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Deep Decarbonization of the European Power Sector Calls for Dispatchable CSP

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Abstract. Concentrating Solar Power (CSP) offers flexible and decarbonized power generation and is one of the few dispatchable renewable technologies able to generate renewable electricity on demand. Today (2018) CSP contributes only 5TWh to the European power generation, but it has the potential to become one of the key pillars for European decarbonization pathways. In this paper we investigate how factors and pivotal policy decisions leading to different futures and associated CSP deployment in Europe in the years up to 2050. In a second step we characterize the scenarios with their associated system cost and the costs of support policies. We show that the role of CSP in Europe critically depends on political developments and the success or failure of policies outside renewable power. In particular, the uptake of CSP depends on the overall decarbonization ambition, the degree of cross border trade of renewable electricity and is enabled by the presence of strong grid interconnection between Southern and Norther European Member States as well as by future electricity demand growth. The presence of other baseload technologies, prominently nuclear power in France, reduce the role and need for CSP. Assuming favorable technological development, we find a strong role for CSP in Europe in all modeled scenarios: contributing between 100TWh to 300TWh of electricity to a future European power system. This would require increasing the current European CSP fleet by a factor of 20 to 60 in the next 30 years. To achieve this financial support between € 0.4-2 billion per year into CSP would be needed, representing only a small share of overall support needs for power-system transformation. Cooperation of Member States could further help to reduce this cost.

INTRODUCTION AND POLICY CONTEXT

As part of the European Green Deal, the European Union (EU) aims at full climate-neutrality of all sectors by 2050 and a 40 % reduction of greenhouse gas emissions (GHG) by 2030 compared to 1990 levels [1][2] which is expected to be revised towards 55 % [3]. The achievement of the EU's energy and climate targets will require high shares of wind and photovoltaics (PV) in the power system as well as dispatchable renewable generation technologies to balance the fluctuating generation patterns of wind and PV. Concentrating Solar Power (CSP) is a dispatchable, renewable power technology that facilitates the transition towards a decarbonised electricity system in the EU. It provides flexible, CO_2-free electricity to the grid and supports the integration of other renewable electricity technologies. Since solar resources for CSP are richest in the southern countries, cooperation between Member States helps to make this potential also available to northern countries within the EU and facilitate overall energy and climate target achievements. Cooperation is generally characterized by shared efforts and risks, cost optimised investments over all countries instead of separate, national strategies (e.g. cross-border renewable projects) and high shares of energy trading (physically or statistically) [4]. In recent years limited progress has been achieved in cooperation in the field of RES across the EU. To facilitate RES cooperation, a variety of cooperation mechanisms have been defined in EU

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regulation in prior, and, as stated in [5], currently (as of October 2020) four binational agreements have been taken to collaborate on 2020 RES target achievement. Further agreements can be expected in the 2020 context and beyond. In this context, the European Commission is strongly encouraging EU Member States to make of these cooperation mechanisms for achieving RES targets for 2020, 2030 and beyond in a cost-effective manner, cf. [5].

This paper informs on a model-based assessment of the potential future role for CSP in a 2050 low-carbon European power system and the associated investments as well as the public support needed to developing CSP. The work builds on a deliverable from the MUSTEC project [6] – a European research project funded by the Horizon 2020 program aiming at analysing the role of renewable energies (RES) cooperation for an enhanced market uptake of CSP in Europe.

METHOD OF APPROACH AND KEY ASSUMPTIONS

The Applied Modelling System

The modelling works undertaken combined two core elements: a power system analysis, identifying the need for CSP in a decarbonised European electricity system of tomorrow, and an energy policy analysis to assess implications for and impacts of dedicated support policies for CSP and other renewables. Consequently, two distinct energy system models have been applied in an integrated manner, complementing each other in the analysed aspects:

- Green-X: the (renewable) energy policy assessment model; used for analysing policy-driven renewable investments, renewable developments and related impacts on costs, expenditures and benefits.
- Enertile: the energy system model, serving to shed light on the interplay between electricity supply, storage and demand in the EU electricity market.

Green-X analyses the renewable energy (RES) investments, RES diffusion rates, and related impacts on costs, expenditures and benefits for the energy system. Enertile simulates the hourly dispatch of all components of the electricity system: supply, storage and demand in the electricity market. The covered geographic area is EU28 for the years 2030, 2040, and 2050. Moreover, Enertile is also used within this integrated assessment to identify the gap in power system flexibility that can economically best be filled by CSP (in conjunction with internal thermal storage) under the given system boundaries like heading towards carbon neutrality by 2050. In practical terms, CSP stands here in full competition to other flexibility options like cross-border electricity exchange, thermal power plants using fossil fuels (under given carbon constraints) or green gas, demand-side flexibility measures and various storage technologies including hydrogen.

Key Assumptions

Aiming for full decarbonization by 2050 as default, specifically in the electricity sector which has been claimed by several studies, cf. [7], as one of the easiest being fully decarbonized in future, has certain implications:

- (Fossil) CCS is no option; only RES & nuclear are applicable for meeting future electricity demand;
- A strong increase in carbon prices is used in modelling to achieve full decarbonization;
- The expansion of the nuclear fleet across EU Member States is an exogenous assumption, depending on policy pathway. Nuclear power supply in 2050 consequently varies from 29-466 TWh at EU28 level;
- Natural gas is replaced by renewable/green gas by 2050 (at a higher price).

A strong increase in electricity demand is presumed as default, caused by increased sector coupling (e-mobility, e-heat/industry) in accordance with the aim for carbon neutrality. More precisely, assumptions on sector-coupling are set in accordance with an assessment of energy system transformation pathways as conducted within the recently completed H2020 project SET-Nav (cf. [7])

The uptake of variable RES, specifically of onshore wind & PV, is strong but has certain limits of e.g. social acceptance that is acknowledged in the modelling of technology-specific RES diffusion done by use of the Green-X model.

Cost Projections for CSP

For the CSP plants, an 11 hours thermal storage system and a site -specific ratio between field and generator is assumed. Investment costs for 2030, 2040 and 2050 as listed in Table 1 and used in modelling are the average estimations of [7], [8], [9], and [10] – all adapted for an 11 hours storage CSP plant following the tower concept. For validation, these cost trends were compared to current project costs, taken from [11] and [12]. Fixed operation & maintenance (O&M) costs are derived from a comprehensive literature collection applicable in [13]. Variable O&M costs are the average of [8] and [9].

TABLE 1. Cost assumptions for CSP in Enertile in the MUSTEC project

Year	Lifetime [a]	Specific investment [$€_{2010}$/kW]	Fix O&M cost [$€_{2010}$/(kW a)]	Var. O&M cost [$€_{2010}$/MWh]	Efficiency
2030	30	3525	66.7	0.046	44%
2040	30	3078	53.3	0.046	49%
2050	30	2554	40.0	0.046	52%

Definition of Scenarios

Energy policy is the key driver for energy-related investments, and specifically for the electricity sector. Energy policy interventions may take the form of imposing energy and climate targets, applying detailed regulations and market rules, or facilitating the uptake of certain technologies via dedicated support instruments. The scenario assessed in the course of this study acknowledge the important role of energy policy, reflecting differences in policy choices and preferences across Europe. Thus, the specific design of assessed scenarios builds on a detailed bottom-up analysis of policy pathways/preferences in the EU, Germany, France, Italy and Spain (cf. [14]). Two ideological worlds are represented by the scenarios.

- *Cooperation*: On the one hand, there is the setting of enhanced "(RES) Cooperation" across the EU. Here we take the assumption that all EU countries intensify cooperation in the field of renewables in forthcoming years. Specifically, we presume that a least-cost approach is followed, reflecting full competition across technologies and corresponding sites across the whole EU. Deployment of RES technologies will consequently take place in those countries where it is most cost-efficient from the power system perspective towards the 2030 (and 2050) (renewable) energy and climate target achievement. This world is represented by the EU dominant (market-centered) policy pathway.
- *National Preferences*: On the other hand, we model the four countries analyzed in detail (i.e. France, Italy, Germany, and Spain) according to their own (dominant) preferences as stated in the 2030 National Energy and Climate Plans (NECPs). This world is representing the "National Preferences" which can differ to a large degree between the countries in terms of technology choices, RES ambition, etc.

These two policy worlds – i.e. "Cooperation" and "National Preferences" – are then compared and complemented by different *sensitivity analyses*, resulting in scenarios with low electricity demand levels, limited availability of competing demand-side flexibility options, limited grid extensions, and lower decarbonization ambitions.

Complementary to above, within the energy policy analysis a focal assessment on identifying *the need for and impact of RES cooperation* between Member States from a quantitative perspective is conducted. It informs on how RES cooperation may facilitate the uptake of CSP in future years. In general, RES cooperation is assumed to facilitate a levelling of country-specific risk for RES investors and to redistribute the cost of the RES uptake across the whole EU, so that host countries for the uptake of CSP and other RES technologies do no longer have to pay the whole bill. As default we have taken in modelling the assumption that RES cooperation is taking place post 2020. In the sensitivity analysis performed we showcase the consequences if attempts to initiate RES cooperation across the EU will not take place, meaning that RES investors in specifically southern European countries face a "High Country Risk".

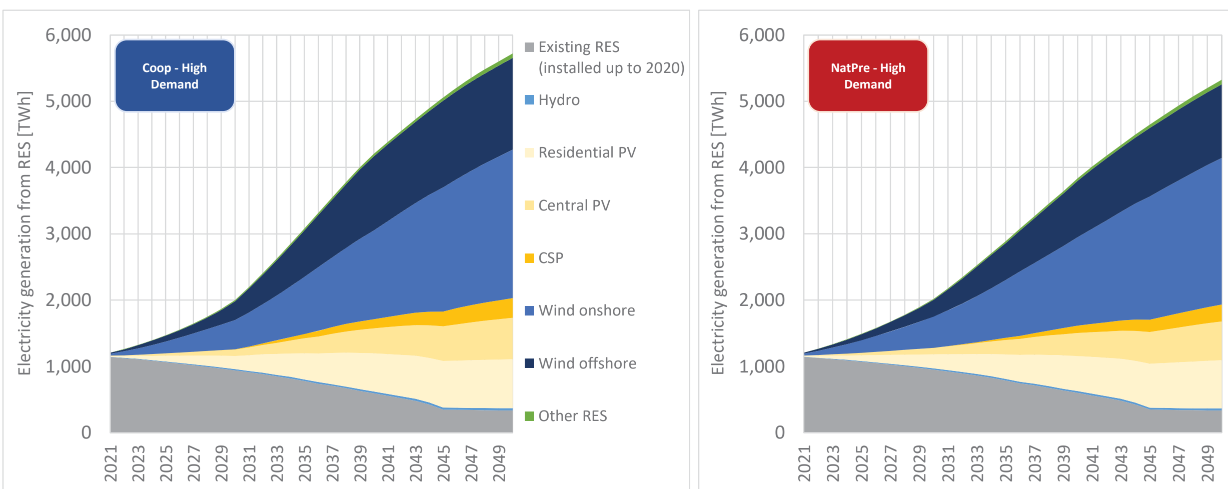
Please note that for increasing transparency in the approach used and the underlying data and results, key modelling data is publicly available at [15].

RESULTS AND DISCUSSION

The Uptake of Renewables for Deep Decarbonization – A Closer Look at the Diffusion of RES Technologies and at Corresponding Investments

In the last thirteen years, the RES deployment in the EU28 has more than doubled. This impressive trend needs to be maintained in all scenarios: taking deep decarbonisation as our overall guiding principle implies an increase of the RES shares to about 56 % by 2030, and to at least 90 % by 2050: RES shares vary by then from ca. 90 % ("National Preferences", assuming a still strong nuclear deployment in France) to about 97 % ("Cooperation", assuming no built-up of new nuclear across the EU). In absolute terms the accompanying strong growth in electricity consumption imposes even a strengthening of RES developments in future years compared to the historic record. Electricity generation from RES needs to at least double within the next twelve years and to more than quadruplicate until 2050 as applicable from Fig. 1, providing a technology-breakdown of the development of electricity generation from RES up to 2050 at EU28 level for the two key scenarios ("Cooperation" vs "National Preferences").

According to our modelling, the lions-share of new generation will come from fluctuating renewables. Key trends in technology-specific developments are that onshore wind dominates the picture – both by 2030 and by 2050. Offshore wind energy is the second largest contributor to the overall RES uptake in future years, followed by photovoltaics where residential and central PV systems are expected to increase significantly. In our model CSP is the fifth largest contributor to RES generation serving as "gap filler" for the system flexibility to the EU power system that relies on large shares of variable renewables – as identified in the power system analysis. Other technologies like hydropower, biomass, geothermal electricity, tidal stream or wave power show only comparatively minor contributions in future years under the underlying framework conditions where least-cost options are prioritised in modelling.



(a) (b)

FIGURE 1. Technology breakdown of the development of electricity generation from RES up to 2050 at EU28 level according to the "Cooperation – High Demand" (a) and the "National Preferences – High Demand" scenario (b) (Source: Green-X modelling)

A Closer Look at the Role of CSP in a Decarbonized European Electricity System of 2050

Our modelling results reveal that there is a clear need for dispatchable CSP in a future European electricity system, driven by the policy goals of carbon neutrality and full decarbonisation – but the need for CSP, competing with other zero carbon technology options that offer flexibility to the power system, varies across assessed scenarios. Within the power system analysis, we consequently shed light on identifying the influence of key energy policy decisions on the overall role of CSP in the EU electricity system up to 2050, given the technology meets its cost reduction goals. In particular, we analysed how cross-border cooperation ("Cooperation" vs. "National Preferences"), sector coupling and electricity demand levels (“High Demand” vs. “Low Demand”), underlying RES policy concepts and pathways (“Low Climate Ambition”), and infrastructural developments/prerequisites (“Limited Grid”) impact the market uptake of CSP in the EU. In all scenarios we find that a strong increase of power generation from CSP contributes to cost-optimal future power-systems increasing EU CSP generation from 5TWh in 2018 by a factor of twenty to sixty in the next thirty years contributing 100TWh to 300 TWh to the EUs power generation (see Fig. 2 below).

Our results show that in particular the degree of cooperation between countries, the size of demand, and the number of available interconnections are important determinants for the uptake of CSP, below we elaborate in detail on their respective impacts.

Concerning the question whether cooperation among European countries leads to higher expansions of CSP power plants, our modelling results are ambiguous. While in the case of very high electricity demand CSP generation is somewhat higher in the “Cooperation” scenario than in the “National Preferences” scenario, this tendency is reversed in the case of lower demand. However, a high electricity demand is more probable in a world with very ambitious decarbonisation targets, which may enhance the perspectives of CSP.

Furthermore, our results indicate that a higher electricity demand increases the generation gap for CSP. Because CSP is more expensive than other renewable technologies, CSP capacities are increasingly installed when the potentials of other renewable technologies like wind and PV are already exploited to a higher degree.

As they hinder the use of fossil power plants, high climate policy ambitions are a very important driver for CSP uptake. First, as a backup of fluctuating renewables and second, as supply of electricity demand exceeding the realizable potential of other renewables. Hence, CSP with its advantage of renewable dispatchability becomes more important under such conditions.

Finally, a highly developed transnational power grid proves to be an ambivalent factor for the development of CSP. On the one hand, interconnections are an enabler of CSP, especially as the areas with largest and least expensive potential of CSP generation are located on the European periphery (Spain, Portugal, and Italy). Due to their peripheral location, especially Spain and Portugal depend on a strong power grid interconnection to the rest of Europe in order to export larger amounts of electricity from CSP (if the conversion of the electricity e.g. to hydrogen with subsequent international trading, which is less efficient than direct electricity trade, is excluded). On the other hand, a highly interconnected European power grid smooths the fluctuations of wind power and PV feed-in, so that the need for additional supply-side flexibility, including CSP, decreases. In contrast to above, a more limited power grid interconnection hinders the uptake of CSP in Portugal and Spain while favouring the use of CSP in other countries like France or Italy – because it sets a limit to the import of electricity from neighbouring countries and reduces the system flexibility provided by the grid, thereby increasing the need for dispatchable CSP.

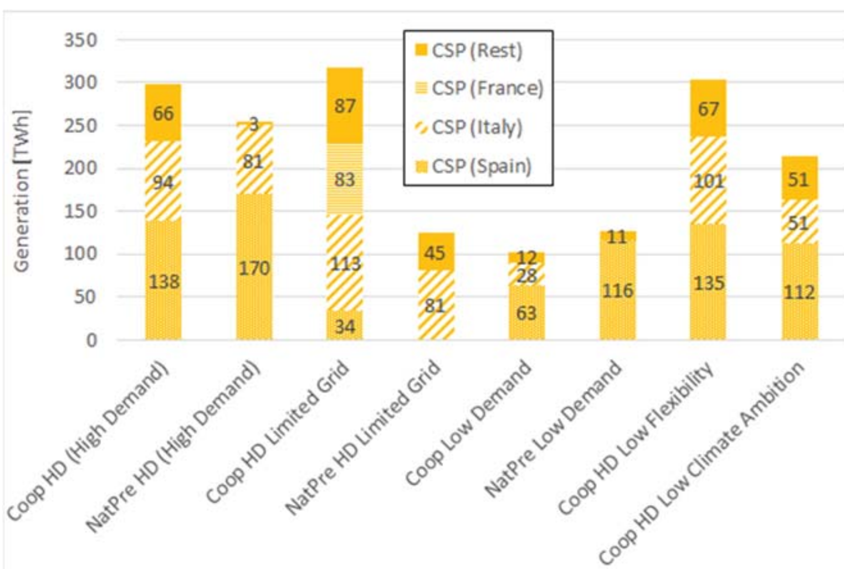


FIGURE 2. Electricity generation from CSP in the EU28 in 2050 for the different scenarios calculated for this analysis.

Figure 2 compares the generation of CSP in the considered scenarios and sensitivities. The two main scenarios, "Cooperation" (Coop) and "National Preferences" (NatPre) assuming high demand growth, have a CSP generation of 300 TWh respectively 250 TWh. Here, the generation of CSP in Spain is highest with 138 TWh respectively 170 TWh. As discussed previously, the scenarios with low demand and the "National Preferences" scenario with a limited grid show the highest deviation for the generated CSP electricity.

Strong Investments into CSP and Other RES Technologies Are Needed in Forthcoming Years

Strong investments in RES technologies are necessary for making the transition towards carbon neutrality in the EU's electricity sector, average yearly investments range for the key scenarios analysed from €91 billion ("National Preferences") to €100 billion ("Cooperation"), reflecting the differences in RES ambition. Investments are slightly higher (€96 to 106 billion per year) in case of grid limitations, and lower in magnitude if demand grow less than expected (64 to 72 billion €).

For CSP in general similar observations can be drawn: Among the scenarios that follow a policy pathway of "Cooperation" average yearly investments in CSP range from €8.0-8.8 billion when a high demand growth is expected, and to only €2.5 billion in the case of low demand growth. The corresponding figures for the "National Preferences" scenarios are €6.4 billion for the default case of high demand growth and €2.8 billion for the low demand growth scenario. Compared to that total investment volumes that need to be dedicated to renewables in the electricity sector, these figures imply that on average about 7-8% of these are for CSP if a high demand growth will arise and the target of carbon neutrality by 2050 is taken up seriously in energy and climate policy making. Still about 4% of the total yearly RES investments would fall on CSP if sector coupling and in consequence electricity demand will not increase as expected.

Support Is Needed to Facilitate the Strong Uptake Of CSP and Other RES Technologies – But New RES Installations Come at Significantly Lower Cost Thanks to Technological Progress

For modelling the required support for CSP and other RES, a common approach for the RES policy framework dedicated to facilitate the RES uptake is followed: the assumption is taken that (technology-specific) auctions for sliding feed-in premiums are implemented within all EU MSs in future year, following a pay-as-bid principle.

Results indicate that for enabling high shares of CSP in 2050 there is a need for dedicated support in the near- to mid-term future. Average (2021-2050) yearly support expenditures dedicated to CSP in the analysed scenarios range from €0.4 billion (both scenarios of "Low Demand") to €2.0 billion ("Cooperation – High Demand" with or without less (demand-side) flexibility). This corresponds well to the underlying CSP deployment trends, and specific support for CSP (per MWh RES generation) is consequently hardly affected by analysed changes in input parameter like grid limitations, demand flexibility, etc.

The bulk of identified RES-related support expenditures up to 2050 is however dedicated to existing RES, established in the years up to 2020 since they have come at higher cost. Support for new RES (installed post 2020) is expected to strongly decline over time due to technological progress and the projected increasing prices in wholesale electricity markets. A key element for achieving this decline in support for new RES installations, specifically for variable RES like wind and solar PV, is the expansion of the cross-border transmission grid since this facilitates RES integration and the balancing of under- and oversupply across countries in times of high variable RES infeed.

Figure 3 provides a comparison of the resulting average (2021-2050) yearly RES-related support expenditures across assessed scenarios. This graph indicates a comparatively broad spectrum for the average yearly support expenditures, ranging from €10.2-29.2 billion. Expenditures are lowest in scenarios with low demand growth, and highest in the case of imitations in expanding the cross-border transmission grid.

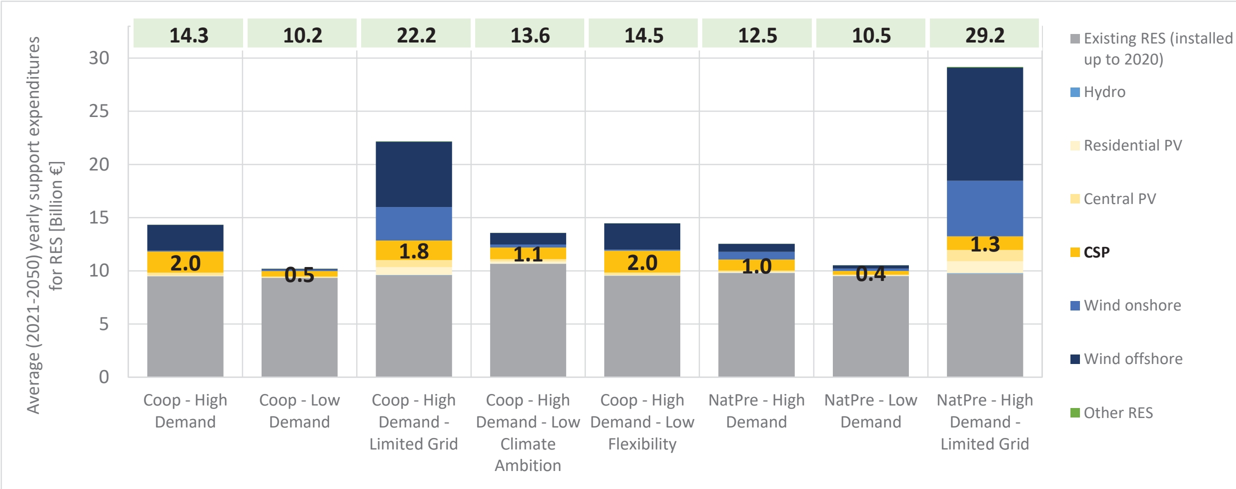


FIGURE 3. Comparison of the resulting average (2021-2050) yearly support expenditures for RES technologies in the electricity sector in the EU28 in different scenarios (Source: Green-X modelling)

There Is a Need for and Positive Impact of RES Cooperation on the Cost for the Uptake of CSP and Other RES Technologies

Figure 4 shows how RES cooperation affects the need for dedicated support at technology level, here referring the EU28 on average. More precisely, this graph indicates the future development of the specific support per MWh RES generation up to 2050 according to two variants of the "Cooperation – High Demand" scenario, i.e. the default case assuming RES cooperation and the sensitivity case assuming no RES cooperation and, in consequence, the influence of a (in some countries) "High Country Risk". For CSP a strong impact of RES cooperation is getting apparent: In the absence of RES cooperation support when a "High Country Risk" is prevailing in many of the southern European host countries of expected future CSP developments a significantly higher specific support is required.

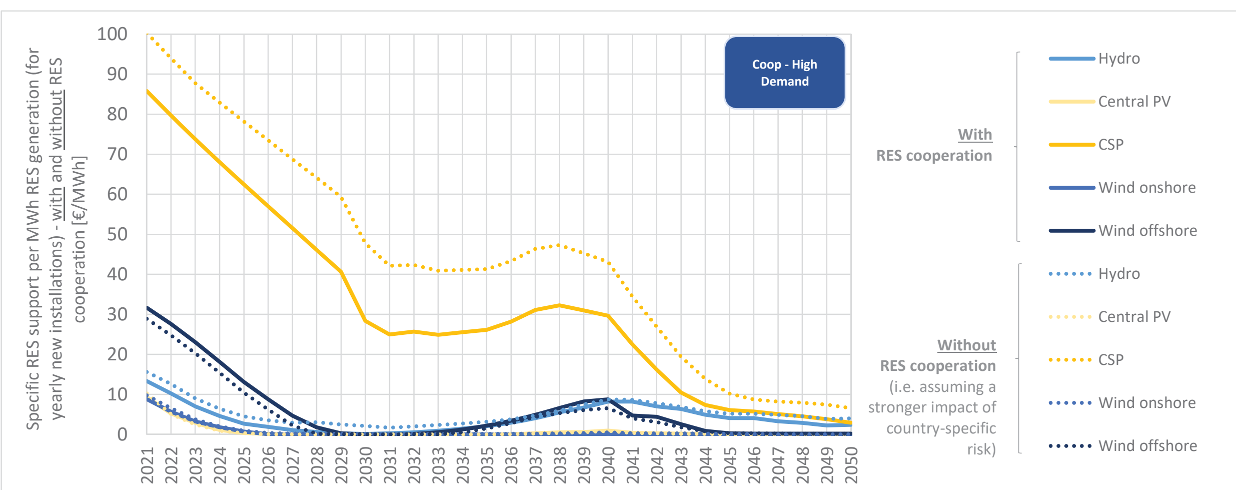


FIGURE 4. Development of the specific support per MWh RES generation up to 2050 on average at EU28 level according to selected assessed scenarios ("Cooperation – High Demand", with and without RES cooperation ("High Country Risk")) (Source: Green-X modelling)

At the aggregated EU28 level for total RES one can also identify a clearly positive impact of RES cooperation, specifically of the levelling of country risk in financing, on RES-related support expenditures. More precisely, in the absence of levelling country risk in project financing across the EU support cost would increase 5-11 % at the aggregated EU level according to the scenarios assessed. This indicates that strong differences in financing conditions across EU countries as we still see them today are less preferential for the decarbonization of the EU's electricity sector.

CONCLUSIONS AND POLICY RECOMMENDATIONS

Key findings from the power system and the corresponding energy policy analysis are that dispatchable RES technologies like CSP will play an important role within the European 2050 power system, driven by the aim for climate neutrality within the power sector in particular, the energy sector in general as well as of the whole economy. The dispatchability of CSP helps to balance the fluctuating generation patterns of wind and PV, serving to provide a balance between supply and demand as required in a power system of today and in future. Key enabler for a strong uptake of CSP in Europe are the expected strong growth in electricity consumption, driven by sector-coupling (e-mobility, e-heating & cooling, e-industry), and higher climate ambitions which limit the availability of other low but not zero carbon flexibility options like fossil-based CCS. The role of grid interconnections is ambiguous: it is an enabler of CSP uptake but also mitigates the need for dispatchable supply as it also smooths fluctuating feed-in.

Moreover, we can clearly conclude that there is a need for and positive impact of RES cooperation on the cost for the uptake of CSP and other RES technologies. A (more) fair effort sharing can then be triggered by RES cooperation and the accompanying redistribution of support expenditures across countries, so that host countries do no longer have to pay the whole bill for the uptake of CSP and other comparatively costly RES technologies which are relevant for the achievement of decarbonization aims and for supply security. That can be seen as crucial for countries like Cyprus, Portugal and Greece – all acting in the exemplified scenario as CSP hosts – but also for countries like Latvia and Estonia, acting as host for the wind uptake in the North of Europe.

Strong investments in CSP and other RES are needed in forthcoming years as well as dedicated financial support. At EU28 level CSP accounts here for investments that range from € 2.5-8.8 billion on average per year in the period up to 2050, corresponding to 7-8% of all RES-related investments, and dedicated financial support in range of € 0.4-2.0 billion per year under default assumptions on demand growth and climate ambition. given the technology meets its cost reduction goals.

A key necessity for the strong uptake of CSP in Europe (but also globally) is that the technology meets its cost reductions goals, which, in turn, requires substantial investments in the technology by now and in the near future. Whether we will see CSP as part of the EU's future electricity system will mainly depend on the price signals this technology receives from the market and the underlying political will. These price signals could take the form of targeted support, e.g. in the form of RES auctions. One of the most important features of auctions to facilitate CSP market uptake is that they value dispatchability of electricity generation (cf. e.g. [16]). This can be achieved by requiring firm power with a specified generation profile which is complementary to fluctuating RES generation which will be mainly characterized by PV in places with rich solar resources. Other possibilities for CSP to receive the right market signals are higher remuneration levels at times of higher demand or a required minimum storage time for RES.

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