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Policies to keep and expand the option of concentrating solar power for dispatchable renewable electricity

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Abstract

Concentrating solar power (CSP) is one of the few renewable electricity technologies that can offer dispatchable electricity at large scale. Thus, it may play an important role in the future, especially to balance fluctuating sources in increasingly renewables-based power systems. Today, its costs are higher than those of PV and wind power and, as most countries do not support CSP, deployment is slow. Unless the expansion gains pace and costs decrease, the industry may stagnate or collapse, and an important technology for climate change mitigation has been lost. Keeping CSP as a maturing technology for dispatchable renewable power thus requires measures to improve its short-term economic attractiveness and to continue reducing costs in the longer term. We suggest a set of three policy instruments – feed-in tariffs or auctions reflecting the value of dispatchable CSP, and not merely its cost; risk coverage support for innovative designs; and demonstration projects – to be deployed, in regions where CSP has a potentially large role to play. This could provide the CSP industry with a balance of attractive profits and competitive pressure, the incentive to expand CSP while also reducing its costs, making it ready for broad-scale deployment when it is needed.

Keywords: Concentrating solar power; solar thermal power; policy support; policy design; innovation.

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Highlights

- CSP is one of the few options to generate renewable dispatchable power at large scale
- Expansion is slow and generation costs higher than of solar PV and wind power
- Deployment and industry continuity are keys to keeping CSP as an option for the future
- Feed-in tariffs or auctions reflecting the value of dispatchability can be helpful
- Deployment combined with RD&D and other support for innovation needed

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1 On costs and dispatchability

To curtail climate change to less than 2°C global average warming, it is essential to eliminate CO_2 from the electricity sector by mid-century (Intergovernmental Panel on Climate Change (IPCC), 2014). This requirement for rapid change means that the carrying pillars of the electricity transition must be technologies already available for widespread deployment. Few, if any, disagree that renewables – and in particular wind and solar power – must and will shoulder most of the future power generation burden (Global Energy Assessment, 2012; IPCC, 2011; Obama, 2017). Since both solar photovoltaic (PV) and wind power are intermittent sources, finding ways to store large amounts of electricity has emerged as a crucial challenge for power sector decarbonization. Both wind power and PV would need to rely on a separate storage system, such as batteries, to become dispatchable. Concentrating solar power (CSP), in contrast, offers the possibility of integrated thermal storage and is able to store energy collected during day and use it for generation at a later time, including after sundown (Trieb *et al.*, 2013). As thermal storage allows a CSP station to operate at a higher capacity factor, adding storage increases dispatchability but adds little or nothing to the levelised costs of electricity (LCOE) compared to a plant with no storage (Lilliestam *et al.*, 2012; Mehos *et al.*, 2016). This makes CSP a valuable option for producing dispatchable renewable electricity, both for bulk power and especially for balancing intermittent renewable sources.

Yet, CSP appears to be fighting a losing battle and there is a risk that the technology will not step out of its current small niche, as policy-makers focus their attention on support for the seemingly lower-cost wind power and solar PV. Despite having experienced strong cost reductions through technological improvements and economies of scale over the last 5 years – 2/3 lower than the support paid for the Spanish CSP fleet up to 2013 – recent (end 2016) CSP power purchase agreements (PPAs) are on average around \$0.15 per kWh[1], see Figure 1 (Lilliestam *et al.*, 2017; Mehos *et al.*, 2016). Although costs have decreased strongly, CSP remuneration is a multiple of recent PPAs from auctions for solar PV, which averaged \$0.05 per kWh in 2016 (International Renewable Energy Agency (IRENA), 2017).

[1] In fall 2017, two CSP PPAs (in Australia and Dubai) closed at below USD 0.07 per kWh (CSPplaza, 2017; Hill, 2017). Little detail of these deals is known, and at the time of writing, in October 2017, project construction has not started.

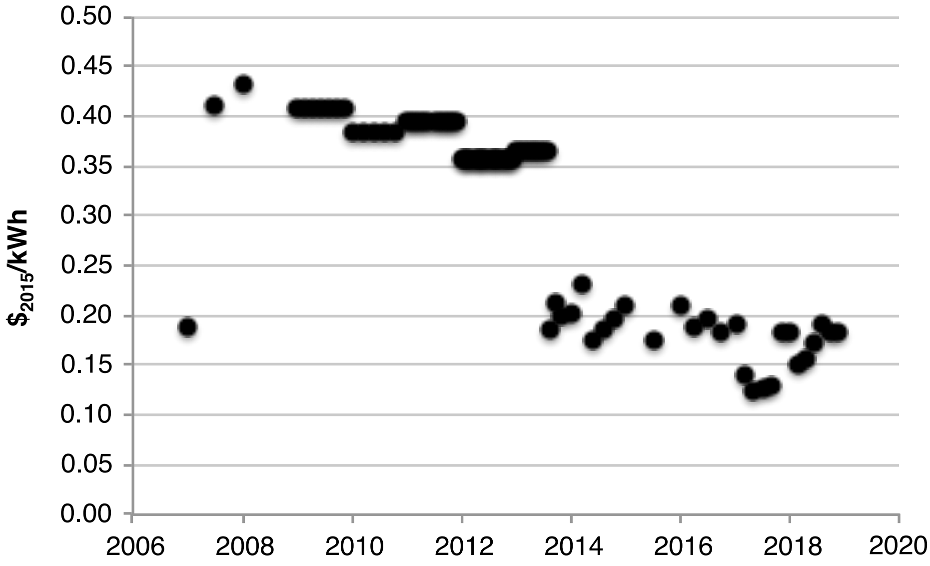

Figure 1: Remuneration of all existing (end 2016) CSP stations and for projects under construction with disclosed data (about 80% of all projects). Source: www.csp.guru.

However, it is important to note that whereas PV has run through much of its learning curve, CSP is still an immature technology with large cost reduction potential left: in 2016, the current global PV capacity was 300 GW, compared to 5 GW for CSP. When the world-record low bid for PV was \$0.12 per kWh, in late 2011, the global PV capacity was 75 GW – 15 times higher than the current CSP capacity (National Renewable Energy Laboratory (NREL), 2017; SolarPowerEurope, 2016, 2017).

Further, the comparison of LCOEs is misleading as it does not consider the dispatchable nature of CSP (when equipped with thermal storage (Jorgenson *et al.*, 2014)). In 2015, Abengoa won a tender in Chile for a 210 MW hybrid PV/CSP plant; whereas the strike price (\$0.11 per kWh) was remarkable only for being the second *highest* of all bids, this was the first time a solar power station won a technology-open auction for 24/7 dispatchable electricity (HeliosCSP, 2015). In late 2016, SolarReserve bid for a PPA at \$0.06 per kWh for the Copiapó 240 MW solar tower with 14 hours of storage, enough for continuous baseload generation, also in the Chilean Atacama desert (CSP Today, 2016). Whereas this is still more expensive than PV built on similarly optimal sites, CSP is far cheaper than PV combined with sufficient battery storage to achieve a comparable level of dispatchability: the cost comparison is especially beneficial for CSP for longer storage times (six hours or longer), and indeed large-storage stations are slowly becoming the norm for CSP stations across the world (Feldman *et al.*, 2016; Jorgenson *et al.*, 2014; Lilliestam *et al.*, 2017). In sum, CSP with thermal storage is today cheaper than PV with batteries for the same level of dispatchability, and it is increasingly competitive – sometimes even with fossil fuels – in places where this dispatchability is rewarded.

Future price developments will dictate whether CSP maintains this advantage. On the one hand, both PV and battery costs are declining, and it is conceivable that a combination of the two could become less expensive than today's CSP with thermal storage within a few years. Feldman *et al.* (2016) suggest that PV with up to 6 hours of battery storage is likely to close the cost gap to CSP in the next decade, whereas CSP remains competitive for larger storage installations. On the other hand, learning rates for CSP are similarly high as for PV and batteries (Lilliestam *et al.*, 2017; Schmidt *et al.*, 2017), and if CSP maintains a relative growth rate similar to PV and batteries, then it is likely to experience cost reductions that keep pace and perform better than in Feldman's analysis, maintaining its competitive advantage.

For this to occur, however, deployment of CSP with thermal storage will need to continue and increase, and herein lies a problem. In the long run, dispatchable renewables such as CSP may have an important role to play in all parts of the world, possibly including imports from deserts to non-desert regions (Labordena *et al.*, 2017; Lilliestam *et al.*, 2016; Lilliestam and Patt, 2015; Trieb *et al.*, 2015; Veum *et al.*, 2015). In most desert regions where CSP is a potentially competitive option in the short term, however, such as in the Middle East and North Africa, or parts of Latin America, PV and renewable power in general remain underdeveloped, and that in turn means that the dispatchability of CSP does not currently carry a high economic benefit. Today, most desert countries either have little intermittent generation, or they have sufficient flexible fossil generation capacity to balance the PV and wind power they have; as long as climate policy is no strong constraint to these countries, this situation may remain. In other words, CSP right now is competing on LCOE against non-dispatchable renewables, and especially against PV without batteries. That is a competition that it loses, and there is reason to expect that investment in CSP could grind to a halt, or fail to start at all, in these regions unless governments maintain or introduce dedicated CSP policy support. Under such a scenario, by the time the renewable dispatchability of CSP does take on value and becomes truly needed, either alone or as a complement to balance PV and wind power generation, CSP will have been locked out of the market, and the world will have lost one of its weapons in the arsenal against climate change.

2 Risks and requirements for continued learning in CSP

In order to keep CSP as a valuable technology for decarbonization and, especially, for balancing of intermittent renewables, it is essential to develop it in a manner that leads to cost reductions, thereby maintaining and improving its attractiveness in the market. Achieving this is not simply a matter of adding new capacity, but requires more precise considerations in the design of support policies. In particular, such policies must address two critical risks that the CSP industry is currently facing.

The first risk is that one or more of the larger firms that manufacture CSP components or put them together into complete plants leave the market. 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, as shown in Figure 2 (Lilliestam *et al.*, 2017).

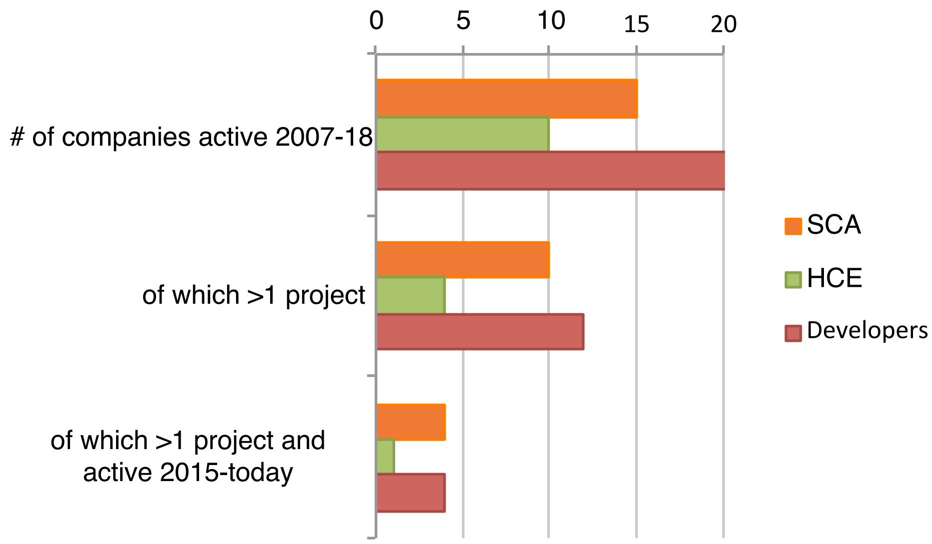

Figure 2: Number of companies active in project development and in the manufacturing of CSP-specific components (solar collector assemblies (SCA) and heat receivers (HCE)). Source: www.csp.guru (end-2016 version, Lilliestam *et al.*, 2017).

These firms have a lot of tacit knowledge, both with component manufacturing and plant construction but also with respect to the operation of a CSP plant. Unlike PV, or even wind, a CSP plant may require years of operation, with engineers making fine adjustments to its various components and the plant operation schedule, before it reaches full output (Desmond, 2016; EIA, 2017). The knowledge of how to do this is not tied up in patents, but in the living memories of engineers. If these engineers leave the industry, because their firm shrinks or exits the CSP market, then such knowledge and know-how is lost, and the cost curve for the technology as a whole suffers. This has already happened once in the history of CSP: although costs decreased strongly following the construction of the first CSP plants in California in the 1980s, the industry collapsed in 1991 and when expansion began again in Spain, 17 years later, the LCOE of the first Spanish stations was almost twice as high – and the learning curve had to begin anew (Lilliestam *et al.*, 2017). Hence, continuity in the industry is essential: support policies for CSP must be designed so as to make it sufficiently profitable, with a sufficiently large and predictable stream of projects for firms to stay solvent, stay in the market and accumulate knowledge and experience. This would likely also create new opportunities for new entrants and a more diverse, more competitive CSP market, and one that is more robust in case dominant companies fail.

The second risk is that project developers and operators fail to take advantage of innovations, and as a result fail to push costs down. A property of any complex piece of machinery, such as a CSP plant, is that its stable operation is sensitive to the performance of a large number of separate components and sub-systems (Hobday, 1998). If any of these should fail to perform as expected, with respect to any one of a wide range of parameters, other parts of the system are affected. A result is that developers of complex engineering projects are typically conservative with respect to plant design, using well-known components instead of new and innovative ones, in order to minimize the technological risk. As current CSP support schemes offer long-term stable prices (e.g. PPAs from auctions, or feed-in tariffs) that reduce or eliminate the price risk, the technology risk becomes a relatively more important factor: seeking ways to minimize this risk is fully rational for any single project.

This means that for commercial deployment to be the stage for technological innovation, policy support needs to reward a greater degree of risk taking. It however also means that one should not expect that commercially deployed stations will be the only driver of innovation and cost reduction: policy support actively investing in or supporting demonstration plants in order to test new components, could facilitate a more rapid rate of to-scale experimentation and technological learning (Nemet and Baker, 2009).

Consequently, policy support needs to provide competitive pressure for innovation and cost reductions, but not to the extent that it places the profitability of industrial players at risk. In the last 5 years, CSP costs have decreased rapidly, but PPA levels have decreased even faster, see Figure 3, leading to a greatly increase cost pressure for new projects; this pressure has been one of the driving forces behind the decreasing CSP costs in the last 5 years (Lilliestam *et al.*, 2017).

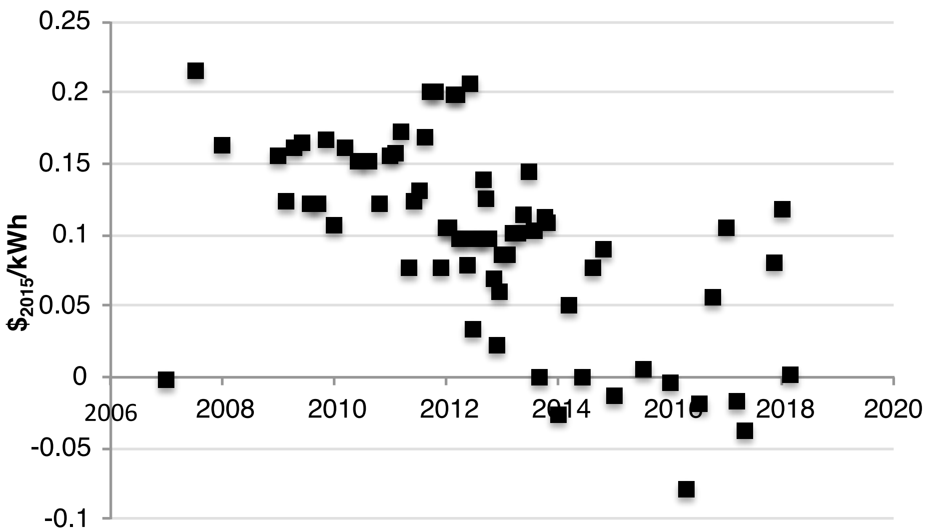

Figure 3: Development of the cost pressure for CSP projects 2007-2018 (operationalized as remuneration minus LCOE (5% WACC, 25 years life; for details see (Lilliestam *et al.*, 2017)). Data source: www.csp.guru.

An increasing cost pressure was expected, as competitive auctions have become the dominant policy instrument for CSP support, taking over from feed-in tariffs. In a typical auction, the lowest bid – which is not necessarily the most innovative project – wins the contract. This creates a strong likelihood of a *winner's curse* (AURES, 2017; IRENA, 2015): the firm that is most optimistic about yield and technology cost development – both of which are uncertain, especially for immature technologies – will win the bid, and yet it is precisely this firm that is most likely to have been too optimistic. Winning the bid could put it out of business, or force the developer to squeeze supply chain actors to the point that they are put out of business; indeed, the increased cost pressure in CSP policy support also correlates in time with a decrease in market actor diversity. There are some indications of winner's curse in CSP, especially in India, where PPAs were particularly low and project execution appears hasted. In Godawari, for example, the solar resource was reported to be 20% lower than expected as no on-site measurements had been done, which greatly increased costs as the solar field had to be expanded to be able to fulfill the PPA delivery requirements; the resulting cost increase was exacerbated as all critical components were imported and the Rupee had in the meantime lost 25% against the Dollar (Sunderasan, 2015).

3 Policy instruments for CSP deployment and innovation

To further reduce the cost of CSP and make it available at scale in the future when renewable dispatchability is needed, both deployment and innovation must be pushed and supported today by policy. Unlike past support schemes, which were mainly implemented in industrialized countries, the support policies for CSP are needed in countries with deserts, including the US and Australia, but particularly in transition countries with growing electricity markets, such as China, India, and countries in Latin America, MENA and southern Africa. In this respect, the trend is encouraging: CSP support schemes and RD&D policies have spread from Europe and the US, and today transition countries drive the expansion. For CSP to continue growing and developing, this diffusion of CSP support to more countries needs to continue.

3.1 Deployment policies

As dispatchability is the *raison d´être* for CSP, and continuity and diversification of the industry are key to cost reductions, three points are important for deployment support: it must reward dispatchability, include firm and predictable cost pressure, and allow for a steady and predictable expansion pace. For the dispatchability reward, the degree of dispatchability depends on the system in which the CSP is needed: options include time-of-day pricing (e.g. as in South Africa), if there is a pronounced peak in the system; if the demand curve is flatter, a baseload or availability requirement as in Chile (e.g. always available capacity between 7.00 a.m. and 24.00 p.m.) could be suitable. As for the instrument type, we see at least two possible options that can address all three criteria.

The first option is auctioning schemes, which are already the dominant instrument to support CSP deployment. Such policies are thus feasible, and elements addressing all three points above have been part of at least one auctioning scheme in the past, although no country has so far included all three components. The auctioning system in South Africa, which offers a time-of-day bonus during peak hours, is an example of a policy rewarding dispatchability; in principle, auctions can hold both types of dispatchability reward described above, thus reflecting and rewarding the value added to the system, and not merely the LCOE (Mehos *et al.*, 2016). Auctions have had a very strong cost pressure, and possibly too strong: in South Africa, for example, PPA levels have decreased by over 40% in two years, raising concerns of financial viability for all involved actors, and of winner's curse. Solving these problems would mean project selection criteria other than merely lowest cost (e.g. second-lowest cost, high penalties for non-realization, or various prequalification measures, see (Kreiss *et al.*, 2017)), combined with a degressive but predictable bid cost cap to still maintain firm cost pressure. Further, as auctions award batches of capacity followed by periods of no new projects, they can lead to start-stop markets, which are especially problematic for manufacturers as it leaves supply-chain investments highly uncertain. Solving this would require a predefined stream of auctions for several years ahead, but this would reduce the flexibility of policy-makers to decide what to auction based on recent developments, and thus reduce the political attractiveness of auctions. Auction schemes can thus be designed to address all three criteria, but it is difficult and may partially contradict the political rationale of such schemes.

A second option, and one that could easier address all three requirements, are feed-in tariffs. These allow for non-negotiated grid connection and tariff access for all stations fulfilling a set of predefined criteria, and can thus deliver a steady and predictable stream of projects. The Spanish FIT, for example, was very successful and triggered almost 50 CSP stations – arguably it was too successful, as its high cost was one reason for its cancellation – and although it hardly led to the optimal use of thermal storage, it did trigger a long pipeline of CSP projects, which was the base for the rise of the Spanish CSP industry. Further, and unlike the Spanish FIT, feed-in tariffs can (and should) be degressive and thus decrease over time, thereby both putting cost pressure on developers and limiting the support scheme cost, and they can be designed to include time-of-day bonuses (Couture *et al.*, 2010; del Río, 2012). Degressive, time-of-day rewarding feed-in tariffs without a capacity cap (or with a cap high enough to allow for several projects each year) could be a suitable instrument for CSP deployment, ensuring both increased experience with construction and operation, and that this experience is maintained in economically sound firms. Such a scheme would also be feasible to implement, and all aspects have been part of feed-in tariffs in different places around the world.

3.2 RD&D policies

Deployment alone may not suffice to trigger innovation in CSP, as the technology risk of new approaches is high and private investment in research, development and demonstration (RD&D) in the electricity sector is notoriously low (del Río and Bleda, 2012; Grubb, 2014; Nemet and Baker, 2009), and as developers have good reason to be conservative in plant design. At least two types of policy instruments can usefully address this. First, RD&D plants can be instrumental to test and develop new CSP system designs, by allowing new configurations, components, materials, or systems to be tested at scale, outside the lab; these may also serve as demonstration stations to prove that new concepts such as using an organic Rankine cycle at low irradiation sites, or use CSP waste heat for other purposes such as cooling or water desalination, and to develop them further through learning-by-doing. Of the few existing RD&D CSP plants, most are located in Europe or the US, and none are located in the regions where the CSP potential is highest but operating conditions may be different. For example, RD&D plants in the sandy deserts of the Gulf region, or in high altitude in

Chile or China could thus be important to develop and test new components and/or designs that suit these particular environments. Enhancing existing and building new international research collaborations will also help to spread innovative CSP solutions.

Second, the deployment support can be made to also support innovation, both through the design of the support criteria, and through dedicated, additional instruments. An example could be risk guarantees for novel designs implemented for the first time: the state bears a part of the risk, should the new design not work well; such schemes exist in different countries, for example for geothermal power in Switzerland (Swiss Federal Office of Energy, 2015). A further instrument could be state loan guarantees, which were a key instrument for the CSP development in the US (US Department of Energy, 2016), to share the risk of innovative projects at low (or no) cost to the government: such support lowers financing costs, but only causes costs for the state if the project goes bankrupt. Such policies to help cover the risks associated with deploying innovative components and designs are needed to enable risk-averse developers to develop and use new approaches in commercial-scale CSP projects.

4 Conclusions and policy implications

We believe that it is important to keep the CSP technology as an option for supplying dispatchable renewable power in the future, in particular as a technology for balancing intermittent renewable sources in decarbonized power systems: dispatchable CSP is a potential enabling technology for very high shares of solar PV and wind power. Losing CSP as an economically viable option could prove to be a great loss for the global efforts for decarbonization. When intermittent renewables become dominant and dispatchable or baseload fossil fuel and nuclear generation is phased out across the world, having lost CSP as an option would make the transition to renewables more expensive and complicated. To overcome this problem and keep CSP as a maturing technology requires improving its short-term economic attractiveness while simultaneously improving performance and reducing costs in the longer term. Here, we suggest that a set of policy instruments need to be deployed in parallel, in the arid regions where CSP has a potentially large role to play already in the short term.

These instruments are on the one hand deployment policies, designed so as to both reward the key advantage of CSP – its dispatchability – and balance a firm downward cost pressure, so as to trigger cost reductions and new more efficient plant designs, with sufficient profits for industry, so as to keep companies in business. Such policies, which could be either auctions or feed-in tariffs, must reward dispatchability, include firm and predictable cost pressure, and allow for a steady and predictable expansion pace. A time-of-day bonus, a long-term path for decreasing support, and a high or no capacity limit in the support schemes are possible and well-known ways to include these requirements in national auction or feed-in tariff systems.

On the other hand, deployment alone may not suffice to trigger innovation and reduce costs in the longer term: for this, dedicated RD&D policies, in the countries where deployment is supported, may be necessary. Such policies could include demonstration plants in the specific environments where expansion can be expected to take place in the short to medium term. They should also include policies, included in the deployment support, to help cover or share the increased risk of implementing new and innovative components and designs, so as to get risk-averse developers to seek and test radical technical improvements.

Implementing these two sets of policies in tandem could provide the CSP industry with a balance of attractive profits and competitive pressure, the structure to expand CSP while also reducing its costs, making it ready for broad-scale deployment when it is needed.

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