PROMOTION OF CONCENTRATING SOLAR THERMAL POWER (CSP) IN SPAIN: PERFORMANCE ANALYSIS OF THE PERIOD 1998-2013

Helena Martín[a1]*, Jordi de la Hoz[a1], Guillermo Velasco[b1], Miguel Castilla[b2], José Luís García de Vicuña[b2]

[a]Department of Electrical Engineering

[b]Department of Electronic Engineering

Universitat Politècnica de Catalunya (UPC)

[1]Escola Universitària d'Enginyeria Tècnica Industrial de Barcelona (EUETIB)

Carrer del Comte d'Urgell, 187, 08036, Barcelona, Spain

[2]Escola Politècnica Superior d′Enginyeria de Vilanova i la Geltrú (EPSEVG)

Av. Victor Balaguer, s/n., 08800 Vilanova i la Geltrú, Spain

*Corresponding author. Tel.: +34 934 137 325; fax: +34 934 137 401

E-mail address: m.helena.martin@upc.edu

Abstract

A thorough analysis of the Concentrating Solar Thermal Power (CSP) development in Spain in the period 1998-2013 has been carried out in order to identify the main drivers behind the bubble-like behaviour exhibited by this renewable technology. Tending a parallelism with the basic principles of the control systems theory has facilitated the identification of the main shortcomings in the design of the various control frameworks governing the CSP deployment in the studied period. The CSP

disorderly proliferation propitiated by inefficient control mechanisms has resulted in an overrun cost to the electricity system that has tried to be mitigated with the application of retroactive measures seriously harmful for the investors. It is expected that the conclusions drawn from this comprehensive review of the Spanish case have a general relevance for other countries undertaking the development path of renewable technologies.

Keywords

Concentrating Solar Thermal Power (CSP), Spain, Regulatory Framework, Feed-in Tariff (FIT), Renewable Energy

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1. Introduction

After the first initiatives undertaken by the United States in the 80s, the CSP industry was virtually stopped until the mid 2000s. Since then, the worldwide CSP installed capacity has experienced a great expansion due to the application of incentive mechanisms. Specifically, during the five-year period 2008–2013 the CSP installed capacity around the world increased near 50% per year on average [1].

By the end 2013 Spain was the world leader in cumulative CSP capacity, accounting for over 67% of the global total. Out of the 3,425 MW of worldwide cumulative CSP capacity in 2013, 2,300 MW corresponded to Spain, followed by the United States of America (USA) with 882 MW. The rest of the installed capacity was mainly located in countries of the Middle East and North Africa (MENA) region and India [1].

Nevertheless, the Spanish figures for 2012 were even stronger. In 2012 Spain accumulated more than 76% of the world's CSP capacity. That year, the Spanish cumulative CSP capacity increased by more than 95% compared to 2011. In fact, over 950 MW of the 970 MW installed in 2012 worldwide, were brought into operation in Spain [2,3], making double the number of facilities from one year to the next, from 20 in 2011 to 44 in 2012 [4].

The loss of momentum that the Spanish CSP figures for 2013 are beginning to reflect are due to recent drastic changes in its policy for the promotion of renewable energy sources (RES). These changes have made unfeasible to build new CSP plants on Spanish soil beyond the end 2013. The CSP cumulative capacity was limited to a maximum of 2,520.7 MW [5], which should come into operation before the end 2013 to be eligible for the feed-in-tariff (FIT). As a result, Spain is soon expected to pass the baton of CSP global leadership to the USA, which by April 2015 had 1,700 MW in operation and 1,770 MW in various stages of construction and development [6].

Despite the prominent global role of Spain in the CSP deployment, there are few references addressing the various aspects of its development in the context of its national energy policy. Thus, the effect of several variables on the cost of electricity from CSP is analysed in [7] in order to guide the design of the economic incentives. Also, in [8] the CSP figures are considered in the general framework of electricity from RES for the assessment of the benefits and costs of the RES deployment in Spain between 2002 and 2011 or for the estimation of the resulting support expenditures in Germany and Spain over the period 2010–2020 in [9]. In [10] the Spanish case alongside other 9 countries is taken as a benchmark to analyse the CSP energy market in 8 Arab countries. In [11] the specific regulatory framework that led to the CSP Spanish leadership (Royal Decree (RD) 661/2007) is compared to the national incentive programs of 5 CSP emerging countries and some lessons are extracted. So far, however, there are no specific studies on the performance of CSP in Spain in the whole period encompassing from its beginnings to its runaway expansion and the complete closure of the sector.

Comparatively, the number of references analysing the CSP deployment in the context of the national energy policy of those countries currently having operational CSP plants is much more significant. As relevant examples, [12] considers the USA case and [13] refers to the overall MENA region. Particular countries of the MENA region are specifically looked at in other references, such as Algeria in [14], Egypt in [15] and Morocco in [16]. The case of India has received substantial attention in [17-19] and the case of Australia has been assessed in [20]. Likewise, China has received considerable attention in [21-24] and the case of Thailand is considered in [25].

Even the assessment of the CSP potential in the energy policy framework of countries that at present have no commercial CSP plants has received comparatively more attention in the literature. This is the case of Brazil [26], Chile [27], Cyprus [28], Malaysia [29], South Africa [30], Turkey [31] and Zimbabwe [32].

Following this gap, this paper follows the thread of the performance of the CSP sector in Spain from its beginnings to the present day. Firstly, the different energy policy targets applied to the Spanish CSP sector are identified and then, based on public data, the policy results are evaluated. From this comparison, the bubble-like behaviour exhibited by the CSP sector is clearly evidenced (Section 2). Next, in search of the causes of such behaviour, the paper precisely describes and synthesizes all the different regulatory and economic frameworks that have governed the Spanish CSP (Section 3). Following the recent works [33,34], the paper then draws on basic control theory principles to analyse the Spanish CSP regulatory and economical frameworks. Under this approach, the inefficiencies in the several legal frameworks that gave rise to the CSP bubble are identified. It is also highlighted how each of the successive regulatory changes tried to correct the inefficiencies of the previous frameworks, thus showing the causal relationship between the subsequent stages (Section 4). Also, the interaction of the Regions or Autonomous Communities (AACCs) and the State in the CSP promotion is examined in search of potential causes for the asymmetrical distribution of the CSP facilities across Spain (Section 5). Finally, all the factors deemed relevant for the evolution of the Spanish CSP sector during the period of analysis are duly systematized and conclusions are raised (Section 5).

2. The Spanish CSP energy policy, objectives and results

In 1999 it was issued the first renewable energy (RE) plan (PER) that established specific targets for the CSP in Spain, namely, the PER 2000-2010 [35]. It set the goal of reaching 200 MW of installed capacity by 2010.

This plan was reviewed in 2005 by the PER 2005-2010 [36]. It raised the previous 200 MW capacity target to 500 MW by 2010.

The cumulative capacity targets set in the different PERs for the CSP in Spain have been represented in Figure 1 in red dashed line. Also, the evolution of the cumulative installed capacity has been plotted in blue solid line and the annual installed capacity has been shown using green solid line columns. Complementarily, the period covered by the different PERs and legal rules has been marked off.

FIGURE 1

At first glance, the evolution of the CSP cumulative installed capacitive appears to be close to its targets, thus misleading into thinking that the implemented energy policy worked properly.

Nevertheless, this impression vanishes when it is considered the fact that the 2,299.5 MW in operation at the end 2013 (see Figure 1) were developed in the context of an energy policy designed to reach only 500 MW. In other words, with a target of 500 MW in force, the CSP sector was allowed to embark on installing 4.6 times more cumulative capacity than planned[1].

A set of actions (that will be accurately detailed in the following sections) were taken to address this failure of the CSP energy policy. First, the allowed overcapacity was forced to enter into operation in several phases until the end 2013. In Figure 1 it has been represented in blue dotted line what could have been the possible evolution of the cumulative capacity without this imposed delay. By this deferral mechanism, the technical and the economic impact that the concurrent entry into operation of this excess capacity would have entailed for the Spanish electricity system was mitigated to some extent.

Then, the new CSP capacity targets for the period 2011-2020 were aligned with the capacity currently under development. Thus, in November 2011 the PER 2011-2020 [37] established stepwise increasing capacity targets of 3,001 MW by 2015 and 4,800 MW by 2020, respectively. The new capacity targets were adapted after the event to acknowledge the bubble-like behaviour exhibited by the CSP sector.

The allowed excess over the 500 MW initial capacity target resulted also in a proportional excess over the planned cost to the electricity system (and therefore on the taxpayer). In order to reduce this impact a series of retroactive cutbacks in the granted incentive system were applied. These retroactive measures, however, might have compromised the viability of the CSP plants in operation and have created a climate of legal uncertainty with devastating effects on the credibility of Spain as a destination for international investment.

3. Description of the 1998-2013 economic and regulatory frameworks for the CSP in Spain

[1] If the 2,520.7 MW maximum authorized capacity is taken as a reference instead of the 2,299.5 MW finally installed at the end 2013, then the 500 MW capacity target was exceeded in 5.0 times.

3.1. The 1998-2004 subperiod: laying the ground of the Spanish CSP sector

As background to this initial 1998-2004 stage it is worth considering some policy milestones that prepared the way for the subsequent Spanish CSP energy policy.

Thus, in November 1997 the European Commission produced a White Paper for a Community Strategy and Action Plan for RE [38]. It raised the goal of covering 12% of the primary energy demanded in the European Union (EU) in 2010 with renewable energies. Unlike other more mature power generation technologies, no specific contribution was outlined for CSP. Nevertheless, it was counted among the minority renewable technologies that could offer significant potential in the future. In the belief that a least one of these technologies could be exploited commercially over the coming decade, a marginal contribution of 1 GW by 2010 was assumed for them. This 1 GW power goal by 2010 at European level, although not exclusive for CSP, could be considered as a precursor of the targets set for CSP by the regulatory frameworks and energy plans to come.

In Spain, the generation facilities not exceeding 50 MW using as primary energy renewable energy, waste or cogeneration had been legally differentiated from the conventional technologies and had been integrated into a Special Regime (SR) to boost their promotion. The SR had been regulated since 1980 by different rules.

Nevertheless, the Electricity Sector Law 54/1997 of November 1997 [39] redefined the framing of the SR in a context of liberalisation of the activities of electricity production and commercialization. The Electricity Sector Law 54/1997 also incorporated the EU objective for renewable energies to reach 12% of the demand for primary energy by 2010. To achieve this goal, the law made a commitment to establish a plan to promote renewable energies.

With this background in view, the beginning of the first analyzed stage 1998-2004 was marked by the enactment of RD 2818/1998 in December 1998 [40]. This RD elaborated the regulatory development of the Electricity Sector Law 54/1997 as regards the SR. In this framework, all facilities using solar energy as primary energy were classified in the group b.1, making no specific reference to photovoltaic (PV) or CSP technologies.

The remuneration of the energy fed into the grid was based on the electricity pool price plus a premium, and additionally a complement for reactive energy. As long as the installed solar capacity did not exceed 50 MW, the premium for the facilities with rated power up to 5 kW was set to 36.0607 c€/kWh. For facilities over 5 kW it was set to 18.0304 c€/kWh. Unlike other technologies, no annual update for the solar premiums was provided.

Alternatively, solar facilities could elect not to apply the pool price plus premium funding system but a full price to receive. Its initial value was set to 39.6668 c€/kWh for facilities up to 5 kW and 21.6364 c€/kWh for those beyond 5 kW. These initial values were approximately equivalent to the pool price plus premium system, and no provision was made for their annual update.

All the incentive systems were established without time limit, but it was envisaged a review of premiums and prices every four years.

In December 1999, in fulfilment of the commitment introduced in the Electricity Sector Law 54/1997, the Plan for the Promotion of Renewable Energy for the period 2000-2010 (PER 2000-2010) was developed [35]. For the first time specific targets were established for CSP. By 2010 the goal was to reach 200 MW of installed capacity and 413 GWh/year of generated energy, corresponding to 2,065 h/year of equivalent operation.

In December 2000, the RD 1955/2000 [41] modified the RD 2818/1998 by expressly including solar thermal power into group b.3, along with geothermal, wave, tidal and hot and dry rocks energies. As a result of this modification, it was precluded the possibility of considering solar thermal facilities as part of the group b.1 devoted to facilities using solar energy as primary energy. For the group b.3, the premium to add to the pool price was 3.2755 c€/kWh and the alternative full price to receive was 6.7313 c€/kWh. Both the premium and the alternative full price to receive of group b.3 would be updated annually according to the change in the average selling price of electricity.

In August 2002 the RD 841/2002 [42] further modified the RD 2818/1998, repealing the amendment introduced by RD 1955/2000 that included solar thermal power in the group b.3. In turn, the group b.1 was subdivided into two subgroups, namely, b.1.1 for plants using PV solar energy as primary energy, and b.1.2, for plants utilizing solar thermal energy as primary energy to generate electricity. This newly created group b.1.2 was granted a premium of 12.0202 c€/kWh, with no annual update mechanism. Unlike PV facilities in group b.1.1, the CSP plants in group b.1.2 could not elect to receive an annually updatable full price as an alternative to the pool plus premium funding system. Also, RD 841/2002 specifically declared that fuel could be used to maintain the heat storage temperature during periods of interruption of electricity generation.

By 2004, six years after the regulatory development of the SR, there were no commercial CSP plants in operation or in the construction stage in Spain [3].

In order to facilitate the assessment that will be carried out in the Section 4, it has been summarized in the Table 1 how the different regulatory changes in the subperiod 1998-2004 affected the power target, the funding system and other characteristics of interest.

TABLE 1

3.2. The 2004-2007 subperiod: the CSP projects became bankable.

In March 2004, the entry into force of RD 436/2004 [43] repealed the previous RD 2818/1998 and RD 841/2002. It introduced two alternative remuneration options indexed to the average electricity tariff (AET) of each year. On the one hand, a CSP plant selling electricity to a distribution company would receive a regulated tariff consisting of a 300% of the AET for the first 25 years since its start up and 240% thereafter. On the other hand, a CSP plant selling electricity freely in the market would perceive a premium plus an incentive on top of the electricity pool price. The premium was 250% of the AET for the first 25 years since its start up and 200% afterwards, and the incentive was 10% of the AET for the whole lifetime of the plant. In both cases, the percentages to perceive were adjusted to 80% of their initial values after the first 25 years. Regardless the selected energy selling option, all CSP facilities would also receive a complement for reactive energy. The selected selling option should be maintained for a minimum period of one year. The AET for the year 2004 was 7,2072 c€/kWh.

A review of the tariffs, premiums, incentives and complements defined in RD 436/2004 was announced for the year 2006. Also, every four years starting from 2006, a further review would take place. The reviews would come into force on 1st January of the second year after that in which the revision was made. Additionally, the revisions would not have retroactive character since they would not apply to facilities in operation prior to their entry into force. Notwithstanding the foregoing, a review would take place also when the CSP installed capacity reached 200 MW. This de facto put at 200 MW the power limit to qualify for the economic conditions initially set by RD 436/2004.

The RD 436/2004 specified the type and quantified the use of fuels to maintain the heat storage temperature. CSP facilities receiving a regulated tariff could use either natural gas or propane to that end only during periods of interruption of electricity generation. The annual fuel consumption should be less than 12% of their electricity production. However that percentage would increase to 15%, and without time limitation of fuel use, for CSP facilities selling energy to the market.

In order to improve the operation of CSP plants, the subsequent RD 2351/2004 of December 2004 [44] amended the more strict provisions on fuel use initially made by the RD 436/2004. While keeping the same fuel percentages, the RD 2351/2004 allowed the utilization of any fuel type. Besides, the requirement of fuel usage only during the periods of interruption of power generation was eliminated. Instead, it was allowed the fuel use to maintain the temperature of the heat transfer fluid to compensate for the lack of solar irradiation that could affect the planned delivery of energy.

In August 2005 it was published the Renewable Energy Plan in Spain 2005-2010 (PER 2005-2010) [36]. Several factors advised the review of the previous plan for the period 2000-2010. On the one hand, the pace of development of some RES was significantly lower than necessary to achieve the 2010 targets. On the other hand, due to the sustained increment in primary energy consumption in the period 2000-2004, RES targets had to be further increased to meet the goal of covering 12% of the primary energy demand in 2010. The PER 2005-2010 also incorporated two indicative objectives set for Spain by the European Parliament and the Council of the European Union, namely, reaching 29.4% of electricity generation from RES (Directive 2001/77/CE) [45] and using 5.75% biofuels in transport by 2010 (Directive 2003/30/CE) [46].

Regarding CSP, the PER 2005-2010 stated that the 200 MW power limit of RD 436/2004 was a barrier to the development of the sector. Even more, some AACCs in Spain had already modified their own goals of CSP capacity for 2010 to an aggregate of 405 MW. So, the new CSP power and energy targets for 2010 were established at 500 MW and 1,298 GWh/year, respectively, corresponding to 2,596 h/year of equivalent operation.

In June 2006, the Royal Decree-Law (RDL) 7/2006 [47] was issued in order to align the remuneration of RES under the SR to the actual evolution of their cost. The rise in oil prices was increasing the AET, and through it, the remuneration of RES was also augmenting without direct justification. Consequently, the Royal Decree-Law 7/2006 established that the future revisions of the AET would not apply to the remuneration of RES under the SR. It was also announced a forthcoming reform in the remuneration of the SR facilities.

In March 2007 started its commercial operation the first CSP facility in Spain, a 11.02 MW central receiver plant with 0.5 h of thermal energy storage capacity [3,48].

The presented regulatory changes in the analysed subperiod 2004-2007 have been summarized in Table 2.

TABLE 2

3.3. The 2007-2009 subperiod: the speed-up of the Spanish CSP sector

In May 2007 the RD 661/2007 [49] entered into force, which repealed the previous RD 436/2004. The RD 661/2007 definitely decoupled the remuneration of the SR of the AET used so far. Otherwise, the basic structure of the regulation of the SR remained largely the same.

As with the RD 436/2004, facilities could perceive a regulated tariff or alternatively the negotiated pool price plus a premium. Whatever the remuneration option, it was reduced to 80% of its initial value after the first 25 years of operation of the CSP plant. The regulated tariff for the first 25 years was 26.9375 c€/kWh and 21.5498 c€/kWh thereafter. The premium for the first 25 years was 25.4000 c€/kWh and 20.3200 afterwards. As a novelty, the sum of the market price plus the premium was bounded between an upper limit of 34.3976 c€/kWh and a lower limit of 25.4038 c€/kWh. Regardless of their energy selling option, the facilities would also receive a complement for reactive energy. The selected option should be maintained for a minimum period of one year.

An annual update of the tariffs, premiums, complements and upper and lower limits was established. This would be done according to the increase in the Consumer Price Index (CPI) minus 25 basis points (BPS) until 31 December 2012, and 50 BPS thereafter. Also, it was anticipated a review of the remuneration framework in 2010 that would apply those plants brought into operation from January 1, 2012. From that moment, new revisions would take place every four years, ensuring a reasonable profitability. Facilities entering into operation prior to 1st January of the second year after that in which a revision was made would be unaffected.

An additional mechanism was also established to determine the period of maintenance of the regulated tariffs and premiums. Once reached 85 % of the power target of a technology, a period of not less than one year would be set during which properly registered facilities could still qualify for the premiums and tariffs.

The RD 661/2007 incorporated the indicative target for Spain, already included in the PER 2005-2010, that at least 29.4% of gross electricity consumption in 2010 should be generated with RES. In this line, the capacity targets established for the different RE technologies coincided with those previously set by the PER 2005-2010. For the case of CSP, it was 500 MW. However, future increases were allowed in the power objectives, provided this would not compromise the safety and stability of the system and whenever necessary. Moreover, the commitment to start in 2008 the elaboration of a new plan for renewable energies for the period 2011-2020 was set. The new objectives of this plan would condition the next revision of the remuneration framework planned for late 2010.

The RD 661/2007 allowed the possibility of hybridization of various fuels and/or technologies. It also required all the SR facilities larger than 10 MW to be ascribed to a generation control centre, to ensure at all times the reliability of the electric power system. On the other hand, the previous regulations only demanded a guarantee of 2% of the budget of the facility to request access to the transmission network, but not for the distribution network. The RD 661/2007 required guarantees to process the access both to the transmission network as well as to the distribution network. For the CSP case, these guarantees were 20 €/kW.

A 49.9 MW parabolic trough facility with 7.5 h of thermal energy storage capacity was the second CSP plant to enter commercial operation in Spain in December 2008 [3,47].

The modifications experienced in the subperiod 2007-2009 in the capacity target, the funding system and other relevant characteristics have been summarized in Table 3.

TABLE 3

3.4. The year 2009: the boom of the Spanish CSP sector

In April 2009 the Council of the EU adopted the climate-energy legislative package [50]. It was a set of binding legislation that established the overall EU environmental goals for 2020 known as the "20-20-20" targets, namely, a 20% reduction in greenhouse gas emissions from 1990 levels, a 20% improvement in the energy efficiency and a 20% share of RES in the EU's final energy consumption. The Directive 2009/28/CE [51] of March 2009, included in the climate-energy legislative package, specifically set for Spain a minimum 20% share of RES in its national final energy consumption, coincident with the overall target for the entire EU.

In May 2009 the RDL 6/2009 [52] entered into force, which introduced important changes in the access to the remuneration of the RD 661/2007. These changes were justified by the growing impact that the remuneration of SR was having on the tariff deficit, i.e., the lack of incomes of the electric system to cover all its expenses. It was argued that this imbalance could put at risk the short-term sustainability of the electric system, both economically and technically. Thus, an emergency measure for the planning of non-PV[2] RE facilities was implemented.

In order to qualify for the economic framework of RD 661/2007, the enrolment in a Register of Pre-Allocation of Remuneration (RPAR) managed by the central Government became compulsory. In turn, to obtain the registration in the RPAR a number of demanding requirements ought to be met. Among other conditions, it was required a connection point to the electrical network, resources to undertake at least 50 % of the project investment, a purchase agreement for a minimum of 50% of the value of the equipment and a new guarantee of 100 €/kW for the CSP case.

Registrations would be accepted in the RPAR while the power objective of a technology was not attained. Thereafter, in order not to lose the entitlement to the pre-assigned remuneration, projects would have 36 months to be completed and to start selling energy.

Nevertheless, ongoing projects meeting all the requirements at the entry into force of the RDL 6/2009 should apply for registration in the RPAR within 30 calendar days and deposit the guarantee

[2] PV technology had a specific own procedure, laid down by Royal Decree 1578/2008 of 26 September, 2008.

within 30 additional calendar days. In case that the projects registered in this way did not cover the power target, the economic framework of the RD 661/2007 would be maintained until the target was achieved. Conversely, if the power target was exceeded, the remuneration of RD 661/2007 would be applied to all the registered projects, but would not be extended beyond. In the latter case, restrictions on annual implementation and start up of the registered facilities could be established in order not to compromise the technical and economic sustainability of the electric system. Also, a new legal and economic framework was announced for projects not qualifying for the remuneration of the RD 661/2007.

Prior to the entry into force of the RDL 6/2009, 3 CSP plants with an aggregate installed power near 81 MW were commercially operating in Spain. By the end 2009, the RPAR for the CSP technology was closed down and 56 projects amounting near 2,340 MW[3] obtained the corresponding registration from a total of 104 applications totalling 4,499 MW. The entry into operation of the registered facilities was distributed in 4 phases until the end 2013, the first about 880 MW and near 500 MW the following ones [53,54].

The changes introduced by the RDL 6/2009 have been summarized in the Table 4.

TABLE 4

3.5. The 2010-2013 subperiod: the bursting of the Spanish CSP sector

In the 2010-2013 subperiod, a set of new regulatory elements that restricted the entitlement or reduced the remuneration of the CSP facilities under the RD 661/2007 was issued.

To start with, by the end 2010 three new regulations were enacted in this regard. Thus, the RD 1565/2010 [55] entered into force in November 2010. It established additional technical requirements for the SR facilities and redefined the concept of substantial modifications of installations that would entail losing the entitlement to the remuneration of the RD 661/2007. On the other hand, it set the possibility of granting a specific economic framework to innovative CSP projects for an aggregate total of 80 MW. That call was finally resolved in favour of a 49,90 MW facility that extended the RPAR to 57 CSP projects totalling near 2390 MW. The premium and upper and lower limits for the selected facility

[3] The last published update of the RPAR included 58 CSP projects amounting near 2440 MW [5].

fell by 15% compared to the RD 661/2007 levels and it ought to start selling energy between January 1, 2014 and July 1, 2015 [56].

Subsequently, the RD 1614/2010 entered into force in December 2010 [57]. It set limits to the number of equivalent operating hours at rated power eligible for the remuneration of the RD 661/2007 (see Table 5). Also, the more advantageous pool price plus premium remuneration option was eliminated for a period of 12 months. The operational CSP plants would perceive the regulated tariff from January 1, 2011 and the facilities under construction since their date of commissioning. However, during this period the percentage of power generation from fuel associated to the regulated tariff could rise from 12% to 15%. Additionally, the planned revision of the economic system anticipated in RD 661/2007 was delayed by two years, so that instead of January 1, 2012, it would apply to new installations brought into operation from January 1, 2014, onwards.

TABLE 5

In December 2010 it was also issued the RDL 14/2010 [58], establishing urgent measures to correct the electricity sector tariff deficit. It obligated all power producers to pay a toll of 0.5 €/MWh for the energy fed into the transport and distribution networks, from January 1, 2011 onwards.

During 2011, no new rules affecting the remuneration of CSP plants under RD 661/2007 were issued. Rather, the Law 2/2011 of March 2011 [59] transposed into the Spanish legislation the energy objectives of the Directive 2009/28/CE and, as previously did the RD 661/2007, set up the elaboration of a RE plan for the period 2011-2020 (PER 2011-2020). The PER 2011-2020 [37] was approved in November 2011 and established as non-binding CSP capacity and energy targets 3,001 MW and 8,287 GWh/year by 2015 and 4,800 MW and 14,378 GWh/year by 2020, respectively.

The year 2012 brought the end of the FIT system for the new facilities of the SR and also introduced further cuts to the remuneration of the facilities eligible for the economic framework of the RD 661/2007.

Thus, the RDL 1/2012 of January 2012 [60] temporarily suspended the procedure of registration in the RPAR and suppressed the economic incentives of the RD 661/2007 for the new facilities of the SR. This measure would not affect neither operating plants nor those already inscribed in the RPAR.

On the other hand, the Law 15/2012 of December 2012 [61] introduced a new 7% tax on the gross revenues of all electricity producers and cancelled tax exemptions for the energy products used in the electricity generation. Additionally, the FIT was suppressed for the percentage of electricity generated with fuels in certain RE plants. In the case of CSP facilities that meant a cumulative fall in revenue between 19% to 22% (7%+(12% to 15%)), besides new taxes to the energy products employed to warm up the heat-transfer fluid.

Also, the RDL 29/2012 of December 2012 [62] excluded from the economic framework of RD 661/2007 the plants that were not fully completed before the deadline or with elements not reflected in the implementation project. It was explicitly defined when a facility could be considered as fully completed and when not.

In 2013, new regulatory measures reduced the remuneration of the SR facilities. Thus, the RDL 2/2013 of February 2013 [63] replaced the CPI for the annual update of the remuneration of all the electricity sector activities by a more stable index. It was the core inflation at constant taxes, i.e., the CPI at constant taxes excluding energy prices and unprocessed food. This change meant a drop around 3% in the remuneration for 2013 [64]. Also, the premium on top of the electricity pool price was set to 0 €/kWh and its upper and lower limits were removed, turning the hitherto less attractive regulated tariff into the only profitable remuneration option. For the CSP technology, the regulated tariff for 2013 was around 10% lower compared to the premium plus pool price for 2012. Both measures applied retroactively from 1 January 2013 and resulted in a new 13% decline in the CSP remuneration.

In July 2013 the RDL 9/2013 [65] came into force, which adopted urgent measures to guarantee the financial stability of the Spanish electricity system. It repealed the prevailing RD 661/2007 and the RPAR mechanism of RDL 6/2009 and modified the Electricity Sector Law 54/1997 to introduce the principles upon which a future new legal and economic framework for the SR facilities would be based.

The former regulated tariff and premium on top of the pool price concepts were replaced by the pool price plus a specific remuneration compensating for the investment and operational costs that could not be recovered with the incomes from the sales of energy in the pool. This specific remuneration would vary according to the typology of the facilities and would be such that an efficient and well managed company could obtain a reasonable return of investment along its regulatory lifetime. The reasonable return was set, before taxes, at the average yield during determined period of the 10-year Spanish bonds in the secondary market plus an appropriate differential and the parameters of the specific remuneration could be revised every six years. The costs determined by rules not applicable to the entire Spanish territory (those set by the AACCs) or those not responding exclusively to the generation of electricity would not be considered for the calculation of the specific remuneration. To qualify for the new economic framework, the enrolment in a specific remuneration regime Register managed by the central Government became compulsory.

For the particular case of those SR facilities that were entitled for the FIT before the entry into force of RDL 9/2013, the average yield of the 10-year Spanish bonds would be calculated over the last 10 years and a differential of 300 BPS would be added (amounting to 7,395%). While the future legal and economic framework was implemented, the remuneration of these SR facilities would be provisionally paid according to RD 661/2007 but it would be recalculated afterwards pursuant to the new regulation. As an exception, the innovative 49.9 MW CSP project under the RD 1565/2010 maintained its specific remuneration.

In December 2013, the Law 54/1997 was repealed almost entirely by the new Electricity Sector Law 24/2013 [66]. Recognizing the inability of the regulatory measures taken in the last years to eradicate the tariff deficit, the Law 24/2013 set as one of its basic purposes the recovery of the economic and financial stability of the electricity system. As novelties, it suppressed the SR concept and referred instead to production facilities with specific remuneration, regulated the temporary closure of production facilities and defined regulatory periods of six years. The percentage of electricity generated from fuels would not perceive the specific remuneration, but only the pool price.

The principles of RDL 9/2013 for the remuneration of the production facilities from RES were incorporated, although new elements intended to adjust the remuneration to the cyclic situation of the economy and to the electricity system needs were introduced. Thus, the new RE production facilities would qualify for a specific remuneration only on certain exceptional basis established by the Government and it would be awarded by a competitive procedure. The average yield of the 10-year Spanish bonds for the first regulatory period of the new facilities would be calculated over the three months prior to the entry into force of RDL 9/2013 and a differential of 300 BPS would be added. Besides the review of the remuneration parameters at the beginning of the six-year regulatory periods, some of them could also be adjusted at the three-year half-periods.

The remunerations perceived by the existing SR facilities before the entry into force of RDL 9/2013 would not give rise to any claims even if the reasonable return defined in the new economic framework for their regulatory lifetime was exceeded.

By the end 2013 deadline, 50 CSP plants with 2,299.5 MW of aggregated capacity were commercially operating in Spain. 10 out of the 60 initially envisaged plants were finally withdrawn (two 49.9 MW parabolic trough and eight dish Stirling plants totalling 71.39 MW), on the grounds of the loss of revenue due to the last regulatory changes. Likewise, the 49.9 MW innovative CSP project with deadline 1 July 2015 was also suspended [3].

The regulatory changes affecting CSP in Spain in the subperiod 2010-2013 have been summarized in the Table 6.

TABLE 6

3.6. Beyond the period

The new legal and economic framework for the production facilities from RES was finally regulated by the RD 413/2014 of June 2014 [67], which developed the basic principles already contained in RDL 9/2013 and integrated in the Law 24/2013. In turn, the remuneration parameters to be applied during the first regulatory half-period were approved by the Order IET/1045/2014 of June 2014 [68].

According to the CSP Industry Spanish Association, the new regulatory framework posed a 15% mean cut in the CSP remuneration, which added to the retroactive measures adopted in the previous years rose the cumulative cut to 50% [69].

4. Analysis of the 1998-2013 economic and regulatory framework for the CSP in Spain

4.1. Applied methodology

The performance of CSP in Spain in the studied period is here analysed under the perspective of feedback control systems. A parallelism is tendered between the economic and regulatory frameworks governing CSP and a simplified equivalent control scheme. The intention behind this approach is not to build an accurate model of the CSP sector, but rather to identify the energy policy elements inducing the fast expansion and subsequent stagnation of this market in Spain drawing on basic control theory principles.

This methodology was recently applied in [32,33] to analyse the PV boom occurred in Spain in 2008. It proved a useful tool to ascertain the causes that led the PV sector to instability and for assessing the measures intended to curb its unbridled behaviour.

4.2. Assessment of the 1998-2009 economic and regulatory frameworks for the CSP in Spain in control terms

4.2.1. Initial control structure, FIT definition and delays

In our approach, an analogy has been built between the regulatory frameworks governing CSP in Spain and the basic closed loop control scheme shown in the Figure 2.a. In this way, the input or set point to the control system is the CSP target applied by the several PERs, the system to be controlled is the Spanish CSP sector and the response or system output is the CSP capacity actually installed. The control block represents the diverse electricity sector rules and laws affecting CSP, enacted in order to hit its power target. The error signal applied to the control block is the difference between the set point and the system output. In turn, the output generated by the control block as a function of the error signal is the FIT that stimulates the response of the controlled CSP sector. This feedback mechanism allows adjusting the control action according to the system output results.

FIGURE 2

The review of the funding systems in force in the period 1998-2009 (see Tables 1-3) shows that in all cases the FIT value was independent from the evolution of the error signal. Consequently, the control scheme applied in practice was open loop (see Figure 2.b), without a feedback mechanism intended to adjust the control action to the system output evolution.

The decoupling of the FIT and the error signal in the period covered by the RD 2818/1998, RD 436/2004 and RD 661/2007 can be observed in detail in the subplot corresponding to the probe labelled A in the Figure 2.b. In this subplot it has been represented the evolution of the two existing remuneration options. Thus, the regulated tariff is shown in blue solid line and the premium on top on the pool price in solid red line, along with its upper and lower limits in brown and orange dashed lines, respectively. For comparison purposes, it has been represented in the same subplot the evolution of the error signal in the same period, in yellow dotted line.

In the subperiod 1998-2004 covered by the RD 2818/1998 the error stood at 100% (see Figure 2.b. probe A subplot). Initially, the issuance of RD 2818/1998 aroused the interest of some companies in developing the first commercial CSP projects on the belief that the remuneration for the solar facilities was also applicable to the CSP technology [70]. Then the RD 1955/2000 classified solar thermal power into a different group, with economic incentives below 20% of the corresponding to the solar facilities. Although the RD 841/2002 reinstated the CSP into the group of facilities using solar energy as primary energy and raised the remuneration, it was still inadequate for accessing funding. This initial uncertainty in the control law to be applied and the inadequacy of the final stimulus level were responsible of the lack of response of the system. The ability of open loop control systems to accurately perform an action lies solely in its good calibration, which in turn requires a precise model of the controlled plant. And as shown by the facts, the implemented control law was far from being well calibrated.

With the RD 436/2004 in force in the subperiod 2004-2007, the control system continued running open loop. Nevertheless, its increased FIT levels triggered the system response out of its state of paralysis (see Figure 2.b. probe A subplot). By as early as the end 2004, three projects in progress totalling 110 MW could be identified, along with other initiatives in the development phase amounting 325 MW. Therefore, not only the 200 MW capacity target of the RD 436/2004 but also the 500 MW target of the PER 2005-2010 for the year 2010 were virtually assured without the need for any other additional stimulus measure [36].

Although open loop, the RD 436/2004 controller incorporated review mechanisms linked to the achievement of its 200 MW power target and other unspecified periodic adjustments. Nevertheless, the intrinsic delay of the implementation process of the CSP facilities did not allow testing the performance of these mechanisms because another ill-defined characteristic precipitated the end of the RD 436/2004 term. The control law depended on the AET, an external parameter linked to the rising oil prices, alien to the CSP controlled system and decoupled from the error signal. This shortcoming led to a regulatory intervention (RDL 7/2006) that froze the controller output and to the announcement of a forthcoming new control scheme, all of this when no CSP plant had been completed yet.

The new control framework RD 661/2007 in force from 2007 maintained the open loop structure. Although the control law was disassociated from external parameters not directly related to the plant, it still failed to be linked to the error signal. Instead, as in the former control frameworks, periodic but unspecified adjustments were envisaged.

Furthermore, the RD 661/2007 increased the control signal applied to the system when the error was decreasing. The new CSP tariff and premium were raised over 17% and 27% respectively, compared to the last updated values of RD 436/2004 (see Figure 2.b. probe A subplot). According to estimates by Government agencies, the Internal Rate of Return (IRR) of a standard 50 MW parabolic trough CSP project with an investment cost of 5,000 €/kW and 2,596 hours of operation per year would be about 9%-10% with the remuneration of the RD 436/2004. The RD 661/2007 would raise this figure to 11%-12% [71]. All of this when the PER 2005-2010 had appraised the 500 MW power target for 2010 as achievable without additional stimulus measures to those laid down by RD 436/2004 and had even anticipated a 10% decrease in the CSP cost of investment in 2008 and a 6% in 2009, 2010 [36].

4.2.2. Pulse disturbance effect of the RD 661/2007 transition mechanism

Besides the above-mentioned periodic but unspecified adjustments envisaged for the FIT, the RD 661/2007 incorporated and additional review mechanism. A yet to be decided review would apply at the undetermined time of achievement of the 85% of the RD 661/2007 500 MW capacity target. From that moment on, the increased controller output would still be applied for an undefined period of not less than one year (see Table 3). All the uncertainty associated to the term of maintenance of the increased FIT could have contributed to generate a call effect of investment in the CSP sector. Companies should undertake investment decisions before the undetermined end of the propitious conditions. This could be likened to the application of a superimposed pulse signal to the system set point.

When the figures of the CSP capacity requesting grid access are examined, a clear picture of the pulse effect of the RD 661/2007 is obtained. With a 500 MW capacity target in force, 4,100 MW of CSP capacity had requested access to the grid by 2007 [71]. By 2009, this figure had escalated to 15,563 MW [37] (see Figure 3).

FIGURE 3

The main plot in the Figure 3 shows the sharp contrast between the size of the capacity requesting grid access by 2007 and by 2009 (in red bars), the cumulative capacity target (in red dashed line) and the cumulative installed capacity (in solid blue line). Due to the large difference in scale, the last two magnitudes have been represented again in a separate subplot to make them visible. The future Spanish CSP bubble was brewing.

4.2.3. New control structure: improving the open loop structure with a saturation mechanism

By means of the RDL 6/2009, new control measures were implemented that abruptly limited the growth of CSP bubble that was taking shape. Nevertheless, although new elements were added to the former control scheme, its open loop design was maintained. The interpretation in control terms of the resulting scheme is represented in the Figure 4. In this figure, the simple open loop control structure of the RD 661/2007 is delimited by a dashed red frame, whereas the joint control framework of RD 661/2007 and RDL 6/2009 is delimited by a dash-dotted blue frame.

FIGURE 4

Two different control actions can be distinguished in the measures introduced by the RDL 6/2009. On the one hand, the total power limit established in the RPAR acted as a saturation block placed at the output of the system (see Figure 4, *power limitation mechanism* box). Regardless the magnitude of $P_{investment}$, i.e., the cumulative capacity of the CSP projects in the investment stage, the saturation mechanism limited the value of $P_{awarded}$, i.e., the cumulative capacity of the CSP projects that got the registration in the RPAR.

In the heat of the CSP bubble generated within the RD 661/2007 control framework, a $P_{investment}$ of 15,563 MW had requested access to the power grid and had deposited the corresponding economic guarantees[4] [37]. Due to the power limitation mechanism, below 30% of that $P_{investment}$ applied for the RPAR, in view of the stringent conditions imposed. Finally, the value of $P_{awarded}$ amounted to around 15% of $P_{investment}$. As these figures reflect, the saturation mechanism implemented in the RPAR contained the runaway trend of the system response (see Figure 4, *power limitation mechanism* subplot). Nevertheless, $P_{awarded}$ represented almost five times the capacity target of RD 661/2007. The CSP bubble and the associated overrun cost to the electricity system had been limited, but not avoided.

On the other hand, the orderly distribution of $P_{awarded}$ into 4 different phases deferred the cost to the electricity system of the fivefold exceeded capacity target. This cost deferral mechanism is interpreted in the Figure 4 by the implementation of 4 parallel branches following the RPAR saturation block. The parallel branches include own saturation blocks that limit $P_{awarded}$ to the specific amount of CSP power allocated to every phase. After a delay, the $P_{awarded}$ of a determined phase is converted into $P_{installed}$. While the phase 1 branch only includes the delay attributable to the implementation process of the CSP plants, the other branches incorporate additional delays accounting for their restrictions on annual start up (see Figure 4, *cost deferral mechanism* subplot).

In the Figure 4, it is also shown that the power limitation and the cost deferral mechanisms incorporated by the RDL 6/2009 were the first attempts to control the cumulative cost associated to the capacity target overshoot. Nevertheless, although the aim of these measures was the control of the cost to the electricity system, no cost target was established. Rather, the cost was indirectly

[4] For the typical 50 MW CSP plant installed in Spain, the economic guarantees would amount to 1M€. This figure reduces significantly the possibilities of applications of speculative nature.

controlled through one of the variables involved in its calculation, namely, $P_{installed}$. The product of a limited and delayed $P_{installed}$ by the mean operating time would render a limited and delayed amount of energy shed into the electricity system. In turn, the product of this energy by the FIT would also result in a limited and delayed cost.

4.3. Assessment of the 2010-2013 economic and regulatory frameworks in control terms

When translating the regulatory measures of the period 2010-2013 into an equivalent control scheme, two different subperiods split by the RDL 9/2013 must be distinguished. While the set of measures prior to the RDL 9/2013 added new elements to the existing control framework, the RDL 9/2013 dismantled the previous structure and addressed the problem with a new approach.

4.3.1. New measures for the cost reduction prior to the RDL 9/2013

Analyzing first the regulatory measures prior to the RDL 9/2013 (see Table 6), two lines of action intended for the control of the cost can be identified. On the one hand, an upper limit was put on the number of equivalent operating hours at rated power. Only the energy produced within this ceiling would be eligible for the remuneration of the RD 661/2007. Putting a cap on the energy qualifying for the remuneration amounted to bounding the cost.

On the other hand, the introduction of tolls and taxes, the elimination of tax exemptions for the energy products, the cancellation of the more advantageous premium plus pool price funding system and the FIT suppression for the percentage of energy generated with fuels can be translated into an equivalent reduction of the actual or equivalent FIT received. Limiting the equivalent FIT, the cost to the electricity system was also limited.

The figure 5.a shows the interpretation in control terms of the two aforementioned cost reducing approaches applied to the RD 661/2007-RDL 6/2009 framework. The resulting scheme is delimited by a dotted green frame. Thus, the unbounded mean operating time that linked $P_{installed}$ to the produced energy in the Figure 4 has now been replaced by a capped operating time (see Figure 5.a, *remunerated operating time reduction mechanism* box). Also, the different measures reducing the actual FIT perceived are interpreted as a constant *K* less than the unity that multiplies the nominal FIT (see Figure 5.a, *effective FIT reduction mechanism* box).

FIGURE 5

4.3.2. RDL 9/2014 new regulatory approach

Otherwise, the RDL 9/2013 put an end to the former open loop control of $P_{installed}$, where the cost problem was indirectly addressed by adding a series of concurrent saving measures. Instead, the foundations were laid for a new control scheme of closed loop nature with the cost to the electricity system as the controlled variable (see Figure 5.b). The remuneration parameters would be reviewed periodically, trying to reconcile a reasonable return of investment for the RE facilities with the economic sustainability of the electricity system. The Law 24/2013 elaborated more on the principle of adjusting the remuneration to the needs of the electricity system.

5. The role of the AACCs in the CSP promotion in Spain

As shown in Figure 6, almost all the Spanish CSP facilities have been located in the southern half of the country. In fact, three AACCs concentrate the 95.5% of the installed CSP power, namely Andalusia, Extremadura and Castile-La Mancha (see Figure 6).

FIGURE 6

Figure 6 also shows the average yearly direct normal irradiation (DNI) in the different AACCs in which the country is divided. It is apparent that the southern AACCs mainly concentrate the areas with the highest DNI levels, what makes them the best candidates for the implementation of CSP facilities. The importance of this issue is such that per each additional 100 kWh/m^2 of DNI, a reduction in the levelized cost of CSP energy up to a 4.5% can be attained [73].

Nevertheless, a thorough analysis cannot fail to examine the role played by the AACCs in the uneven results obtained in the CSP promotion across the country.

When the distribution of powers set by the Spanish Constitution [74] between the State and the AACCs is examined, it is found that the AACCs share powers with the State in areas related to RE deployment such as energy and environmental protection. Nevertheless, the AACCs also assume exclusively other powers such as land planning, urban development and housing. This exclusive competence in land issues confers the AACCs the ability to modulate the pace of implementation of RE facilities in their territory. Additionally, the Electricity Sector Law 54/1997 deposited in the AACCs the power of granting the authorization to generation facilities under the SR, for which purpose the AACCs have developed their own administrative procedures. Moreover, the regulation of the physical connection of the facilities to the grid is also competence of the AACCs [75].

In the light of the foregoing, the intervention capacity of the AACCs in the implementation of RE facilities in their territory is evidenced. On the other hand, the economic framework for the remuneration of the SR facilities is competence of the State. Continuing the parallelism with control schemes, this deeper view at the state and regional levels is illustrated in the Figure 7.

FIGURE 7

In Figure 7, the simple control block of the RD 661/2007 framework previously employed in the Figures 4 and 5 is framed by a dotted blue line. Its inner structure is now revealed to a greater detail, showing a unique economic framework followed by a set of parallel branches corresponding to the control capacity of the different AACCs. Regulations of the physical connection to the grid and the administrative procedures for the authorization of RE facilities have been modelled as switches that introduce variable delays. In this way, the AACCs can signal the investors their willingness to host RE facilities in their territories [75], modulating the effect of the common remuneration. Likewise, in Figure 7 the block representing the overall Spanish CSP sector is framed by a dotted red line. Inside, it is pictured a set of coupled regional CSP sectors, to convey the idea that the stimulus signals from particular AACCs can affect the investments decisions undertaken in all the territories. This control structure allowed the interested AACCs to compete for attracting investment in RE facilities, potentially contributing to the asymmetric deployment of some RE technologies in Spain.

In a recent study, the authors evaluated the impact of the different administrative procedures and landscape policies in the uneven growth of the on-floor PV facilities across the Spanish AACCs [76]. It was found that those AACCs with a lower degree of complexity in their administrative procedures achieved better implementation rates. Likewise, the processing time associated with the administrative procedure could have conditioned the choice of the AACC where the facilities would be located. Indeed, the bulky unexpected results of PV power installed in Spain could not have been possible without the existence of AACCs with high speed processing capabilities. In a similar vein, the existence of landscape protection policies in some AACCs could have added to the complexity of their administrative procedures.

Similar conclusions were pointed out in [77], in search of the main reasons for the poor CSP deployment in the AACC of Catalonia (see Figure 6). On the one hand, although existing certain areas with adequate DNI levels, they are still lower than those of the southern AACCs. Also, the administrative procedure for the authorization of CSP facilities in Catalonia was perceived by the developers as longer and more complex than the procedures of other AACCs. Additionally, the structure of land ownership in Catalonia is mainly characterized by a large number of smallholders, as opposed to the dominance of large landholdings in the southern AACCs. This fact could have complicated the achievement of the large tracts of land needed by CSP facilities.

In sum, the higher DNI levels of the southern AACCs along with their potential control capacity to compete for attracting RE investments in their territories can be held responsible for the uneven distribution of the CSP facilities in the Spanish soil.

6. Conclusions.

This paper contributes an in-depth description of all the economic and regulatory frameworks governing the promotion of the CSP technology in Spain in the period 1998-2013. Setting a parallelism between well-established principles of feedback control systems and these legal frameworks has facilitated the identification of the drivers that ultimately led to the creation of a CSP bubble. Likewise, the same methodology has allowed analysing the several measures consecutively applied to limit the economic impact on the Spanish electricity system of the CSP unbridled growth.

The open loop nature of the control schemes implemented in the RD 2818/1998, RD 436/2004 and RD 661/2007 frameworks has been identified as a relevant factor in the runaway path followed by the CSP cumulative installed capacity. The FIT value not only was decoupled from the error signal, but was even greatly increased when the error began to decline.

Also, the transition mechanism introduced by the RD 661/2007, by which an unspecified FIT review would apply at the time of achievement of the 85% of the capacity target, could have acted as a pulse disturbance on the CSP sector. All the uncertainty associated to the term of maintenance of the increased FIT levels might have promoted a call for investment effect contributing to the creation of a CSP bubble.

Likewise, the delay between 2 and 4 years associated to the implementation time of the CSP facilities hindered the control of the system. Monitoring exclusively the cumulative installed capacity kept fundamental information about the capacity in the investment state concealed.

In order to amend the former control deficiencies, by means of the RDL 6/2009 a saturation mechanism was implemented that limited the FIT entitlement to only a 15% of the CSP capacity that had requested grid access. Even after this severe cut, the authorized capacity represented five times the 500 MW power target. Additionally, in order to delay in time the overrun cost that this excess would entail, the RDL 6/2009 introduced a deferral mechanism that distributed into 4 phases the entry into operation of the registered facilities until the end 2013.

In the period 2010-2013, a set of measures intended to reduce the overrun cost to the electricity system of the CSP bubble was implemented. The operating time entitled for the FIT was limited and the actual FIT perceived was decreased by the introduction of new tolls and taxes and other retroactive changes in the funding system.

Finally, in mid 2013 the RDL 9/2013 dismantled the RD 661/2007 control framework and its subsequent amendments and changed completely the control philosophy. The former open loop scheme was transformed into a closed loop scheme, and the cost to the electricity system replaced the cumulative installed capacity as the new set point.

Also, the share of powers between the State and the AACCs in areas related to the RE promotion has been examined, manifesting the potential capacity of the AACCs to compete for attracting RE investments in their territory. This fact along with the higher DNI levels in the southern AACCs could mainly justify the almost exclusive location of the CSP facilities in these regions.

Definitely, the economically unsustainable path of implementation that the CSP has followed in Spain has resulted in the application of retroactive measures that have put at risk the viability of the facilities in operation. The legal certainty concept itself has been compromised, generating mistrust in local and foreign investors. It is expected that the lessons extracted from the thorough analysis of the CSP trajectory in Spain could be useful for those countries undertaking the path of CSP or other RES technologies promotion.

Acronyms

AET	Average Electricity Tariff
AACC	Autonomous Community or Region
BOE	Official State Bulletin
BPS	Basis Points
CNMC	National Commission of Markets and Competition
CPI	Consumer Price Index
CSP	Concentrating Solar Power
DNI	Direct Normal Irradiation
EU	European Union
FIT	Feed-in-tariff
IRR	Internal Rate of Return
MENA	Middle East and North Africa
PER	Renewable Energy Plan
RD	Royal Decree

RDL Royal Decree-Law

RE Renewable Energy

RES Renewable Energy Sources

RPAR Register of Pre-Allocation of Remuneration

SR Special Regime

USA United States of America

Variables

$P_{investment}$ the cumulative capacity of the CSP projects in the investment stage

$P_{awarded}$ the cumulative capacity of the CSP projects that got the registration in the RPAR

Figure list

Figure 5. a) Equivalent control scheme of the RD 661/2007-RDL 6/2009 economical and regulatory framework and the cost reducing measures of the period 2010-2013, b) equivalent control scheme after the RDL 9/2013 issuance. Self-elaboration based on [49,52,55,57,58,60-63,65-68].

Figure 6. Location of CSP facilities and average yearly DNI [kWh/m^2] distribution in peninsular Spain. Self elaboration based on [5,72].

Figure 7. Structure at the state and regional level of the Spanish CSP sector and its economic and regulatory framework under the RD 661/2007. Self elaboration based on [74,39].

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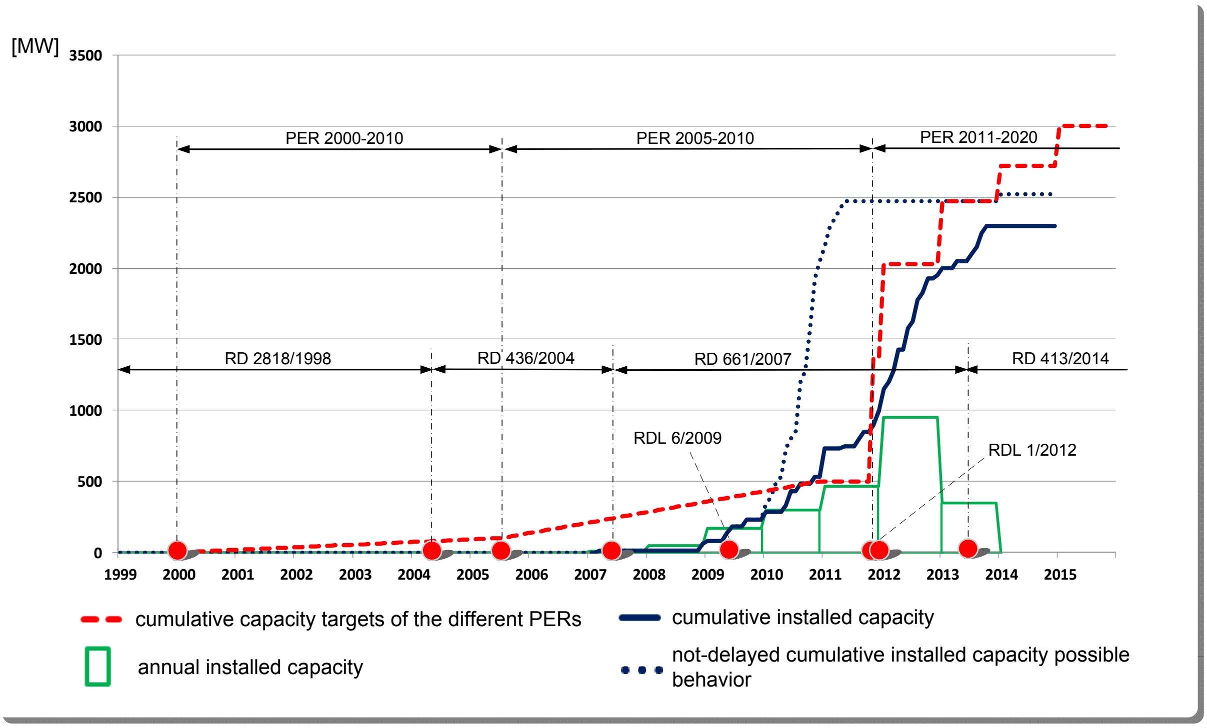
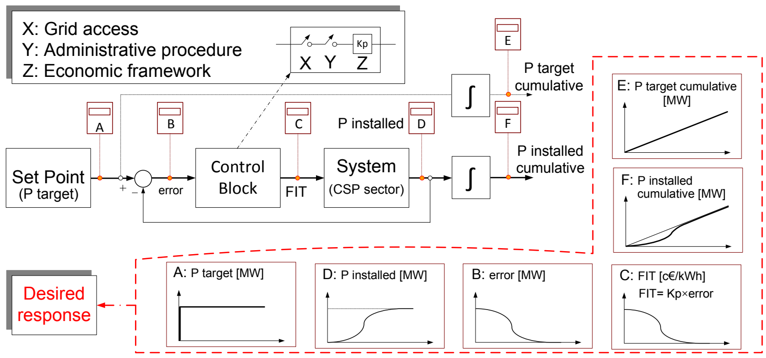
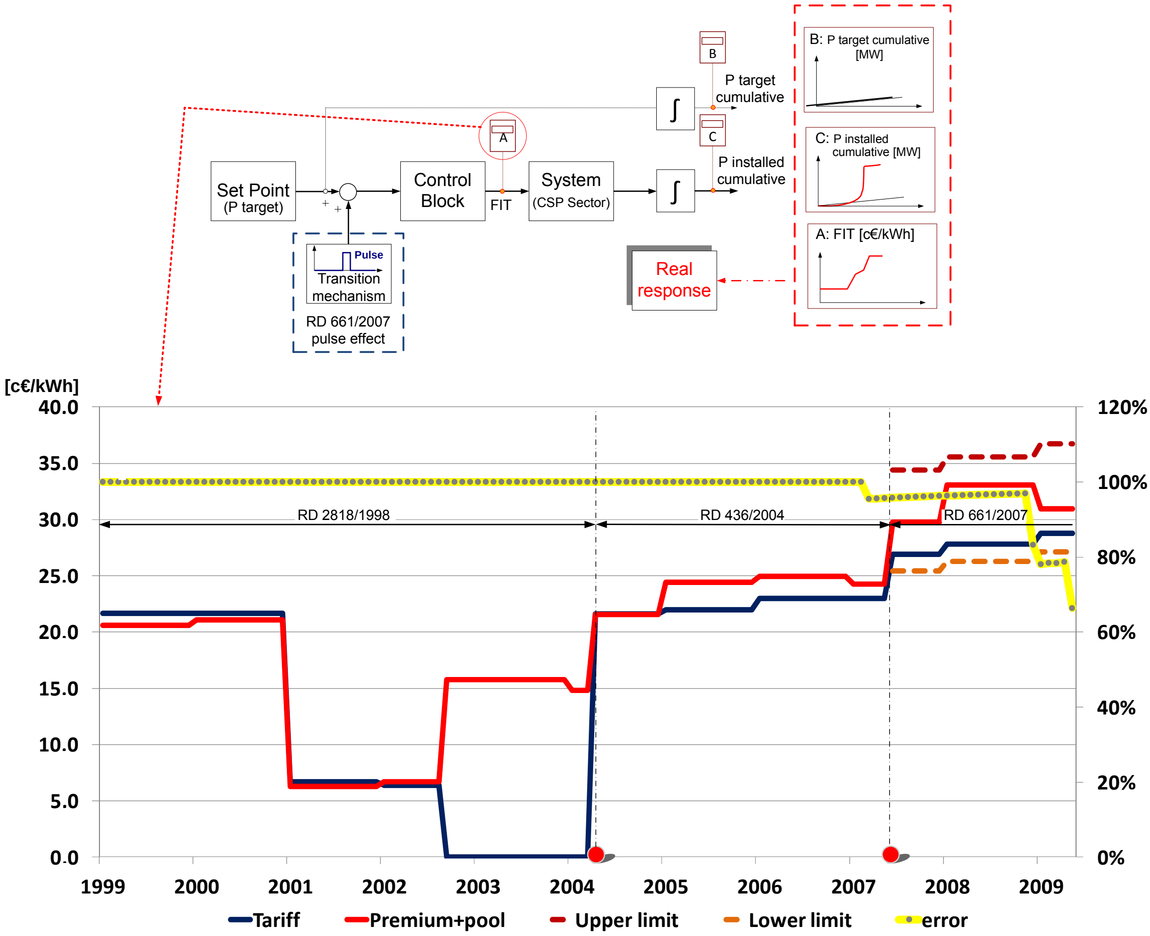




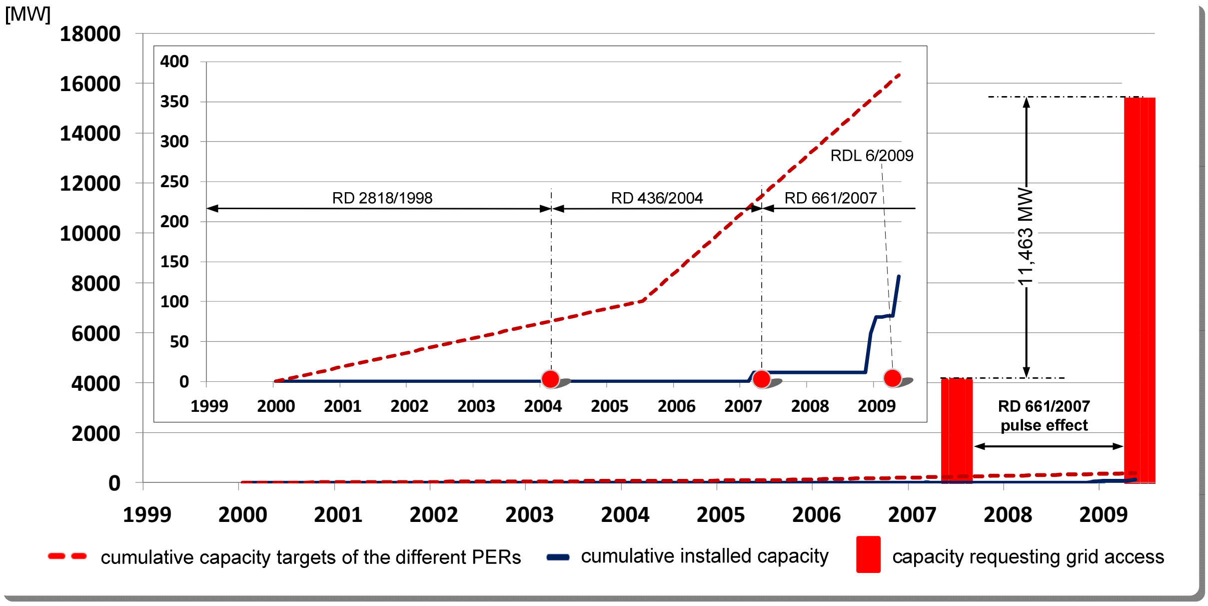
X: Grid access
Y: Administrative procedure
Z: Economic framework
X Y Z
Kp
Set Point
(P target)
error
Control Block
FIT
System
(CSP sector)
P installed
P target cumulative
P installed cumulative
E: P target cumulative [MW]
F: P installed cumulative [MW]
Desired response
A: P target [MW]
D: P installed [MW]
B: error [MW]
C: FIT [c€/kWh]
FIT= Kp×error

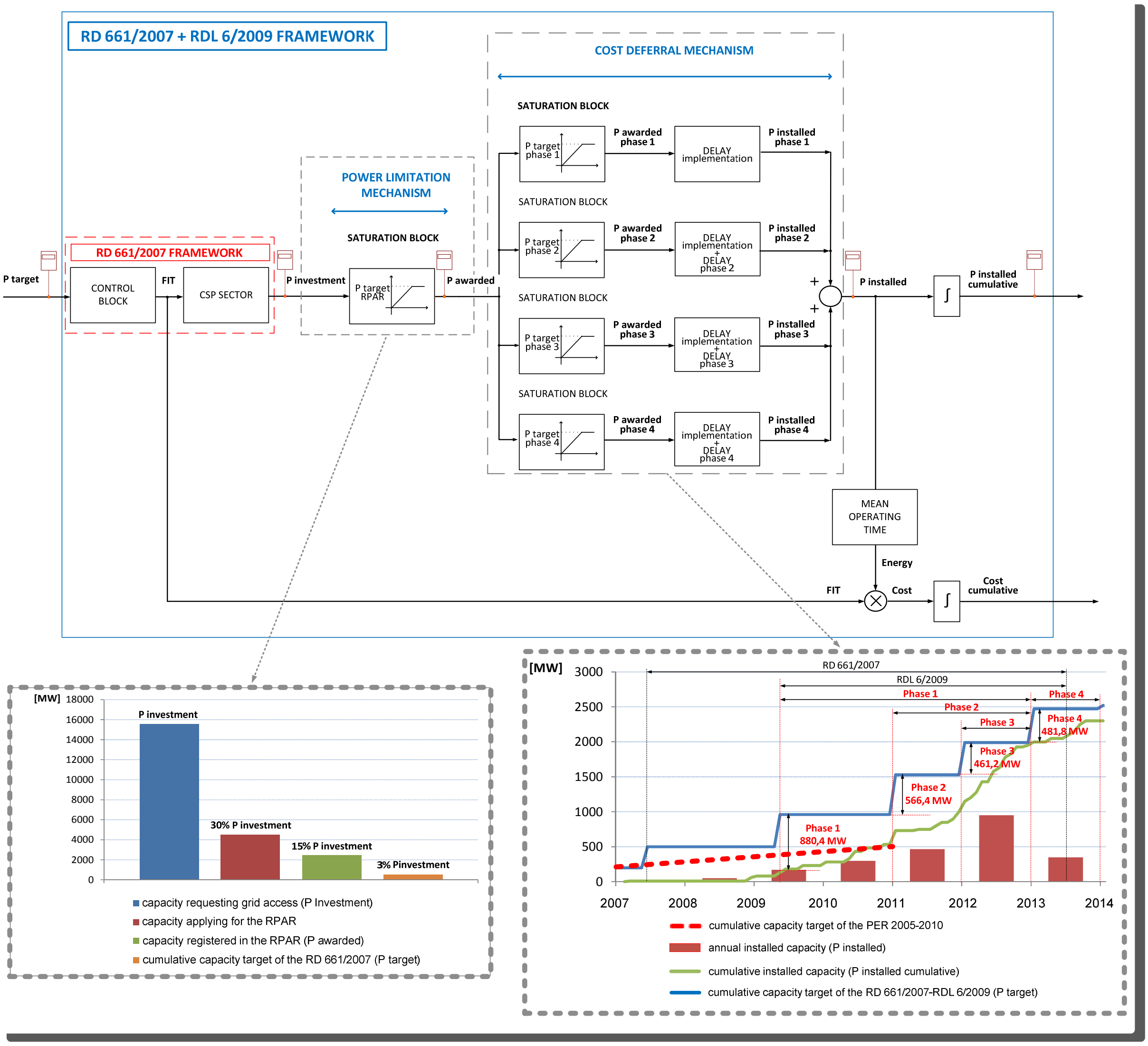
a)



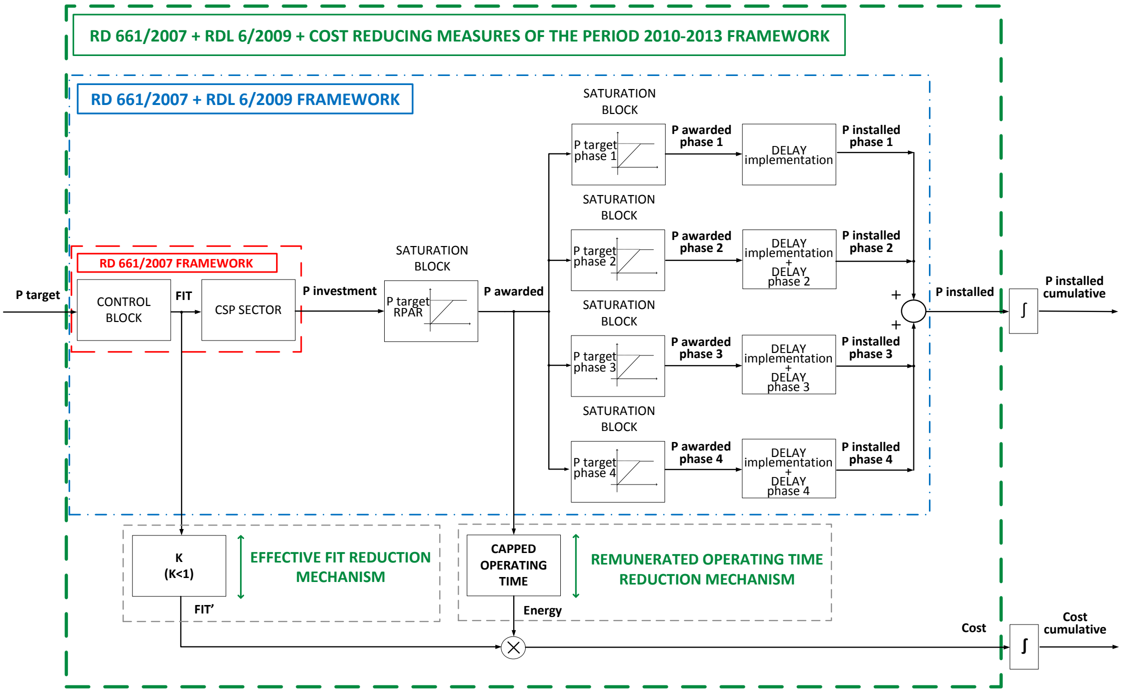
B: P target cumulative [MW]
C: P installed cumulative [MW]
A: FIT [c€/kWh]
P target cumulative
P installed cumulative
Set Point
(P target)
Control Block
FIT
System
(CSP Sector)
Pulse
Transition mechanism
RD 661/2007 pulse effect
Real response
[c€/kWh]
RD 2818/1998
RD 436/2004
RD 661/2007
Tariff
Premium+pool
Upper limit
Lower limit
error

b)

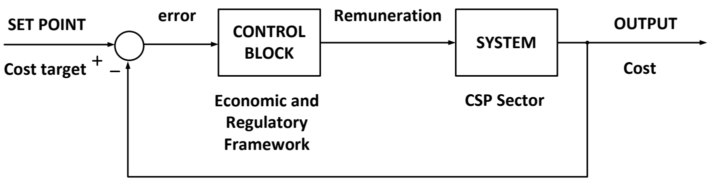

[MW]
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
400
350
300
250
200
150
100
50
RD 2818/1998
RD 436/2004
RD 661/2007
RDL 6/2009
11,463 MW
RD 661/2007
pulse effect
cumulative capacity targets of the different PERs
cumulative installed capacity
capacity requesting grid access



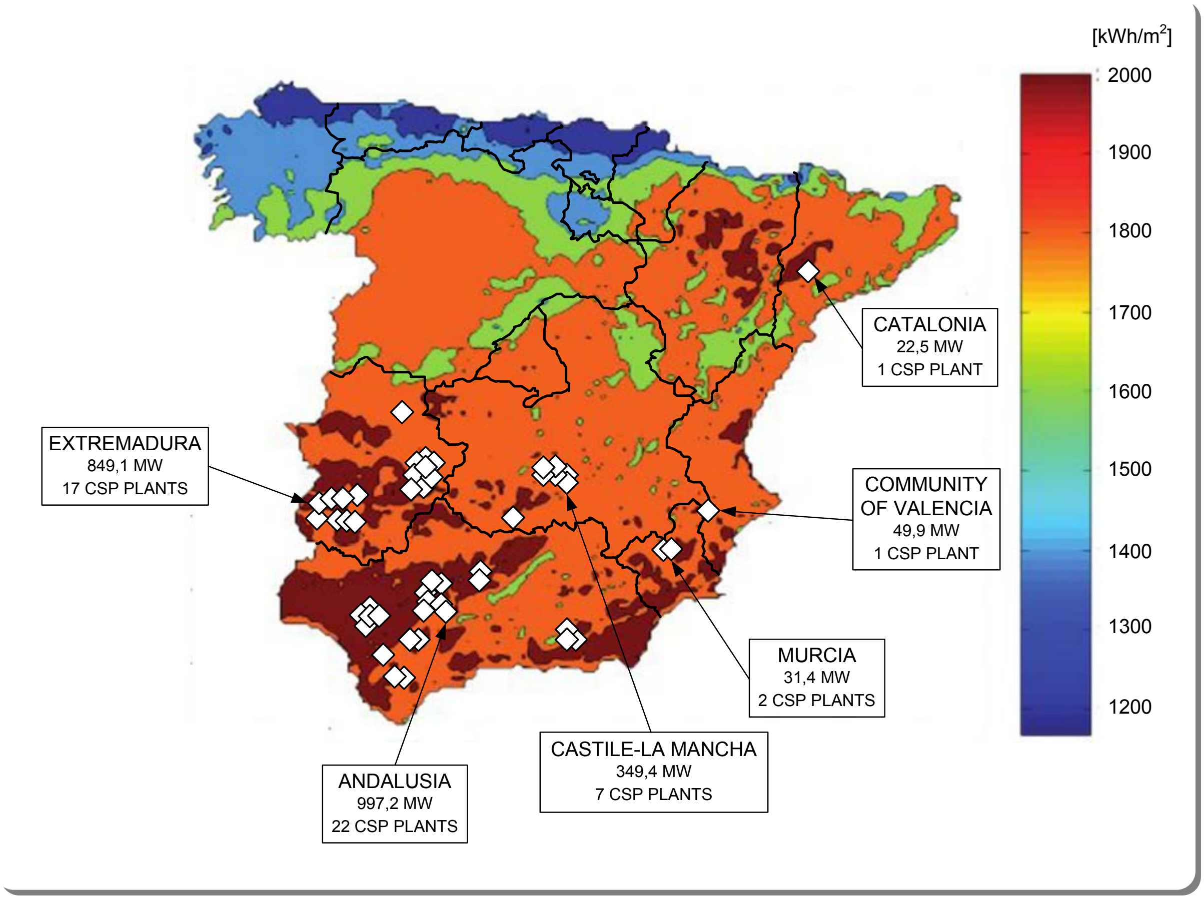
RD 661/2007 + RDL 6/2009 FRAMEWORK
COST DEFERRAL MECHANISM
POWER LIMITATION MECHANISM
RD 661/2007 FRAMEWORK
P target
CONTROL BLOCK
FIT
CSP SECTOR
P investment
SATURATION BLOCK
P target RPAR
P awarded
P target phase 1
P awarded phase 1
DELAY implementation
P installed phase 1
P target phase 2
P awarded phase 2
DELAY implementation + DELAY phase 2
P installed phase 2
P target phase 3
P awarded phase 3
DELAY implementation + DELAY phase 3
P installed phase 3
P target phase 4
P awarded phase 4
DELAY implementation + DELAY phase 4
P installed phase 4
P installed
P installed cumulative
MEAN OPERATING TIME
Energy
Cost
Cost cumulative
[MW]
P investment
30% P investment
15% P investment
3% Pinvestment
capacity requesting grid access (P Investment)
capacity applying for the RPAR
capacity registered in the RPAR (P awarded)
cumulative capacity target of the RD 661/2007 (P target)
RD 661/2007
RDL 6/2009
Phase 1
Phase 2
Phase 3
Phase 4
Phase 1 880,4 MW
Phase 2 566,4 MW
Phase 3 461,2 MW
Phase 4 481,8 MW
cumulative capacity target of the PER 2005-2010
annual installed capacity (P installed)
cumulative installed capacity (P installed cumulative)
cumulative capacity target of the RD 661/2007-RDL 6/2009 (P target)


RD 661/2007 + RDL 6/2009 + COST REDUCING MEASURES OF THE PERIOD 2010-2013 FRAMEWORK
RD 661/2007 + RDL 6/2009 FRAMEWORK
RD 661/2007 FRAMEWORK
P target
CONTROL BLOCK
FIT
CSP SECTOR
P investment
SATURATION BLOCK
P target RPAR
P awarded
P target phase 1
P awarded phase 1
DELAY implementation
P installed phase 1
P target phase 2
P awarded phase 2
DELAY implementation + DELAY phase 2
P installed phase 2
P target phase 3
P awarded phase 3
DELAY implementation + DELAY phase 3
P installed phase 3
P target phase 4
P awarded phase 4
DELAY implementation + DELAY phase 4
P installed phase 4
P installed
P installed cumulative
K (K<1)
EFFECTIVE FIT REDUCTION MECHANISM
FIT'
CAPPED OPERATING TIME
REMUNERATED OPERATING TIME REDUCTION MECHANISM
Energy
Cost
Cost cumulative

a)


SET POINT
Cost target
error
CONTROL BLOCK
Remuneration
SYSTEM
OUTPUT
Cost
Economic and Regulatory Framework
CSP Sector

b)


[kWh/m2]
2000
1900
1800
1700
1600
1500
1400
1300
1200
CATALONIA
22,5 MW
1 CSP PLANT
EXTREMADURA
849,1 MW
17 CSP PLANTS
COMMUNITY OF VALENCIA
49,9 MW
1 CSP PLANT
MURCIA
31,4 MW
2 CSP PLANTS
CASTILE-LA MANCHA
349,4 MW
7 CSP PLANTS
ANDALUSIA
997,2 MW
22 CSP PLANTS

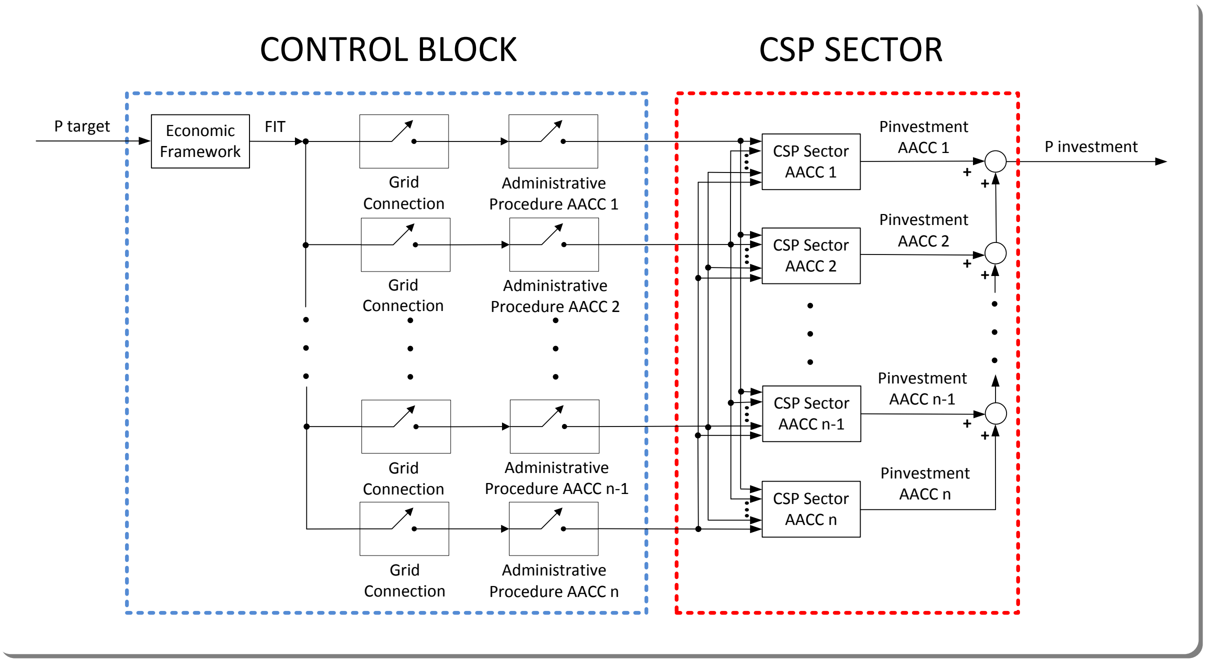

CONTROL BLOCK
CSP SECTOR
P target
Economic Framework
FIT
Grid Connection
Administrative Procedure AACC 1
Administrative Procedure AACC 2
Administrative Procedure AACC n-1
Administrative Procedure AACC n
CSP Sector AACC 1
CSP Sector AACC 2
CSP Sector AACC n-1
CSP Sector AACC n
Pinvestment AACC 1
Pinvestment AACC 2
Pinvestment AACC n-1
Pinvestment AACC n
P investment

Table 1. Key features of the economic and regulatory framework for CSP in Spain in the period 1998-2004. Self-elaboration based on [35,39-42].

Legal Rule	Basic Feature	Power/Energy Targets	Funding System	Remuneration [c€/kWh]	Time Limit	Annual Update	Review	Fuel Use [% electricity production]
Law 54/1997 Repealed by: Law 24/2013	Redefinition of the SR	12% of the primary energy demand reached with RES by 2010	n.a.[a]	n.a.	n.a.	n.a.	n.a.	n.a.
RD 2818/1998 Amended by: RD 1955/2000 RD 841/2002 Repealed by: RD 436/2004	Regulatory development of the SR Group b.1 for solar energy	12% of the primary energy demand reached with RES by 2010	Premium on top of the pool price	18.0304 (P_n <5 kW)[b]	No	No	Every 4 years	No
			Full price to receive	21.6364 (P_n > 5 kW)				
PER 2000-2010 Reviewed by: PER 2005-2010	Renewable energy plan for 2000-2010	200 MW and 413 GWh/year by 2010 of CSP	As in RD 2818/1998	As in RD 2818/1998	As in RD 2818/1998	As in RD 2818/1998	As in RD 2818/1998	As in RD 2818/1998
RD 1955/2000 Repealed by: RD 841/2002	Group b.3 for solar thermal energy	n.a.	Premium on top of the pool price	3.2755	No	According to average selling price of electricity	Every 4 years	No
			Full price to receive	6.7313				
RD 841/2002 Repealed by: RD 436/2004	Subgroup b.1.2 solar thermal energy	n.a.	Premium on top of the pool price	12.0202	No	No	Every 4 years	Yes

a: n.a. is the abbreviation for "not addressed"

b: P_n, nominal or rated power

Table 2. Key features of the economic and regulatory framework for CSP in Spain in the period 2004-2007. Self-elaboration based on [36,43,44,47].

Legal Rule	Main Characteristics	Power/Energy Targets	Funding System	Remuneration [c€/kWh]	Time Limit	Annual Update	Review	Fuel Use [% electricity production]
RD 436/2004 Amended by: RD 2351/2004 Repealed by: RD 661/2007	Remuneration indexed to AET	200 MW of CSP eligible for the initial remuneration	Premium on top of the pool price plus incentive	250% AET plus 10% AET	25 years	According to AET	In 2006	15%
				200% AET plus 10% AET	Thereafter		Every 4 years	
			Regulated tariff	300% of AET	25 years		At 200 MW	12% with restrictions
				240% of AET	Thereafter			
RD 2351/2004	Relaxation of RD 436/2004 restrictions on fuel use	n.a.[a]	n.a.	n.a.	n.a.	n.a.	n.a.	Any fuel type For HTF[b] temperature maintenance
PER 2005-2010 Replaced by: PER 2011-2020	Review of the previous plan for 2000-2010	29.4% of electricity generation from RES by 2010 500 MW and 1,298 GWh/year of CSP by 2010	As in RD 436/2004	As in RD 436/2004	As in RD 436/2004	As in RD 436/2004	As in RD 436/2004	As in RD 2351/2004
RDL 7/2006	Remuneration unlinked to AET updates Remuneration reform announced	n.a.	As in RD 2351/2004, without AET updates	As in RD 2351/2004, without AET updates	As in RD 436/2004	No	As in RD 436/2004	n.a.

a: n.a. is the abbreviation for "not addressed"
b: HTF is the abbreviation for "Heat Transfer Fluid"

Table 3. Key features of the economic and regulatory framework for CSP in Spain in the period 2007-2009. Self-elaboration based on [49].

Legal Rule	Basic Feature	Power/Energy Targets	Funding System	Remuneration [c€/kWh]	Time Limit	Annual Update	Review	Fuel Use [% electricity production]
RD 661/2007 Amended by: RD 1565/2010 RDL 2/2013 Repealed by: RDL 9/2013	Remuneration unlinked to AET Fuels and/or technologies hybridization Adscription to a generation control center if P_n>10 MW 20 €/kW guarantee for CSP network access	29.4% of electricity generation from RES by 2010 500 of CSP	Premium on top of the pool price	25.4000	25 years	According to CPI minus 25 BPS until 2012 and 50 BPS thereafter	In 2010 Every 4 years No less 1 year after 85% (500 MW)	15%
			upper limit	34.3976				
			lower limit	25.4038				
				20.3200	Thereafter			
			Regulated tariff	26.9375	25 years			12%
				21.5498	Thereafter			

Table 4. Key features of the economic and regulatory framework for CSP in Spain in the year 2009, under the RDL 6/2009. Self-elaboration based on [52].

Legal Rule	Basic Feature	Power/Energy Targets	Funding System	Remuneration [c€/kWh]	Time Limit	Annual Update	Review	Fuel Use [% electricity production]
RDL 6/2009 Repealed by: RDL 9/2013	Compulsory enrolment in the RPAR for accessing remuneration Subject to stringent conditions Additional 100 €/kW guarantee for CSP	2,440 MW of CSP in 4 phases: 2009-2012 880,4 MW 2011-2012 566,4 MW 2012 461,2 MW 2013 481,8 MW	As in RD 661/2007	As in RD 661/2007	As in RD 661/2007	As in RD 661/2007	As in RD 661/2007	As in RD 661/2007

Table 5. Reference equivalent hours/year set by RD 1614/2010 for the different CSP technologies. Self-elaboration based on [57].

CSP technology	Reference equivalent hours/year
Parabolic trough without storage	2,855
Parabolic trough with 9 h storage	4,000
Parabolic trough with 7 h storage	3,950
Parabolic trough with 4 h storage	3,450
Central receiving tower using saturated steam	2,750
Central tower with molten salt receiver	6,450
Fresnel	2,450
Stirling	2,350

Table 6. Key features of the new regulatory elements affecting CSP in Spain in the period 2010-2013. Self-elaboration based on [37,55,57-63,65,66].

Legal Rule	**Basic Feature**	**Power/Energy Targets**	**Funding System**	**Remuneration [c€/kWh]**	**Time Limit**	**Annual Update**	**Review**	**Fuel Use [% electricity production]**
RD 1565/2010 Repealed by: RD 413/2014	Additional technical requirements for SR facilities Definition of substantial modification Specific remuneration for innovative CSP projects	80 MW of innovative CSP	n.a.[a]	n.a.	n.a.	n.a.	n.a.	n.a.
RD 1614/2010 Repealed by: RD 413/2014	Limit to the operating hours eligible for the remuneration Pool price plus premium eliminated during 12 months	n.a.	Regulated tariff of RD 661/2007	As in regulated tariff of RD 661/2007	As in RD 661/2007	As in RD 661/2007	Review for 2010 deferred until 2012	15%
RDL 14/2010	Charge of 0.5 €/MWh for the generated energy from January 1, 2011	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Law 2/2011	Transposition of the energy objectives of Directive 2009/28/CE Set the development of a renewable energy plan for 2011-2020	Minimum 20% share of RES in the final energy consumption	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
PER 2011-2020	Renewable energy plan for the period 2011-2020	3,001 MW and 8,287 GWh/year of CSP by 2015 4,800 MW and 14,378 GWh/year of CSP by 2020	As in RD 661/2007 until 2013	As in RD 661/2007 until 2013	As in RD 661/2007 until 2013	As in RD 661/2007 until 2013	As in RD 661/2007 until 2013	As in RD 661/2007 until 2013
RDL 1/2012	Suppression of RPAR and remuneration of RD 661/2007 for new SR facilities	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Law 15/2012	7% tax on gross revenue Cancellation of tax exemptions for energy products in generation FIT suppression for generation with fuels in CSP	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RDL 29/2012	Exclusion from the remuneration of RD 661/2007 of plants not completed on time or with non-projected elements	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
RDL 2/2013 Partially repealed by: RD 24/2013	New index for the remuneration update Removal of premium on top of the pool price	n.a.	Regulated tariff of RD 661/2007	As in regulated tariff of RD 661/2007	As in RD 661/2007	According to core inflation at constant taxes minus 50 BPS	As in RD 661/2007	n.a.
RDL 9/2013	Pool price plus a specific remuneration providing a reasonable return	n.a.	Reasonable return before taxes: average yield during determined period of 10-year Spanish bonds in the secondary market plus a differential	For existing facilities: average yield during last 10 years and differential of 300 BP*S (7,395%)	Regulatory lifetime	n.a.	Every 6 years	n.a.
Law 24/2013	Suppression of SR concept Regulation of temporary closure of facilities Regulatory periods of 6 years Pool price for generation from fuels	n.a.	As in RDL 9/2013	For new facilities: average yield during last 3 months and differential of 300 BPS	Regulatory lifetime	No	Every 3 and/or 6 years	n.a.

a: n.a. is the abbreviation for "not addressed"