addition to checking whether any relevant DB has been missing from our literature review. The latter two complement each other, since the expert elicitation provides an overall vision of the CSP TIS, whereas the latter is more circumscribed to the specific DBs faced by investors.

3.2 Literature review

A thorough literature review of the drivers and barriers to CSP deployment, with a focus on the EU in the past, has been performed. This built on the review performed in Del Río et al. (2018, 2016), which was restricted to the 2011-2015 period. A desktop search of documents was carried out. Journal articles, official statistics, reports from industry associations, research organizations and other institutions (the European Commission, IRENA, Protermosolar, ESTELA and IEA, among others), and news items from newspapers, government and company websites were reviewed. The most relevant energy journals were consulted (including the Electricity Journal, Energy Policy, 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). In addition, publications exclusively dedicated to CSP (CSP Today and Helio CSP) were consulted. Furthermore, a general google search for documents in the grey literature was undertaken. Our review covers the last ten years (2008-2017).

Relevant key words ("concentrated solar power", "CSP", "solar thermal electricity") were introduced in the search engines of the journals and in google. Sometimes, internal search engines were enough to identify relevant studies. When the internal search engine did not work well, we had to look at each issue in the last 10 years. After all the a priori relevant documents were collected, a triple-filter was applied. First, those contributions merely focusing on the technical aspects of CSP were removed from our database. Second, we read the remaining articles and focused on those which dealt with at least one driver or barrier to CSP. Finally, the geographical focus on the EU led to the dismissal of papers with an exclusive non-EU scope. Those with a world-wide scope were deemed relevant for our study, since they included insights on the European situation and/or on the technology which indirectly were of relevance for an EU perspective on the topic.

Two general conclusions can be inferred from the literature review. First, with the aforementioned exception of Del Río et al. (2018, 2016), an all-encompassing identification and assessment of all the drivers and barriers to CSP has not been published, even less so in an EU context. Second, while several drivers/barriers have been identified as relevant for the diffusion of CSP in the EU, their relative importance has not been analysed. This is the reason for using the investors' survey and expert elicitation (see below), i.e., to interview relevant stakeholders in order to gain further insights on their ranking.

With respect to Del Río et al. (2018), which in turn draws on research carried out by the authors in the EU-funded Towards 2030 project (Del Río et al. 2016), where the focus of attention is not only on CSP, but on wind off-shore as well, the review performed in this paper is more comprehensive in several respects. First, this one is based on an integrated and fully developed analytical framework (developed in section 2 of this document), which takes into account a wide array of DBs to RETs which have been looked for in the aforementioned information sources specifically for CSP. This leads to the consideration of more factors acting as either drivers or barriers than Del Río et al. (2018, 2016). Second, the period covered in this review is broader, covering 2007-2018, rather than only 2011-2015. Third, more information sources have been consulted in this study. Finally, partly as a consequence of the previous points, the results of our analysis lead to a greater number of possible DBs.

3.3 Expert elicitation survey

Expert elicitations are a proven method when the research interest does not focus on a defined target universe, i.e., usually proxied by representative individual observations that are extrapolated to that universe, but rather when the aim is to capture a body of knowledge (Tversky & Kahneman 1974; Chan et al. 2011), usually closely related to a specific technology paired with high technological uncertainty. This is traditionally related to less mature and highly risk-inherent technologies where the "public" availability of knowledge is reduced. Although CSP can hardly be considered an immature technology today, at least regarding parabolic trough and solar tower designs, it was so until recently. Additionally, there is high technological dynamism and uncertainty regarding future developments. CSP is a very specific knowledge field (i.e., tacit knowledge has a very high relevance) which is why accessing this knowledge is difficult and public information is largely unavailable. Expert elicitations seem a promising tool to capture this tacit knowledge and get a precise notion of this dynamism and uncertainty.

In recollecting knowledge and assessing probabilistic estimations about uncertain quantities, expert elicitations are fundamentally different from other survey types. This is reflected in its methodology. Expert elicitations have to follow a strict and robust protocol to ensure uncovering the experts' deep information which is not available elsewhere whilst minimizing potential biases. This is essential, as any judgement (including expert judgement) of probability and risk under uncertainty is based on mental heuristics (Tversky & Kahneman 1984). Robust expert elicitation protocols harness principles from decision theory, risk analysis, psychology, statistics and economics (Hogarth 1987; Cooke 1991b) to counteract several biases and heuristics (Table 1).

Table 1 Description of biases and heuristics in expert elicitation protocols.

Bias / heuristic	Description
Availability heuristic	Greater weights are attributed to events with higher visibility and therefore more easily memorable
Anchoring heuristic	Previous known values are only adjusted instead of performing independent estimations.
Representativeness heuristic	Separate events, that look "similar", are treated as symmetrically conditional.
Control heuristic	It is assumed to have a minimum level of control or influence over all (future) events.
Base-rate fallacy	Case-specific information is attributed more importance than "general" or base-rate information, leading to conclusion of uniqueness of each event.
Overconfidence	More optimistic estimations due to heightened confidence.

Egocentric attribution	Behavioural choices of the group an expert belongs to are considered to be more common than alternative choices.
Motivational bias	Intentional change of answers in order to influence the studies outcome.

Source: Own elaboration from (Kahneman & Tversky 1984; Durbach et al. 2017; Keeney & Von Winterfeldt 1991; Cooke 1991a; Ross & Anderson 1982; Cooke 1991b; Baker & Keisler 2011; Bistline 2014; Hultman & Koomey 2007)

In order to achieve maximum robustness and guarantee transparent, structured and bias-minimized expert elicitations, state-of-the-art debiasing strategies were employed during the expert elicitation (Fischhoff 1984; Kahneman & Tversky 1984). The experts were asked to self-assess their level of expertise. The specific purpose and process of the study was explained and any questions or reservations were taken into account. Confidentiality was assured. Concepts, variables and measurement were introduced and decomposed, if necessary. The experts were asked to expand their information and assumptions. Very importantly, the experts were encouraged to explain their reasoning, thoughts, etc., instead of just giving a brief numerical answer. Any potential inconsistencies between barriers and drivers were pointed at and resolved with the expert. Also, answers were validated and corrected for non-regressiveness. After the elicitation, the outcome of the studies was checked for motivational influence.

The choice of experts in this approach is critical. They need to be representative actors in the entire technology value chain who are active around the technology. Experts and governmental and non-governmental officials can also be potential sources of information (Tigabu 2017, p.5). The experts were selected based on hard criteria in their corresponding reference class. The classes of academia (A), industry (I), policy makers (P) and thought leaders/other indirect stakeholders exist. The classes were created to cover the widest set of experts relevant to the objectives of this MUSTEC task possible. The eligibility criteria to belong to each one of the stakeholder categories are as follows:

- A: High impact publications in indexed journals (Q1) in the fields of renewable energy, energy or energy policy, with titles and/or abstracts specific to CSP (measured in amount per quartile), relevance of the publication in terms of scientific diffusion (measured in amount of citations) and other diffusion (measured in amount of presentation on academic, industrial or policy-focused conferences or workshops), consistent trajectory of CSP-related publications (measured in cumulative amount of consecutive years with CSP-related publications), and network of co-authors with abovementioned characteristics (measured on dichotomous scale of yes/no).
- I: Firms historically or currently active as an industrial player in the European CSP market i.e., as component manufacturer, developer or owner (measured on dichotomous scale of yes/no for both past and present), level of activity in Europe (measured in amount of

projects involved), consistent trajectory of CSP projects (measured in cumulative amount of consecutive years with new CSP involvement). Within these firms the persons were chosen as a function of knowledge and experience they might possess (proxied by their position and hierarchical level) and active engagement in CSP-related field (measured in amount of presentation on industrial or policy-focused conferences or workshops).

- P: Area of policy directly related to CSP (measured on a dichotomous scale of yes/no), or to renewable energy cooperation mechanisms (measured on dichotomous scale of yes/no) and ascribed to an institution of the European Union or its member states (measured on dichotomous scale of yes/no, with preference for the EU-level and Spain).
- T: Level of expertise and knowledge of the CSP sector including all aspects thereof and going beyond academia, industry and policy (measured in amount of publications in the grey literature, i.e., blogs and articles in CSP related press, presentations on conferences, workshops, participation in expert groups and other relevant activities).

According to expert elicitation protocols, no hard rules on the optimum number of experts exist. On the one hand, additional experts increase the diversity of judgement, yet on the other their marginal usefulness decreases. Almost all past expert elicitation have a range of 6 to 12 experts.

For this study, 24 experts were identified according to the abovementioned criteria. 10 agreed to participate in the elicitations, which were carried out by telephone between May and July 2018. A typical elicitation took slightly over an hour (average: 69 min, minimum: 44 min, maximum: 90 min). Right after each elicitation, the analysts proceeded to post-elicitation, including highlighting the most important aspects, detection of confirmation or contradiction with other experts previously elicited, and transcription of the main judgements by the expert.

3.4 Investors' survey

In a second and complementary step, the analysis was focused on the decision in favour or against a specific investment in CSP in the European Union. This decision is conditioned by factors that influence either as drivers or as barriers. Their relative importance is not at all homogeneous among the investors. Rather, it depends on contextual and situational *perceptions* of drivers and barriers by the investor. Perception-based quantifications can be recollected with the help of specialized surveys distributed representatively among a target universe.

In the case of the investment decision in CSP in the EU some important pitfalls have to be taken into account. First, the target universe of investors in CSP in the EU is relatively small. Second, it is not always clear, if a given factor influences such a decision in a predetermined way (say, always as a driver); a given factor might act as a driver for some decisions and as a barrier for others. Third, some investors have faced the above-mentioned investment decision repeatedly, maybe even with different outcomes. The survey was carefully designed in order to account for these issues.

Given the small target universe, a great deal of attention was paid to raising response rates to the maximum. Personal invitations were sent out with an incentive to participate (participation in return for information on the CSP sector). Confidentiality and anonymity were assured. The relevance of the MUSTEC study to policy makers and industry players was highlighted, as was the potent European framework Horizon 2020. A three-step individual follow-up was performed, consisting in a gentle reminder 10 days after the first invitation (alternating deliberately the weekday and time of the mailing) and another reminder 12 days thereafter emphasizing the importance of participation (the "stick"). Lastly, a "very last reminder" was sent containing a teaser of the novel and unexpected information recollected potentially of interest to CSP players (the "carrot").

In total, 29 firms and contacts were identified with the help of MUSTEC consortium partners, i.e. ESTELA and COBRA. The identification criteria were 1) having directly invested in CSP plants, 2) having the plant currently in operation (not under construction or in planning phase), 3) with commercial aims (no prototypes or demo plants) and 4) being currently active. All contacts were invited in May 2018 in accordance with the process described above. The contact details of 2 persons were permanently invalid because they had left their companies. Three reminders were sent. 20 answers were collected, almost all of them in a very short timeframe after the initial invitation, or one of the reminders. Out of these, 15 answers were completed and thus usable for this study. This translates to a response rate of 55.6% on the (localizable) target universe and a "click-rate" (survey accesses) of 74.1%. Both numbers are more than satisfactory, given the electronic set-up of the survey. In addition, given the small number of the target universe, these response rates are very comforting.

By reason of the contextual and situational dependence of the *perceptions* of drivers and barriers, i.e., a given factor can be perceived as either a driver or a barrier, for all items a semantic differential scale was created. Such a scale identifies two diametrically opposed extremes and has an intermediate neutral point. In the present case, a factor was impartially stated and the respondent was asked to quantify it either as a driver, barrier or neutral (not influencing the decision). For each side of the semantic differential scale, 9 levels were introduced (three major levels of high, medium and low), and within these, three intermediate levels (again high, medium and low) in order to provide sufficient potential for differentiation between the factors and complying with recommendations from specialized literature on the matter. In using such a rather detailed scale, we followed a suggestion made by our consortium partners at CISOT. The advantages are clear, being the scale suitable for the purposes of this study and validated in previous literature. Of course, a 19-point scale (2x9+1) is unmanageable for respondents, which is why an easy to use and convenient graphical interface (so-called "slider") was newly developed with our survey service provider. The pilot tests with 6 experts on environmental and energy economics and familiar with carrying out surveys from different international universities and research institutions provided feedback on the survey. All comments received on the interface were very positive. Major flaws of the questionnaire were not detected, and minor changes were made following their advice.

With the aim to disentangle repeated investment decisions, the respondents were guided to pick a representative one and stick to it throughout the survey.

4. RESULTS

This section provides the results of the literature review (4.1), the investors' survey (4.2) and the expert elicitation (4.3).

4.1 Literature review

The literature review has led to the identification of many factors which have acted as drivers or barriers of CSP deployment in the EU in the past. When searching for those factors, the TIS literature and complementary literatures have been taken into account and all possible factors have initially been considered. It is not possible to provide a ranking of the importance of each factor by only looking at the literature, and this ranking has been the focus of the research with the other two methods (expert elicitation and investors' survey).

Two lists of the identified drivers and barriers to CSP deployment in the EU which have been identified are provided below. Often times, drivers and barriers are the two faces of the same coin (factor) but we decided to make them explicit in order to infer the specific comments from the interviewees in the investors' survey and expert elicitation. As mentioned in the analytical framework, the focus on the DBs could be at two different albeit complementary levels, e.g., the TIS and investors' levels.

DRIVERS AT THE TIS LEVEL

The table below provides the results of our literature review, i.e. a list of the drivers to CSP deployment in the EU at the TIS level (i.e., encompassing also the lower levels, see Figure 2) and a brief description of those drivers. The drivers can be classified in several broad categories, i.e., techno-economic (T), policy/political (P), those related to social acceptability (SA), supply chain related (SC), knowledge-based (K) and those related to resource availability (RA).

MUSTEC
Market Uptake of Solar Thermal Electricity

Table 2 Drivers at the TIS level.

DRIVERS	BRIEF DESCRIPTION	CATEGORY
Proven technology (low technology risks)	Technology risks are inherent to complex technology systems. 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.	T
DNI levels	Higher DNI levels obviously lead to lower generation costs for the same level of installed capacity. Therefore, places with higher DNI levels are more attractive for potential investors. This factor could be regarded as a precondition rather than as a driver.	RA
Cost reductions	Since one main barrier to the diffusion of CSP may have been its high costs (see Del Río et al. 2018), cost reductions are obviously a main driver for this technology. Cost reductions are due to several factors, including economies of scale, learning effects at both the industrial and plant level, increased size and technological improvements due to innovation. The first two are the result of deployment, whereas innovation is both the result of RD&D and, to a lesser extent, deployment. Several contributions suggest that there have been and will be substantial cost reductions for CSP. IRENA (2018) estimates that total installed costs of newly commissioned CSP projects have fallen by 27% in 2010-2017. 37% and 43% LCOE reductions are expected for parabolic trough and solar tower, respectively, in 2015-2025 (IRENA 2016). Recent auction results for CSP projects that will be commissioned after 2020 show costs falling to between 0.06$/kWh and 0.10$/kWh (IRENA 2016, p.16).	T
Improvement of the technology over time.	The technology, with a long development journey, has already reached the commercial stage. However, it is only at the beginning of its commercial deployment in terms of installed capacity. Therefore, a high technological dynamism and significant improvements and cost reductions can be expected in the future. On the other hand, innovation theory predicts that at the early stage of a technology, different designs compete between each other. This might also be the case with CSP, which has different designs (parabolic trough, solar tower, Fresnel and Stirling), although some experts would disagree that they compete between each other and even that they should be presented in equal terms. Within the different CSP technologies, there are different maturity levels. One design has been dominant (trough) but solar towers are expected to capture an increasing share of the market in the future.	*T*
Dispatchability and higher system value of CSP	The benefits of the technology for the adopter make a technology attractive. CSP has a very attractive feature in this regard. CSP plants with thermal energy storage allow higher capacity factors, dispatchability, contribute to grid balancing, spinning reserve, and ancillary services. They also have the ability to shift generation to when the sun is not shining and/or the ability to maximise generation at peak demand times (World Energy Council 2016, p.31). . It has a *higher system value compared to other, intermittent renewable energy sources*.	T
Development in niches.	Niches provide a space for technologies to improve their performance through learning by use and interacting and through economies of scale (Del Río et al. 2018). Co-generation for domestic and industrial heat use, water desalination and enhanced oil recovery in mature and heavy oil fields are other possible applications of CSP plants which are additional to electricity generation (IEA-IRENA 2013). Hybridization with other technologies can also be considered a niche market for CSP technologies.	T
Local manufacturing capabilities.	Thermal solar power plants demand regular industrial materials. Countries may possess a mature range of industries in the production of components and equipment for electrothermal conversion so that an important part of the value chain can be added locally (Vieira de Souza & Gilmanova Cavalcante 2017). Having a well developed local industry for components would make it easier to have access to those components for plant developers.	SC
Policy- Framework	Framework conditions refer to those aspects of RES-E support that are either outside the	P

related	conditions & policy ambition	support system itself or that may be designed similarly irrespective of the type of system applied (Del Río & Bleda 2012; Bergmann et al. 2008, p.133), including grid access procedures, permit procedures, the existence of long term targets or investment security.	
	Design electricity market/system	Some designs of the electricity system, in which the dispatchablity of electricity generation technologies is considered and valued, may be more favourable for CSP.	P
	Deployment support	Regarding support instruments, two main categories can be considered: RD&D policies (at EU and MS level) and deployment support (at MS level). Both may lead to technological improvements and cost reductions. Several well-known promotion schemes for renewable energy deployment exist, which could also be applied to support CSP, including feed-in tariffs (FITS) and feed-in premiums (FIPs), whether administratively –set or set through auctions, quotas with tradable green certificates (TGCs), soft loans and investment subsidies (See Mir-Artigues & Del Río 2016, for a detailed description).	P
	RD&D support	Support for research, development and demonstration (RD&D) can be a driver of the technology since it leads to improvements and cost reductions. This support can be provided in several ways, e.g., support to industry (e.g., fiscal incentives), to public research centres (direct RD&D support) and to innovative demonstration plants within a public-private collaborative framework. Other policy interventions may favour networking and collaboration between private and public actors.	P
	Regional policies	Regions may provide support to CSP plants either directly (i.e., investment support) or indirectly (streamlining of administrative permits).	P
	Carbon prices.	Carbon prices (whether from emissions trading schemes or carbon taxes) aim to internalize the negative environmental externality related to GHG emissions. Compared to conventional electricity generation, renewables in general and CSP in particular do not emit GHG. Therefore, with a carbon price an extra cost is faced by the former, which makes renewables more competitive. Whether this is so depends on the levels of those carbon prices, so far very low in the context of the EU (EU emissions trading scheme).	P
	Cooperation mechanisms of the RES Directive	The cooperation mechanisms of the RES Directive may encourage the deployment of CSP. Cooperation mechanisms do not only bring greater flexibility for Member States with low potential and/or expensive generation costs to partially meet their national targets in other countries, but also reduce the overall costs to realize the 20% EU RES target in 2020.	P
Social acceptability.		The social acceptability for a technology can be critical for its deployment (i.e., directly) but also to adopt policies which support it (i.e., indirectly). People might value that CSP technology deployment may provide substantial local value addition through localisation of production of components, services and operation and maintenance, thus creating local development and job opportunities.	SA
Complementarity with PV.		The value of CSP will increase further as PV is deployed in large amounts, and, thus, they may complement each other.	T
Strong supply chain.		The presence of several capable actors in each stage of the value chain and the availability of standardized major components makes the technology more attractive for potential investors.	SC
International knowledge collaboration, information flows.		This refers to cooperation among research organizations in different countries and between those and industry. International knowledge collaboration leads to improvements of the technology, cost reductions and information flows, which may influence the speed of diffusion.	K
Strong knowledge base and knowledge generation in EU (vs. non-EU)		Similarly, a strong knowledge generation base in the EU with respect to non-EU countries encourages the diffusion of the technology in the EU.	K
Planning reliability (vs. non EU countries)		Juridical security regarding administrative procedures in the EU may have been an attractive feature of investing in the EU versus investing in non-EU countries.	P
Availability of land		Availability of land in the South of Europe and, particularly, in Spain (with a low population density) may have been an important precondition for CSP deployment in the EU.	RA
Existence of a dominant design (PT)		The existence of a dominant design creates security for their investors and reduces the perception of risks of the technology, since this looks more reliable and mature.	T

	Immature technologies often do not have a dominant design.	

Note: T (techno-economic), P (policy/political), SA (social acceptability), SC (supply chain related), K (knowledge-based) and RA (resource availability).

BARRIERS AT THE TIS LEVEL

The barriers to CSP deployment in the EU at the TIS level found in our literature review are listed in table 3, which also includes a description of those barriers. They can be classified in the same broad categories than the drivers.

Table 3 Barriers at the TIS level.

BARRIERS	DESCRIPTION	CATEGORY
Limited solar resource potentials.	CSP plants can be sited only in areas with adequate solar resources, which restricts its potential deployment in Europe mostly to the Mediterranean area. DNI can reach 2000 kWh/(m²a) in southern Spain which is high compared to other EU countries, but low compared, e.g. to the 2500 kWh/(m²a) corresponding to the MENA region (Kost et al. 2013). As a result, its highest growth potential is outside Europe, in the sun belt region, which includes the Middle East, North Africa, South Africa, India, the southwest of the United States, Mexico, Peru, Chile, western China, Australia, southern Europe and Turkey (IEA-IRENA 2013).	RA
Technology risks	Problems regarding performance of the technology would make it unattractive for potential investors and, thus, slow down its deployment.	T
Lower technology improvement than expected	Unmet expectations about the improvement of the technology over time make it less attractive for potential adopters.	T
Existence/absence of a dominant design.	The fact that there are several technological alternatives may raise the doubts of potential adopters about the virtues of the technology. According to this view, the absence of a dominant design is detrimental for the diffusion of the technology since it makes it less attractive for potential adopters.	T
Cost comparison (higher costs)	Despite the aforementioned cost reductions in the past, the levelised electricity cost (LEC) of CSP has been comparatively higher than for fossil fuel generation and other renewable energy technologies.	T
Lower than expected and uncertain cost reductions.	Cost reductions may have been lower than initially expected. There was little change in the cost range for CSP projects between 2008 and 2012 (LCOE), although, since them, they have substantially been reduced (see above).	T
Competition with PV.	Direct competition from PV is frequently mentioned as a potential barrier for CSP in the future (Del Río et al. 2018). Some authors argue that this competition may have delayed the deployment of CSP in some parts of the world.	T

Access to credit		Access to credit to finance CSP investments may have been a barrier for the uptake of this technology in the past in the EU and it may be so in the future. CSP is capital-intensive, financing costs represent a very relevant part of total costs and access to credit restrictions have occurred in the South of Europe (i.e., for any investment). According to Teske et al (2016, p.93), "since the deployment of STE is still less than that of other technologies, private banks view these projects as higher risk, such that project financing has proven to be an obstacle for solar thermal electricity project developers in recent years. Project developers continue to have difficulties obtaining bank debt to fund their projects, due to the lack of long-term data on STE deployment and the irrational perception of STE as a risky and immature technology".	T
Weakness of supply chain		A narrow market problem in specific stages of the supply chain (few suppliers) may lead to a bottleneck in the supply for certain components and/or an excessive price for those.	SC
Industrial consolidation and vertical integration.		Industrial consolidation (mergers and acquisitions) and vertical integration may lead to fewer actors in the supply chain and, thus, to a lack of competition in a specific stage of the process (Del Río et al. 2018).	SC
Unavailability of standardized major components		Project specific development may be necessary due to unavailability of standardized major components.	SC
Policy-related	General legal framework	These may negatively affect the uptake of the technology (see table on drivers).	P
	Design of electricity market	A design of the electricity system which does not value the dispatchablity of CSP would be unfavourable for this technology.	P
	Retroactivity, lack of stability, ambition of targets.	These policy aspects can also be an important barrier for CSP deployment. Economic and political instability leads to higher risks and makes debt and equity financing more expensive.	P
	Low levels of deployment support	Low levels (or inexistence) of public support for deployment of CSP may have been a barrier to the deployment of CSP	P
	Low levels of support for innovation and demonstration.	Low levels (or inexistence) of public RD&D support to CSP may be a barrier to the improvements, cost reductions and knowledge accumulation required for the successful uptake of this technology in Europe (and elsewhere).	P
	Difficulties in using the cooperation mechanisms	Barriers to the use of cooperation mechanisms of the RES Directive would mean that CSP deployment would also not benefit from their use.	P
Local opposition		Several local environmental impacts (land occupancy, leakages, water availability and impact on the landscape, particularly visual intrusion) may lead to a social backlash (not-in-my-back-yard) for this technology. Poor knowledge about the technology (and its associated advantages over other RES) among different type of stakeholders, including policy makers (visibility gap) may be an indirect barrier.	SA
Administrative procedures.		Legal and administrative barriers (leading to long lead times for deployment and additional costs for project	P

	developers) are usually mentioned as a barrier to the deployment of renewable energy technologies in the EU. To our best knowledge, no study on the legal and administrative barriers specific to CSP is available, neither at the world nor EU level. According to IEA (2014), difficulties in securing land, water and connections and permitting issues have been barriers encountered by developers to establish CSP plants in some countries.	
Exit of large players.	Some large players have exited the market, whether for financial problems or other reasons. This could mean that the knowledge accumulated in those firms may also be lost, which would be detrimental for its further deployment. According to Lilliestam (2018), this is a concern because several players have already left the market, leaving the current CSP market very thin, with only a handful of experienced firms active in each stage of the value chain. However, others believe that engineers from those firms have repositioned themselves in other companies..	SC
Impact of the financial and economic crisis	The financial and economic crisis in the EU countries may have had a negative impact on the deployment of renewable energy technologies in general and CSP in particular. A negative indirect effect could have been expected, either in the adoption of retroactive regulations, lower electricity demand and overcapacity or access to credit restrictions. The economic crisis severely restricted the private sector capital that is used to finance RES-E projects.	T
Overcapacity and meager electricity demand.	One of the consequences of the economic and financial crisis in some EU countries has been a lower electricity demand than expected which, together with substantial investments in other electricity generation technologies in the early 2000s (e.g., CCGTs) has led to overcapacities. Ceteris paribus, this may have been a barrier for the uptake of electricity generation technologies in general and CSP in particular.	T
Low international knowledge collaboration.	Few and non-intensive knowledge flows may be a barrier to the deployment of CSP (breath and depth of cooperation).	K
Land availability	CSP requires substantial space for its deployment. Land availability and competition for land use may have been and could be a hurdle in this context.	RA
Water availability and competition for water use	CSP requires considerable water resources for its functioning. Water availability and competition for water use may have been and could be a barrier for the deployment of this technology in the past and the future.	RA
Low competence in the CSP TIS	Lack of skills throughout the supply chain and CSP technological innovation system may be a barrier to CSP.	K
Knowledge generation increasingly moving outside the EU	Knowledge about CSP has been accumulated in Europe, as a result of support for RD&D and deployment. However, the increasing deployment outside Europe, in addition to the stagnancy of CSP deployment in the European soil, may have also moved knowledge	K

	generation outside the EU, which could have a detrimental impact on CSP in Europe.	
More attractive investment opportunities in CSP outside the EU.	CSP investment opportunities outside the EU have been increasingly attractive for a number of reasons (support from governments, policy mixes, good DNI…). This leads investors to focus on those opportunities to the detriment of investments in the EU.	T
Risk of environmental pollution.	Although, as a renewable energy technology, CSP is cleaner than its conventional counterparts, it still may lead to some environmental pollution (i.e., with oils). This concern could be a barrier for its deployment.	O

Note: T (techno-economic), P (policy/political), SA (social acceptability), SC (supply chain related), K (knowledge-based), RA (resource availability) and others (O).

DRIVERS AND BARRIERS AT THE INVESTOR LEVEL.

As mentioned above, and in line with our analytical framework, in addition to issues (DBs) at the TIS level, this task has identified other DBs specifically influencing investors. These are basically the same DBs than for the TIS, but we add resources, competencies and dynamic capabilities (RCCs) as well as previous experience accumulated in the firm which could influence whether companies invest or do not invest in the CSP technologies.

Table 4 Drivers and barriers.

DRIVER/BARRIER	BRIEF DESCRIPTION
Technological risk	
Maturity of the technology: the technology is (not) mature enough.	Perception of the maturity of the technology (parabolic trough or solar tower)
There is a considerable risk that the technology will not perform as expected.	Perception about the future performance of the technology.
Dispachability and storage	
The dispatchability / storage capability of CSP.	Same as for TIS
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	Perceived reliability and stability of suppliers of components in the future.
Availability of standardized major components.	Perception of the 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.	Same as for TIS
Stability of renewable energy policies	Same as for TIS
Design of the electricity market	Same as for TIS
Deployment support for CSP	Same as for TIS
Research, development and demonstration (RD&D) support	Same as for TIS
Carbon price (emissions trading scheme).	Same as for TIS
Electricity grid	
Access to the grid.	Perception of access to the grid as a barrier.
Level of transmission capacity.	Perception of transmission capacity as a driver or a barrier.
Permits and planning processes	
Reliability of planning and schedule	Perception that the administrative procedures are reliable, including an schedule.
Length (time) and costs of the process.	Perception about the length and costs of the administrative processes.
The need for an Environmental Impact Assessment (EIA)	Perception of the requirements for an EIA as a barrier.
Easiness or difficulty for obtaining construction permits	Perception about the easiness or difficulty for obtaining construction permits
Easiness or difficulty for obtaining grid connection permits.	Perception about the easiness or difficulty for obtaining grid connection permits.
Natural resources	
High/low DNI (direct normal irradiance) with respect to other EU / non-EU countries.	Same as for TIS
Availability of land	Same as for TIS
Availability of water	Same as for TIS
Social acceptance / opposition	

Social acceptability and opposition, such as not-in-my-backyard (NIMBY) syndrome.	Same as for TIS
Resource availability Has the availability of these resources in your firm been a driver or a barrier to the investment in CSP?	In their economic activity, firms are conditioned (constrained or enhanced) by their resource base, which comprises all resources, but also how these are put to use in daily business operations (competences) and how both are changed over time as a result of deliberate and dedicated action (dynamic capabilities). Together, these RCCs form the firm's resource base, according to the Resource-based View and its extensions (Penrose 1959; Barney 1991; Prahalad & Hamel 1990; Grant 1991; Amit & Schoemaker 1993; Bakar & Ahmad 2010).
Financial resources	The existence of adequate financial resources is a basic requisite for any investment. Financial resources may consist of available firm-internal funding or access to external funding and their corresponding conditions. Employing financial resources is attached to an expectation of return, both financially and strategically.
Ownership of patents	Patents are the most "tangible" or observable form of knowledge. In sectors related to technology, knowledge is generally considered the most important firm resource.
Availability of technological experience	Technological experience is the application of technological knowledge. It can initially be gained through demonstration projects and later through regular ones.
Skilled human resources	Knowledge and experience are deeply rooted in the personnel of firms. The Learning Organization (Nonaka 1991; Nonaka & Takeuchi 1995) is fundamentally based on learning human resources that interact and interchange knowledge. For the realization of complex technological projects, a skilled workforce is a prerequisite.
Physical assets, such as installations, equipment and so on	Physical assets determine the scale of business operations a firm can engage in. The existence and adequate use of special physical resources (laboratories, research facilities or demonstration plants) related to experimentation and exploitation may give rise to new and innovative solutions.
Engagement in collaboration networks	Cooperation is usually considered key in overcoming resource-base constraints in firms, as it may grant access to and use of RCC outside of the firm. This aspect has special relevance in highly complex technological projects, such as CSP plants. Collaboration networks may form around the value chain, around specific TIS functions, such as knowledge creation, or center around specific activities. The deeper the collaboration is, the higher is a firm's institutional embeddedness in the corresponding (local, technological, etc.) clusters.
Corporate image	Corporate image is determined by existing firm RCC and how these are perceived by third parties. Corporate image often acts as a proxy of the firm attractiveness i.e., in purchase decisions (both by individuals and firms) or when initiating or during collaborations.
Previous experience Has previous experience been a driver or a barrier to the investment in CSP?	Firms can accumulate experience over time (i.e., it is "sticky"). On the one side, it increases the efficiency of business processes in firms, facilitating the realization of complex projects, on the other it may generate certain path-dependent trajectories that are exploited due to existing and increasing experience, creating situations of lock-in. Experience can cover wide ranges of domains.
Previous technology experience	As firms engage with specific technologies and technological

	configurations, they gain experience with these. Their use and application gets more efficient. With time, selected technologies and configurations can become dominant, leaving alternatives behind.
Previous market experience	Market experience covers aspects related to interactions along the value chain, both up-, down- and "side" stream.
Previous project realization experience	Project realization experience comprises all bureaucratic and organizational steps from early project planning until functioning and includes, if applicable, decommissioning or management of the end-of-life of the project. Both internal and external aspects are covered.
Previous investment in physical assets, such as other CSP plants or components	Despite being relatively easy to modify, change or replace, the existence of physical infrastructure tends to produce lock-in effects (reluctance to change and self-reinforcing acting over the existing physical resource base, especially if newer infrastructure exists). Yet a certain level of physical assets is required when engaging in complex technological projects.
Knowledge accumulated by previous CSP projects	Project experience can generate new knowledge or increase existing knowledge, including numerous aspects going beyond pure technological knowledge.

Source: own elaboration.

4.2 Expert elicitation survey.

The 10 experts were asked about the relative importance of a wide array of drivers and barriers to CSP deployment in the past (until 2018) and the future (between 2018 and 2030). Here the results with respect to past deployment are reported. The questions are related to the TIS level.

4.2.1 *Drivers.*

The following table summarises the results of the analysis on the drivers to the deployment of CSP in the EU. It includes the three most important and the three least relevant drivers per stakeholder being interviewed, both in the past (columns 2 and 3) and the future (columns 4 and 5). When several drivers are equally scored, all are mentioned. The last row shows the most and least relevant drivers for all the interviewees.

Several factors are clearly perceived to be more relevant to explain the deployment of CSP in Europe in the past. These are (in descending order of importance): deployment support, policy framework conditions and policy ambition and the fact that the technology is regarded as proven and, thus, technology risks are perceived as being low. Among the least relevant, three stand out (also in descending order of importance): carbon prices, complementarity with PV and the cooperation mechanisms of the RES Directive.

Regarding the perception on the relevance of the drivers of CSP deployment in the future, the three most relevant are the dispatchability and the associated higher value compared to other, intermittent energy sources, policy framework conditions and policy ambition and the complementarity with PV. The three least relevant include local manufacturing capabilities, a strong knowledge base and knowledge generation in the EU and the existence of a dominant design.

Therefore, framework conditions and ambition are considered a key driver both in the past and the future. It is interesting to note, however, that the perception of the importance of the drivers to deployment clearly differ between the past and the future. In particular the dispatchable feature of the technology is deemed highly relevant in the future, whereas its relevance is low in the past. This is related to the fact that CSP is regarded to provide a complementary generation profile to intermittent renewable energy sources which are also expected to make a significant contribution in the future. The fact that the relationship between CSP and PV is regarded as complementary in the future, but not in the past, is also in line with this interpretation. In contrast, deployment support is deemed very important as a driver in the past, whereas it is not expected to be so in the future. This is probably related to the lower maturity levels and high cost gap of CSP in the past, and with the expectation that the competitiveness of the technology in the future will be more related to its dispatchability property than to its costs in terms of LCOE, despite the high cost-gap being deemed a very important barrier in the past as well as in the future. The fact that cost reductions are not perceived as a main driver of the technology in the future is in line with this interpretation that the competitiveness of the technology is expected to be related to the higher system value of the technology. Finally an interesting result worth mentioning is the negligible role of carbon prices as a driver of the technology, which confirms previous research on its limited influence on high cost-gap technologies and the need to complement it with other instruments in order to encourage their uptake.

Table 5 Responses of the interviewees on the perceived drivers to CSP.

Interviewee	PAST (-2018)		FUTURE (2018-2030)	
	Most relevant	Least relevant	Most relevant	Least relevant
Other 1	• Framework conditions and policy ambition • Strong knowledge base and knowledge generation in EU • Planning reliability in the EU	• DNI levels • Improvement of the technology over time • Design of the electricity market • Carbon prices • EU cooperation mechanisms • Social acceptability • Complementarity with PV	• Planning reliability in the EU • International knowledge collaboration • RD&D support • Availability of land	• Cost reductions • Design of the electricity market • EU cooperation mechanisms • Social acceptability
Industry 1	• DNI levels • Dispatchability and the associated	• Availability of land • Existence of a dominant design	• DNI levels • Dispatchability and the	• Proven technology • EU cooperation

	higher value • Framework conditions & policy ambition • Design electricity market/system • Regional policies • Complementarity with PV	(PT).	associated higher value • Framework conditions & policy ambition • Design electricity market/system • Regional policies • Complementarity with PV	mechanisms • Availability of land • Existence of a dominant design (PT).
Researcher 1	• Availability of land • Proven technology • Deployment support	• EU cooperation mechanisms • Design electricity market/system • Regional policies • Carbon prices • Social acceptability • Complementarity with PV	• Availability of land • Dispatchability and the associated higher value • EU cooperation mechanisms • Complementarity with PV	• Existence of a dominant design (PT) • Strong knowledge base and knowledge generation in EU • International knowledge collaboration • Improvement of the technology over time.
Researcher 2	• Existence of a dominant design (PT) • Framework conditions & policy ambition • Strong supply chain (availability of standardized major components…) • Strong knowledge base and knowledge generation in EU	• Design electricity market/system • Development in niches • Complementarity with PV	• Dispatchability and the associated higher value • Proven technology • Development in niches • Design electricity market/system • Planning reliability	• Regional policies • International knowledge collaboration • DNI levels
Researcher 3	• Framework conditions & policy ambition • Deployment support • RD&D support	• EU cooperation mechanisms • Proven technology • Cost reductions • Improvements of the technology over time • Development in niches • Carbon prices • Social acceptability • Complementarity with PV	• Regional policies • Framework conditions & policy ambition • Deployment support • RD&D support	• Existence of a dominant design (PT) • Proven technology • Development in niches • Local manufacturing capabilities • Strong knowledge base and knowledge generation in EU • Availability of land

Other 2[3]	• Proven technology • DNI levels • Cost reductions • Improvement of the technology over time • Dispatchability and the associated higher value • Local manufacturing capabilities • Framework conditions & policy ambition • Deployment support • International knowledge collaboration • Strong knowledge base and knowledge generation in EU • Availability of land	• Development in niches • Design of the electricity market • Regional policies • Carbon prices • EU cooperation mechanisms • Complementarity with PV • Strong supply chain • Planning reliability in the EU • Existence of a dominant design PT).	• Proven technology • DNI levels • Cost reductions • Improvement of the technology over time • Dispatchability and the associated higher value • Development in niches • Framework conditions & policy ambition • Deployment support • RD&D support • Complementarity with PV • Availability of land	• Design of the electricity market • Regional policies • Strong supply chain • Planning reliability in the EU • Existence of a dominant design (PT)
Policy-maker[4]	• DNI levels • Framework conditions & policy ambition	• EU cooperation mechanisms • Complementarity with PV • Carbon prices	• DNI levels • Dispatchability and the associated higher value • Framework conditions & policy ambition	• Deployment support • Cost reductions
Industry 2	• Deployment support • Framework conditions & policy ambition • Regional policies	• Carbon prices • EU cooperation mechanisms • Complementarity with PV • Strong supply chain	• Cost reductions • Regional policies • Complementarity with PV	• Strong supply chain • Social acceptability • Design of the electricity market • International knowledge collaboration • Planning reliability in the EU • Availability of land
Researcher 4[5]	• Framework conditions & policy	• Dispatchability and the associated	• Cost reductions • Improvement of	• DNI levels

[3] Other 2 scored many drivers with the highest or lowest possible values (100% and 0% respectively). All equally scored drivers are mentioned here, thus the large number of items.

[4] The difference between the highest/lowest scored driver and the next-highest/lowest score was almost 100%, which is why only first-order drivers are reported here.

[5] See footnote 4, which also applies to Researcher 4.

	ambition	higher value • Development in niches • Complementarity with PV • International knowledge collaboration • Strong knowledge base and knowledge generation in EU	the technology over time • Dispatchability and the associated higher value • Complementarity with PV.	
Researcher 5	• Deployment support • International knowledge collaboration • Strong knowledge base and knowledge generation in EU • Planning reliability in the EU • Existence of a dominant design (PT)	• Development in niches • Carbon prices • EU cooperation mechanisms	• Dispatchability and the associated higher value • Cost reductions • Improvement of the technology over time • Design of the electricity market • Complementarity with PV	• Existence of a dominant design (PT) • Proven technology • Social acceptability
TOTAL	• **Deployment support,** • **Policy framework conditions and policy ambition.** • **The technology is regarded as proven and technology risks are perceived as low**	• **Carbon prices.** • **Complementarity with PV** • **Cooperation mechanisms of the RES Directive**	• **Dispatchability and the associated higher value compared to other, intermittent energy sources.** • **Policy framework conditions and policy ambition** • **Complementarity with PV**	• **Local manufacturing capabilities,** • **A strong knowledge base and knowledge generation in the EU** • **Existence of a dominant design.**

Source: Own elaboration.

The experts agreed most on the role of Policy framework conditions and policy ambition, RD&D support, dispatchability, strong knowledge base and knowledge collaboration and existence of a dominant design (PT) (minimum standard deviation), and disagreed most on the role of regional policies (maximum standard deviation).

4.2.2 *Barriers*

Regarding the perception of the importance of the barriers to CSP deployment in the past, three stand out: higher costs, retroactivity, lack of stability and ambition of targets and low levels of deployment support. Retroactivity, lack of stability and low deployment support is probably related to the policy conditions existing in the country where virtually all the CSP capacity had been installed in the EU (Spain) since 2010, with retroactive cuts and a renewable energy moratorium. The three least relevant are low competence in the CSP TIS, risk of environmental pollution and low international knowledge collaboration.

Concerning the barriers perceived as most relevant in the future (2030), these include higher costs, limited resource potentials (DNI) and the retroactivity, lack of stability and ambition of targets. The least relevant are low competence in the CSP TIS, risk of environmental pollution and low international knowledge collaboration. Higher costs will continue to be relevant as a barrier, despite the perception that the future competitiveness of the technology will not reside in its LCOE, but its system value. DNI is rather a precondition than a driver, but it can also be a barrier compared to the higher DNI levels outside the EU.

Table 6 Responses of the interviewees on the perceived barriers to CSP.

Interviewee	PAST (-2018)		FUTURE (2018-2030)	
	Most relevant	Least relevant	Most relevant	Least relevant
Other 1	• Lower technology improvement than expected • Existence of a dominant design • Overcapacity and meager electricity demand.	• Cost comparison (higher costs) • Access to credit • General legal framework • Local opposition • Administrative procedures • Low international knowledge collaboration • Land availability and competition for land use • Water availability and competition for water use • Knowledge generation increasingly moving outside the EU • More attractive investment opportunities in CSP outside the EU.	• Lower technology improvement than expected • Existence of a dominant design • Competition with PV • Low levels of deployment support • Overcapacity and meager electricity demand • Knowledge generation increasingly moving outside the EU • More attractive investment opportunities in CSP outside the EU.	• Lower than expected and uncertain cost reductions • Local opposition • Low international knowledge collaboration • Land availability and competition for land use • Water availability and competition for water use
Industry 1	• Limited solar resource potentials • Cost comparison (higher costs) • Competition with PV	• Knowledge generation increasingly moving outside the EU • More attractive	• Limited solar resource potentials • Competition with PV • General legal	• Difficulties in using the cooperation mechanisms of the RES Directive • Low levels of

	• General legal framework • Design of electricity market	investment opportunities in CSP outside the EU • Difficulties in using the cooperation mechanisms of the RES Directive • Low international knowledge collaboration • Land availability and competition for land use	framework • Design of electricity market	support for innovation and demonstration • Local opposition • Administrative procedures • Financial problems of large players / exit of large players • Low international knowledge collaboration • Low competence in the CSP TIS • Knowledge generation increasingly moving outside the EU • More attractive investment opportunities in CSP outside the EU • Risk of environmental pollution.
Researcher 1	• Limited solar resource potentials • Access to credit • Low levels of deployment support • Land availability and competition for land use	• Existence of a dominant design • Financial problems of large players / exit of large players • Lower technology improvement than expected • Lower than expected and uncertain cost reductions • Industrial consolidation (mergers and acquisitions) and vertical integration • Low international knowledge collaboration • Knowledge generation increasingly moving outside	• Limited solar resource potentials • Technology risks • Access to credit • Low levels of deployment support • Local opposition • Overcapacity and meager electricity demand • Land availability and competition for land use • Water availability and competition for water use	• Existence of a dominant design • Competition with PV • Financial problems of large players / exit of large players.

		the EU • Risk of environmental pollution		
Researcher 2	• General legal framework • Design of electricity market • Retroactivity • Lack of stability • Ambition of targets • Low levels of deployment support • Low levels of support for innovation and demonstration • Difficulties in using the cooperation mechanisms of the RES Directive	• Low international knowledge collaboration • Land availability and competition for land use • Water availability and competition for water use	• Lower technology improvement than expected • Access to credit • Knowledge generation increasingly moving outside the EU	• Low international knowledge collaboration • Land availability and competition for land use • Water availability and competition for water use • Risk of environmental pollution
Researcher 3	• Cost comparison (higher costs) • Competition with PV • Retroactivity • Lack of stability • Ambition of targets	• Existence of a dominant design • General legal framework • Local opposition • Overcapacity and meager electricity demand • Low international knowledge collaboration • Land availability and competition for land use • Risk of environmental pollution.	• Limited solar resource potentials • Retroactivity, lack of stability • Ambition of targets • Low levels of support for innovation and demonstration • More attractive investment opportunities in CSP outside the EU.	• Risk of environmental pollution • Low international knowledge collaboration • Financial problems of large players / exit of large players • Existence of a dominant design.
Other 2[6]	• Cost comparison (higher costs) • Retroactivity • Lack of stability • Ambition of targets • Low levels of deployment support.	• Limited solar resource potentials • Technology risks • Lower technology improvement than expected • Existence of a dominant design • Lower than expected and uncertain cost reductions	• Cost comparison (higher costs) • General legal framework • Retroactivity • Lack of stability • Ambition of targets.	• Limited solar resource potentials • Technology risks • Lower technology improvement than expected • Existence of a dominant design • Lower than expected and uncertain cost

[6] Other 2 scored many drivers with the highest or lowest possible values (100% and 0% respectively). All equally scored drivers are mentioned here, thus the large number of items.

		• Weakness of supply chain (few suppliers in specific stages) • Industrial consolidation (mergers and acquisitions) and vertical integration • Project specific development necessary due to unavailability of standardized major components • Design of electricity market • Difficulties in using the cooperation mechanisms of the RES Directive • Administrative procedures • Financial problems of large players / exit of large players • Impact of the financial and economic crisis • Overcapacity and meager electricity demand • Low international knowledge collaboration • Water availability and competition for water use • Low competence in the CSP TIS • Knowledge generation increasingly moving outside the EU • More attractive investment opportunities in CSP outside the EU • Risk of environmental pollution.		reductions • Competition with PV • Access to credit • Weakness of supply chain (few suppliers in specific stages) • Industrial consolidation (mergers and acquisitions) and vertical integration • Project specific development necessary due to unavailability of standardized major components • Design of electricity market • Design of the electricity market • Low levels of deployment support • Low levels of support for innovation and demonstration • Difficulties in using the cooperation mechanisms of the RES Directive • Local opposition • Administrative procedures • Financial problems of large players / exit of large players • Impact of the financial and economic crisis • Overcapacity and meager electricity demand • Low

				international knowledge collaboration • Water availability and competition for water use • Low competence in the CSP TIS.
Policy-maker[7]	• Limited solar resource potentials • Access to credit.	• Knowledge generation increasingly moving outside the EU.	• Limited solar resource potentials • Access to credit • Land availability and competition for land use • More attractive investment opportunities in CSP outside the EU.	• Impact of the financial and economic crisis • Cost comparison (higher costs) • Low levels of deployment support • Low levels of support for innovation and demonstration • Difficulties in using the cooperation mechanisms of the RES Directive • Financial problems of large players / exit of large players.
Industry 2	• Cost comparison (higher costs) • Retroactivity, lack of stability • Ambition of targets • Administrative procedures.	• Limited solar resource potentials • Lower technology improvement than expected • Existence of a dominant design • Lower than expected and uncertain cost reductions • General legal framework • Financial problems of large players / exit of large players.	• Cost comparison (higher costs) • Industrial consolidation (mergers and acquisitions) and vertical integration leading to even fewer actors in the supply chain • Impact of the financial and economic crisis.	• Limited solar resource potentials • Technology risks • Existence of a dominant design • Competition with PV • General legal framework • Financial problems of large players / exit of large players • Knowledge generation increasingly moving outside the EU • More attractive investment

[7] Due to some un-elicited barriers in some cases, less than three barriers are reported here.

				opportunities in CSP outside the EU • Risk of environmental pollution.
Researcher 4[8]	• Low levels of deployment support.	• General legal framework.	• Retroactivity, lack of stability • Ambition of targets.	• Competition with PV • General legal framework.
Researcher 5	• Difficulties in using the cooperation mechanisms of the RES Directive • Impact of the financial and economic crisis • Existence of a dominant design • Lower than expected and uncertain cost reductions • Competition with PV • Retroactivity, lack of stability • Ambition of targets • Low levels of deployment support • Overcapacity and meager electricity demand.	• Low international knowledge collaboration • Water availability and competition for water use • Risk of environmental pollution.	• Difficulties in using the cooperation mechanisms of the RES Directive • Impact of the financial and economic crisis • Knowledge generation increasingly moving outside the EU.	• Access to credit • Technology risks • Weakness of supply chain (few suppliers in specific stages) • Industrial consolidation (mergers and acquisitions) and vertical integration leading to even fewer actors in the supply chain • Retroactivity, lack of stability, ambition of targets • Financial problems of large players / exit of large players • Low competence in the CSP TIS • Risk of environmental pollution.
TOTAL	• **Higher costs** • **Retroactivity, lack of stability** • **Ambition of targets** • **Low levels of deployment support**	• **Low competence in the CSP TIS** • **Risk of environmental pollution** • **Low international knowledge collaboration.**	• **Higher costs** • **Limited resource potentials (DNI)** • **Retroactivity, lack of stability** • **Ambition of targets.**	• **Low competence in the CSP tis** • **Risk of environmental pollution** • **Low international knowledge collaboration.**

Source: Own elaboration.

The experts agreed most on the role of retroactivity, lack of stability, ambition of targets, low international knowledge collaboration, low competence in the CSP TIS, risk of environmental

[8] Due to some un-elicited barriers in some cases, less than three barriers are reported here.

pollution and project specific development necessary due to unavailability of standardized major components (minimum standard deviation), and disagreed most on the role of limited solar resource potentials, existence of a dominant design, general legal framework, overcapacity and meager electricity demand, competition with PV (maximum standard deviation).

4.3 Investors' survey.

As mentioned above, the specific survey to investors focused specifically on the DBs perceived by this type of stakeholders, taking into account the system-level DBs (at the TIS level) and, additionally and to some extent, the resources, capabilities and competencies (RCCs) of those investors. A distinction between the two CSP technologies (parabolic trough and solar tower) was made. Differently from the expert elicitation, which focuses on the DBs to all CSP technologies in the past (until 2018) and the future (up to 2030), the investor survey was focused on past DBs only (i.e., not on future ones)[9] and on two CSP technologies (parabolic trough and solar tower).

The following table summarises the main results of the analysis. It identifies the main drivers and barriers for either PT or ST, as perceived by investors. Drivers and barriers differ to some extent between PT and ST, especially regarding the drivers.

First, the main drivers for parabolic trough include both aspects of the technology (maturity, expected performance and dispatchability) as well as features of investors (previous technological experience, previous project realization experience and accumulated knowledge). It is quite logical that the maturity of the technology as well as knowledge and experience accumulation are key drivers of the technology, given that it is the most mature CSP design and the one which has attracted most investments in deployment. The fact that it is mature, proven and with a good performance record is obviously very attractive for investors. In addition, there is some path dependency regarding the influence of accumulated experience and knowledge in the firm when taking the decision to invest. This suggests the important role not only of external context conditions to the firm and the features of the technology, but also internal factors to the firm such as RCCs.

[9] The reason for this is rooted in the conceptualization and complementary objective of both methodological tools. Experts possess a large body of implicit knowledge about the CSP sector and are able to prove both robust estimations on the rationale of past events and reasonably-certain estimations about future developments. On the other hand, adopters (investors) are firms which possess deep information about all factors contributing to the investment decision (drivers and barriers) that was valid when the decision was taken. Yet, when no decision process is ongoing, these adopters have no incentive to keep evaluating current or future developments in the CSP sector, which is why an adopter's estimation about the future cannot be deemed reasonably-certain. In order to assure the scientific soundness of this study, it was decided to engage with adopters only about past factors. Notwithstanding, the views of the industry about the future drivers and barriers are partially captured in the responses of the two industry experts in the elicitation survey.

On the other hand, the only relevant driver for investments in solar tower, according to investors, is dispatchability. This is also quite a logical result, given its lower maturity level when compared to parabolic trough and the much lower past investments (and, thus, accumulated experience) in this technology in the past.

Regarding barriers, an interesting and a priori unexpected result is the discouraging role played by administrative processes, construction permits and grid connection both for parabolic trough and solar tower. This certainly signals a role for policy intervention which mitigates those barriers.

Regarding the major differences between PT and ST, technological maturity is a strong driver for PT, while it is neutral for ST, dispatchability is a driver for both, yet a bit more pronounced for ST, the availability of standardized major components is a large driver for PT, while it is a barrier for ST, previous experience accumulated by firms is a large driver for PT as described above while it is much less so for ST. The aspects of energy and general policy (including framework and targets) are very similar drivers/barriers to PT and ST. Internal financing and expected rates of return are also similar across the two configurations, as are administrative procedures and obtaining different kinds of permits etc.

Table 7 Summary of the investors' survey: drivers and barriers to CSP deployment in the EU in the past.

	PARABOLIC TROUGH	SOLAR TOWER
DRIVERS	-Maturity. -Expected performance. -Dispatchability. -Previous technological experience. -Previous project realization experience. -Accumulated knowledge.	-Dispatchability
BARRIERS	-Administrative processes -Construction permits -Grid connection	-Thin markets for solar-specific components -Administrative processes -Construction permits -Grid connection

Source: Own elaboration.

5. CONCLUSIONS.

This deliverable has identified potential drivers and barriers to CSP deployment in the EU. It has also identified their perceived relevance in the past and the future for different types of stakeholders. The drivers and barriers are multifaceted and include different aspects: technological, economic, administrative, policy and social acceptability etc...

Whereas our review of the literature suggests the relevance of a wide array of drivers and barriers, our empirical analyses based on an expert elicitation and an investors' survey suggests that the degree of importance of each driver/barrier differs for different types of stakeholders (industry, researchers, policy makers and others), different time frames (past and future) and different CSP designs (parabolic trough and solar tower).

Regarding the past drivers of CSP deployment, the expert interviews have suggested the importance of deployment support, policy framework conditions and policy ambition and the technology being regarded as proven (technology risks). Dispatchability is regarded as the main future driver of the technology, followed by policy framework conditions and policy ambition and complementarity with PV. The investors' survey confirms the relevance of dispatchability as a driver, together with the key technology features (maturity and good performance of the technology) and investors' features (accumulated knowledge and experience) specifically for the case of parabolic trough.

Regarding CSP deployment in the past, several barriers stand out. These include higher costs, retroactivity, lack of stability and ambition of targets and low levels of deployment support. Higher costs, limited resource potentials (DNI) and retroactivity, lack of stability and ambition of targets are perceived as the most relevant future barriers for experts. The view of investors on those barriers is significantly different. They stress the importance of administrative processes, construction permits and grid connection. In short, the views of investors and experts both regarding drivers and barriers are deemed complementary, since they focus on different levels of analysis.

The perceived relevance of different drivers and barriers suggests the need to combine different types of instruments which address them. In short, a policy mix might be required. Further research efforts in other working packages of the MUSTEC project will be devoted to the identification of suitable instruments and design elements within those instruments to either activate drivers or mitigate barriers to CSP deployment in the future.

6. REFERENCES

Adams, R., Jeanrenaud, S., Bessant, J., Overy, P. & Denyer, D., 2012. Innovating for Sustainability. *Network for Business Sustainability*, p.107.

Amit, R. & Schoemaker, P.J., 1993. Strategic Assets and Organizational Rent. *Strategic Management Journal*, 14(1), pp.33–46. Available at: http://onlinelibrary.wiley.com/doi/10.1002/smj.4250140105/abstract [Accessed December 31, 2013].

Bakar, L.J.A. & Ahmad, H., 2010. Assessing the relationship between firm resources and product innovation performance: A resource-based view. *Business Process Management Journal*, 16(3), pp.420–435. Available at: http://www.emeraldinsight.com/10.1108/14637151011049430 [Accessed September 20, 2013].

Baker, E. & Keisler, J.M., 2011. Cellulosic biofuels: Expert views on prospects for advancement. *Energy*, 36(1), pp.595–605. Available at: http://dx.doi.org/10.1016/j.energy.2010.09.058.

Barney, J., 1991. Firm Resources and Sustained Competitive Advantage. *Journal of Management*, 17(1), pp.99–120. Available at: http://jom.sagepub.com/content/17/1/99.short [Accessed December 31, 2013].

Bauer, F., Coenen, L., Hansen, T., McCormick, K. & Palgan, Y.V., 2017. Technological innovation systems for biorefineries: a review of the literature. *Biofuels, Bioproducts and Biorefining*.

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B. & Truffer, B., 2015. Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. *Environmental Innovation and Societal Transitions*, 16, pp.51–64. Available at: http://dx.doi.org/10.1016/j.eist.2015.07.003.

Bergmann, J., Bitsch, C., Behlau, V., Jensen, S., Held, A., Pfluger, B., Ragwitz, M. & Resch, G., 2008. *Harmonisation of support schemes. A European harmonised policy to promote RES electricity–sharing costs & benefits. A report compiled within the European research project futures-e (work package 3; Deliverable D17)*,

Bistline, J.E., 2014. Energy technology expert elicitations: An application to natural gas turbine efficiencies. *Technological Forecasting and Social Change*, 86, pp.177–187. Available at: http://dx.doi.org/10.1016/j.techfore.2013.11.003.

Boons, F. & Lüdeke-Freund, F., 2013. Business models for sustainable innovation: State of the art and steps towards a research agenda. *Journal of Cleaner Production*, 45, pp.9–19.

Carlsson, B., Jacobsson, S., Holmen, M. & Rickne, A., 2002. Innovation systems: Analytical and methodological issues. *Research Policy*, 31(2), pp.233–245.

Carlsson, B. & Stankiewicz, R., 1991. On the nature, function and composition of technological systems. *Journal of Evolutionary Economics*, 1(2), pp.93–118.

Chan, G., Anadon, L.D., Chan, M. & Lee, A., 2011. Expert elicitation of cost, performance, and RD&D budgets for coal power with CCS. *Energy Procedia*, 4, pp.2685–2692. Available at: http://dx.doi.org/10.1016/j.egypro.2011.02.169.

Cooke, R.M., 1991a. Combining Expert Opinions. Review of the Literature. In *Experts in Uncertainty. Opinion and Subjective Probability in Science*. New York: Oxford University Press, pp. 171–186.

Cooke, R.M., 1991b. Elicitation and Scoring. In *Experts in Uncertainty. Opinion and Subjective*

Probability in Science. New York: Oxford University Press, pp. 121–135.

Del Río, P., 2005. Analysing the factors influencing clean technology adoption: a study of the Spanish pulp and paper industry. *Business Strategy & the Environment*, 14(1), pp.20–37. Available at: 10.1002/bse.426%5Cnhttp://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=17073018&site=ehost-live.

Del Río, P., 2009. The empirical analysis of the determinants for environmental technological change: A research agenda. *Ecological Economics*, 68(3), pp.861–878. Available at: http://dx.doi.org/10.1016/j.ecolecon.2008.07.004.

Del Río, P. & Bleda, M., 2012. Comparing the innovation effects of support schemes for renewable electricity technologies: A function of innovation approach. *Energy Policy*, 50, pp.272–282.

Del Río, P. & Kiefer, C.P., 2018. *An Analytical and Methodological Framework to Analyse the Drivers and Barriers to CSP Deployment in the EU. Report for task 4.2 of the MUSTEC project, funded by the European Commision under the H2020 programme.*, Madrid.

Del Río, P., Peñasco, C. & Mir-Artigues, P., 2018. An overview of drivers and barriers to concentrated solar power in the European Union. *Renewable and Sustainable Energy Reviews*, 81(November 2016), pp.1019–1029. Available at: http://dx.doi.org/10.1016/j.rser.2017.06.038.

Del Río, P., Peñasco, C. & Romero-Jordán, D., 2016. What drives eco-innovators? A critical review of the empirical literature based on econometric methods. *Journal of Cleaner Production*, pp.2158–2170. Available at: http://dx.doi.org/10.1016/j.jclepro.2015.09.009.

Durbach, I., Merven, B. & McCall, B., 2017. Expert elicitation of autocorrelated time series with application to e3 (energy-environment-economic) forecasting models. *Environmental Modelling and Software*, 88, pp.93–105. Available at: http://dx.doi.org/10.1016/j.envsoft.2016.11.007.

Edsand, H.E., 2017. Identifying barriers to wind energy diffusion in Colombia: A function analysis of the technological innovation system and the wider context. *Technology in Society*, 49, pp.1–15. Available at: http://dx.doi.org/10.1016/j.techsoc.2017.01.002.

Eleftheriadis, I.M. & Anagnostopoulou, E.G., 2015. Identifying barriers in the diffusion of renewable energy sources. *Energy Policy*, 80, pp.153–164. Available at: http://dx.doi.org/10.1016/j.enpol.2015.01.039.

Fischhoff, B., 1984. Debiasing. In D. Kahneman, P. Slovic, & A. Tversky, eds. *Judgement under Uncertainty: Heuristics and Biases*. New York: Cambridge University Press, pp. 422–444.

Fouquet, R., 2010. The slow search for solutions: Lessons from historical energy transitions by sector and service. *Energy Policy*, 38(11), pp.6586–6596.

Freeman, C., 1987. *Technology and Economic Performance: Lessons from Japan*, London: Pinter

London.

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, 31(8–9), pp.1257–1274.

Gosens, J. & Lu, Y., 2014. Prospects for global market expansion of China’s wind turbine manufacturing industry. *Energy Policy*, 67, pp.301–318. Available at: http://dx.doi.org/10.1016/j.enpol.2013.12.055.

Grant, R.M., 1991. The Resource-based Theory of Competitive Advantage: Implications for Strategy Formulation. *California Management Review*, 33(3), pp.114–135. Available at: http://www.skynet.ie/~karen/Articles/Grant1_NB.pdf.

Grübler, A., Nakićenović, N. & Victor, D.G., 1999. Dynamics of energy technologies and global change. *Energy policy*, 27(5), pp.247–280.

Hansen, T. & Coenen, L., 2017. Unpacking resource mobilisation by incumbents for biorefineries: the role of micro-level factors for technological innovation system weaknesses. *Technology Analysis & Strategic Management*, 29(5), pp.500–513.

Hanson, J., 2017. Established industries as foundations for emerging technological innovation systems: The case of solar photovoltaics in Norway. *Environmental Innovation and Societal Transitions*, 26(June 2017), pp.64–77. Available at: https://doi.org/10.1016/j.eist.2017.06.001.

Hogarth, R., 1987. Judgement and Choice: The Psychology of Decision . Chichester, New York, Brisbane.

Hultman, N.E. & Koomey, J.G., 2007. The risk of surprise in energy technology costs. *Environmental Research Letters*, 2(3).

IEA-IRENA, 2013. *Concentrating Solar Power Technology Brief*, Available at: https://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP Tech Brief E10 Concentrating Solar Power.pdf.

IEA, 2014. *Technology Roadmap Solar Thermal Electricity*, Paris. Available at: https://www.iea.org/publications/freepublications/publication/%0ATechnologyRoadmapSolarThermalElectricity_2014edition.pdf.

IRENA, 2018. *Renewable Power Generation Costs in 2017*,

IRENA, 2016. *The Power to Change: Solar and Wind Cost Reduction Potential to 2025*,

IRENA, IEA & Ren21, 2018. *Renewable Energy Policies in a Time of Transition*, Available at: http://www.iea.org/publications/freepublications/publication/IRENA_IEA_REN21_Policies_2018.pdf.

Jacobsson, S., 2008. The emergence and troubled growth of a “biopower” innovation system in

Sweden. *Energy Policy*, 36(4), pp.1491–1508.

Jacobsson, S. & Bergek, A., 2004. Transforming the energy sector: The evolution of technological systems in renewable energy technology. *Industrial and Corporate Change*, 13(5), pp.815–849.

Kahneman, D. & Tversky, A., 1984. Intuitive Prediction: Biases and Corrective Procedures. In D. Kahneman, P. Slovic, & A. Tversky, eds. *Judgement under Uncertainty: Heuristics and Biases*. New York: Cambridge University Press, pp. 414–421.

Karltorp, K., 2016. Challenges in mobilising financial resources for renewable energy - The cases of biomass gasification and offshore wind power. *Environmental Innovation and Societal Transitions*, 19, pp.96–110. Available at: http://dx.doi.org/10.1016/j.eist.2015.10.002.

Karltorp, K., Guo, S. & Sandén, B.A., 2017. Handling financial resource mobilisation in technological innovation systems - The case of chinese wind power. *Journal of Cleaner Production*, 142(January 2012), pp.3872–3882.

Katkalo, V., Pitelis, C. & Teece, D., 2010. Introduction: On the Nature and Scope of Dynamic Capabilities. *Industrial and corporate change*, 19(4), pp.1175–1186.

Kebede, K.Y. & Mitsufuji, T., 2017. Technological innovation system building for diffusion of renewable energy technology: A case of solar PV systems in Ethiopia. *Technological Forecasting and Social Change*, 114, pp.242–253. Available at: http://dx.doi.org/10.1016/j.techfore.2016.08.018.

Keeney, R.L. & Von Winterfeldt, D., 1991. Eliciting Probabilities from Experts in Complex Technical Problems. *IEEE Transactions on Engineering Management*, 38(3), pp.191–201.

Kiefer, C.P., Del Río, P. & Carrillo-Hermosilla, J., 2018. Drivers and Barriers of Different Eco-Innovation Types in Firms. A Quantitative, Resource-based Perspective. *Under Review*.

Kost, C., Mayer, J.N., Thomsen, J., Hartmann, N., Senkpiel, C., Philipps, S., Nold, S., Lude, S., Saad, N. & Schlegl, T., 2013. *Levelized cost of electricity renewable energy technologies*, Berlin, Germany.

Lilliestam, J., 2018. *Whither CSP ? Taking stock of a decade of concentrating solar power expansion and development. Deliverable 4.2 of the MUSTEC project, funded by the European Commision under the H2020 programme.*, Zürich.

Lilliestam, J., Labordena, M., Patt, A. & Pfenninger, S., 2017. Empirically observed learning rates for concentrating solar power and their responses to regime change. *Nature Energy*, 2(7).

Malonzo, N.I.H. & Posadas, R.D., 2016. A Technologıcal Innovatıon Systems Analysıs Of The Renewable Energy Technologıes Under The Feed-In- Tarıff Program. , 8(1), pp.1–18.

Markard, J., Hekkert, M. & Jacobsson, S., 2015. The technological innovation systems framework: Response to six criticisms. *Environmental Innovation and Societal Transitions*, 16, pp.76–86.

Available at: http://dx.doi.org/10.1016/j.eist.2015.07.006.

Markard, J., Stadelmann, M. & Truffer, B., 2009. Prospective analysis of technological innovation systems: Identifying technological and organizational development options for biogas in Switzerland. *Research Policy*, 38(4), pp.655–667.

Markard, J. & Truffer, B., 2008. Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy*, 37(4), pp.596–615.

McDowall, W., Ekins, P., Radošević, S. & Zhang, L., 2013. The development of wind power in China, Europe and the USA: how have policies and innovation system activities co-evolved? *Technology Analysis & Strategic Management*, 25(2), pp.163–185. Available at: http://www.tandfonline.com/doi/abs/10.1080/09537325.2012.759204.

Mehos, M., Jorgenson, J., Denholm, P. & Turchi, C., 2015. An Assessment of the Net Value of CSP Systems Integrated with Thermal Energy Storage. *Energy Procedia*, 69, pp.2060–2071. Available at: http://dx.doi.org/10.1016/j.egypro.2015.03.219.

Metcalfe, J.S., 1994. Evolutionary economics and technology policy. *Economic Journal*, 104(425), pp.931–944.

Mignon, I. & Bergek, A., 2016. System- and actor-level challenges for diffusion of renewable electricity technologies: an international comparison. *Journal of Cleaner Production*, 128, pp.105–115. Available at: http://dx.doi.org/10.1016/j.jclepro.2015.09.048.

Mir-Artigues, P. & Del Río, P., 2016. *The economics and policy of solar photovoltaic generation*, Springer.

Negro, S.O., Alkemade, F. & Hekkert, M.P., 2012. Why does renewable energy diffuse so slowly? A review of innovation system problems. *Renewable and Sustainable Energy Reviews*, 16(6), pp.3836–3846.

Nonaka, I., 1991. The Knowledge-creating Company. *Harvard Business Review*, 96(6), pp.96–104.

Nonaka, I. & Takeuchi, H., 1995. *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*, New York: Oxford University Press.

Penrose, E., 1959. *The Theory of the Growth of the Firm*, New York: Wiley.

Planko, J., Cramer, J., Hekkert, M.P. & Chappin, M.M.H., 2017. Combining the technological innovation systems framework with the entrepreneurs' perspective on innovation. *Technology Analysis & Strategic Management*, 29(6), pp.614–625.

Prahalad, C.K. & Hamel, G., 1990. The Core Competence of the Corporation. *Harvard Business Review*, (May-June), pp.1–15.

Reichardt, K., Negro, S.O., Rogge, K.S. & Hekkert, M.P., 2016. Analyzing interdependencies between policy mixes and technological innovation systems: The case of offshore wind in

Germany. *Technological Forecasting and Social Change*, 106, pp.11–21.

Rosenberg, N., 1976. On Technological Expectations. *Economic Journal*, 86(343), pp.523–35.

Ross, L. & Anderson, C.A., 1982. Shortcomings in the Attribution Process: On the Origins and Maintanance of Erroneous Social Assessments. In D. Kahneman, P. Slovic, & A. Tversky, eds. *Judgement under Uncertainty: Heuristics and Biases*. New York: Cambridge University Press, pp. 129–152.

Al Saleh, Y.M., 2011. An empirical insight into the functionality of emerging sustainable innovation systems: the case of renewable energy in oil-rich Saudi Arabia. *International Journal of Transitions and Innovation Systems*, 1(3), p.302.

Schmidt, T.S. & Dabur, S., 2014. Explaining the diffusion of biogas in India: a new functional approach considering national borders and technology transfer. *Environmental Economics and Policy Studies*, 16(2), pp.171–199.

Stephan, A., Schmidt, T.S., Bening, C.R. & Hoffmann, V.H., 2017. The sectoral configuration of technological innovation systems: Patterns of knowledge development and diffusion in the lithium-ion battery technology in Japan. *Research Policy*, 46(4), pp.709–723. Available at: http://dx.doi.org/10.1016/j.respol.2017.01.009.

Stirling, A., 2011. Pluralising progress: From integrative transitions to transformative diversity. *Environmental Innovation and Societal Transitions*, 1(1), pp.82–88.

Tigabu, A.D., 2017. Analysing the diffusion and adoption of renewable energy technologies in Africa: The functions of innovation systems perspective. *African Journal of Science, Technology, Innovation and Development*, 0(0), pp.1–10. Available at: https://doi.org/10.1080/20421338.2017.1366130.

Tversky, A. & Kahneman, D., 1984. Causal Schemas in Judgement under Uncertainty. In D. Kahneman, P. Slovic, & A. Tversky, eds. *1Judgement under Uncertainty: Heuristics and Biases*. New York: Cambridge University Press, pp. 117–128.

Tversky, A. & Kahneman, D., 1974. Judgment under Uncertainty: Heuristics and Biases. *Science*, 185(4157), pp.1124–1131.

Vasseur, V., Kamp, L.M. & Negro, S.O., 2013. A comparative analysis of Photovoltaic Technological Innovation Systems including international dimensions: The cases of Japan and the Netherlands. *Journal of Cleaner Production*, 48, pp.200–210. Available at: http://dx.doi.org/10.1016/j.jclepro.2013.01.017.

Vieira de Souza, L.E. & Gilmanova Cavalcante, A.M., 2017. Concentrated Solar Power deployment in emerging economies: The cases of China and Brazil. *Renewable and Sustainable Energy Reviews*, 72(September 2015), pp.1094–1103. Available at: http://dx.doi.org/10.1016/j.rser.2016.10.027.

Wilson, C., 2012. Up-scaling, formative phases, and learning in the historical diffusion of energy technologies. *Energy Policy*, 50, pp.81–94.

Woolthuis, R.K., Lankhuizen, M. & Gilsing, V., 2005. A system failure framework for innovation policy design. *Technovation*, 25(6), pp.609–619.

World Energy Council, 2016. *World Energy Resources*, Available at: https://www.worldenergy.org/wp-content/uploads/2016/10/World-Energy-Resources-Full-report-2016.10.03.pdf.

Zhang, X., Shen, L. & Chan, S.Y., 2012. The diffusion of solar energy use in HK: What are the barriers? *Energy Policy*, 41, pp.241–249. Available at: http://dx.doi.org/10.1016/j.enpol.2011.10.043.

Who We Are

The MUSTEC consortium consists of nine renowned institutions from six European countries and includes many of the most prolific researchers in the European energy policy community, with very long track records of research in European and nationally funded energy policy research projects. The project is coordinated by Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas-CIEMAT.

Name	Country	Logo
Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas – **CIEMAT**	ES	
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Technische Universität Wien - TU WIEN	AT	
European Solar Thermal Electricity Association – **ESTELA**	BE	
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