Oxy-fuel combustion: A threat or an opportunity for solar

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***Abstract* — The rapid growth of solar, as well as other variable renewable energies, is key for achieving decarbonization targets. However, their integration to the grid and increased curtailment have become a major challenge for their further development in the most successful markets. In this study, the impacts of introducing an oxy-fuel combustion resource in California's energy grid are evaluated. To do so, we use RESOLVE, a capacity expansion model, to predict the energy grid mix for 2030, 2035, 2040, and 2045. Our results indicate that the model chooses to build the oxy-combustion resource when it is available at relatively low costs. While the introduction of oxy-fuel combustion, even at limited scale, reduces the selected operational capacity of solar PV and Lithium-ion batteries, it substantially reduces the curtailment of the solar that *is* installed. Far from being a threat, this reduction could be an opportunity for solar to continue with robust growth, retaining its economic and environmental value even when the procurement of storage might otherwise limit its adoption rate.**

I. Introduction

California has set ambitious targets for decarbonizing its electricity sector as part of its efforts to combat climate change. The state's Senate Bill 100 (SB100) sets targets of 60% of electricity generation with renewable energy by 2030, and 100% carbon-free retail electricity sales by 2045.

There's no doubt that Variable Renewable Energies (VREs), such as solar PV and wind, will play a key role in this decarbonization pathway. However, as the share of VREs increases, their variability and low marginal costs represent a big challenge for a low-carbon electricity sector [1]-[2].

The reduction of the renewable electricity value represents a risk for project economics, potentially leading to investors not being able to recover their costs on the market alone [2] and limiting the additional expansion of solar or wind [1]. Moreover, due to the difficulties of stopping and restarting fossil fuels units in short periods of time, the increased curtailment of renewables also reduces their environmental benefits.

On the other hand, Carbon Capture and Storage (CCS) technologies have been considered to have an important role for reaching net-zero emissions targets globally [3]-[4]. Nevertheless, the role of CCS in California's decarbonization is yet to be defined.

In this study, a particular CCS technology, oxy-fuel combustion, is introduced in a capacity expansion model for predicting 2030, 2035, 2040 and 2045 grid mix in California and evaluating the potential benefits of this technology for solar PV growth.

II. Methods

A. RESOLVE

For modeling California's grid in 2030, 2035, 2040 and 2045, RESOLVE, a capacity expansion model is used. The model is formulated as a linear optimization problem that co-optimizes investment and dispatch for a selected set of days over a multi-year horizon to identify least-cost portfolios for meeting decarbonization targets and other system goals [5]. Fig. 1 shows a diagram with the main inputs and outputs of the model.

The inputs are described in the PSP scenario [6]. For this analysis, the 38MMT Core Portfolio is considered [6].

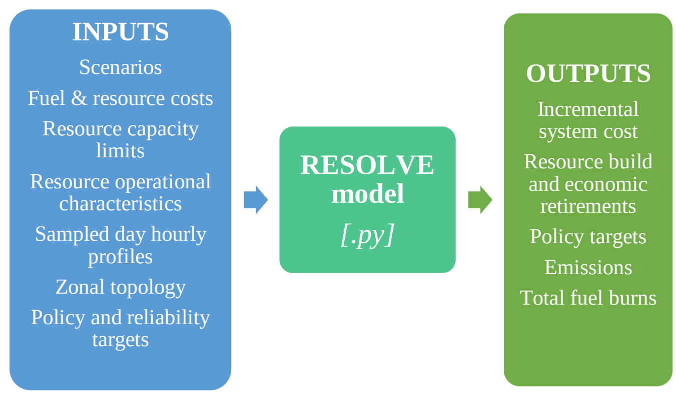

Fig. 1. Schematic of RESOLVE Modeling Components.

B. Oxy-fuel Combustion Resource Modelling

Oxy-fuel combustion or oxy-combustion involves the combustion of a fuel using nearly pure oxygen; hence the flue gas is composed almost exclusively of CO_2 and water vapor [3]. This process has two main benefits:

•NO_X production is greatly reduced, due to the removal of N_2 from the air,

•H_2O can be removed easily by means of dehydration to obtain a high-purity CO_2 stream which presents an opportunity to simplify carbon dioxide capture in power plant applications.

In general, the inclusion of an air separation unit, CO_2 purification and compression stages increase capital cost and energy use, depending on the purity of the input gases [7]-[8]. However, the Allam Cycle represents a cost-competitive alternative for oxy-combustion. In this process, a high-pressure supercritical CO_2 working fluid is used in a highly recuperated cycle that captures all emissions by design. Apart from producing power, the by-products are liquid water and a stream of high-purity, pipeline-ready CO_2 [9]. The cycle can utilize a variety of carbon-based fuels, including natural gas and gasified solid fuels such as biomass and municipal solid waste. This design would allow a cost competitive oxy-combustion process compared to existing thermal electricity generation technologies, with high efficiency and no greenhouse gas emissions [9]-[10]-[11].

The Allam Cycle powered by natural gas is a licensed process by a private company. The company had a technology validation in a testing facility in Texas and announced the first utility-scale project of 300 MWe planned to be operational in 2026, also in Texas [10]. For evaluating the impact of this technology in California, an estimated projection of the maximum operational capacity was defined (Table I).

TABLE I
MAXIMUM OPERATIONAL CAPACITY (GW) PER YEAR FOR OXY-COMBUSTION IN CALIFORNIA.

Year	Maximum Operational Capacity (GW)
2030	0.5
2035	1
2040	2
2045	4

Also, a cost sensitivity analysis was performed, considering a cost range from 1 to 2.5 times the cost of existing advanced Combined Cycle Gas Turbines (CCGT).

III. RESULTS AND DISCUSSION

The operational capacity for California's grid in 2030, 2035, 2040 and 2045 has been modelled using RESOLVE.

For the Baseline scenario, no oxy-combustion resource is available. These results were compared to the case of having oxy-combustion available at different capital costs.

In Fig. 2, the operational capacity of oxy-fuel combustion, for the analyzed years, is shown. For the lowest cost scenario, the maximum operational capacity is reached for all the years, as established on Table I. However, as the cost increases, the operational capacity is reduced getting to zero when the cost is more than 2 times the capital cost of existing CCGT facilities.

Of all the different electricity generation and storage resources, such as wind, geothermal, biomass, pumped-hydro and others, only solar PV and 4-hour Lithium-ion batteries are affected by adoption of the oxy-combustion resource. In Fig. 3 and 4, the operational capacities of these resources, for the different years and cost scenarios are shown.

The oxy-fuel combustion resource, even with limited capacity, reduces the need of 4-hour Lithium-ion batteries as well as solar PV. The major differences are seen for the low-cost scenarios, 100% and 150% of CCGT cost. For example, in 2045, 4 GW of oxy-combustion reduces the need of solar PV by 19 GW and of Lithium batteries by 14 GW. These reductions represent 12% of the overall capacity for both resources, compared to the baseline.

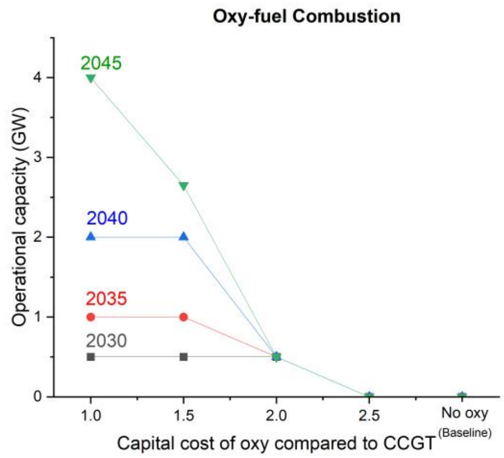

Fig. 2. Oxy-combustion operational capacity for 2030, 2035, 2040 and 2045 as a function of its capital cost.

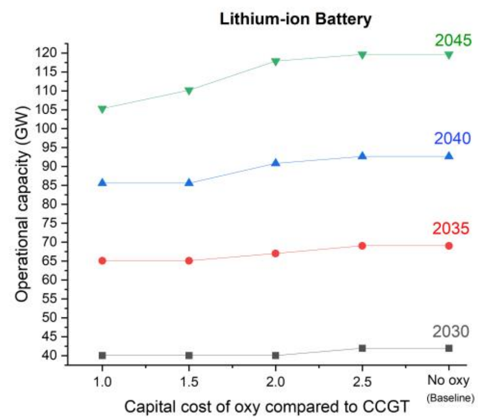

Fig. 3. Lithium-ion batteries operational capacity for 2030, 2035, 2040 and 2045 as a function of oxy-combustion capital cost.

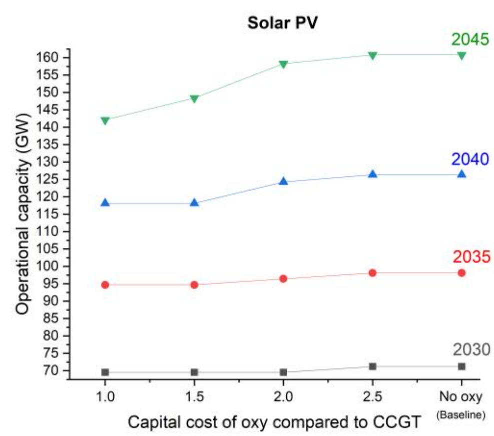

Fig. 4. Solar PV operational capacity for 2030, 2035, 2040 and 2045 as a function of oxy-combustion capital cost.

Looking at the hourly dispatch of the oxy-fuel combustion resource in 2045, for the lowest cost scenario (or maximum operational capacity), it can be seen the complement between this resource and solar (Fig. 5). During winter, for most of the hours of the day, the oxy-combustion resource is at maximum capacity. Moreover, during the summer the resource is OFF or at low capacities, even during night-time. It is also clearly seen that for the intermediate seasons, fall and spring, oxy-combustion complements solar and storage, being ON only from 5PM to 5AM.

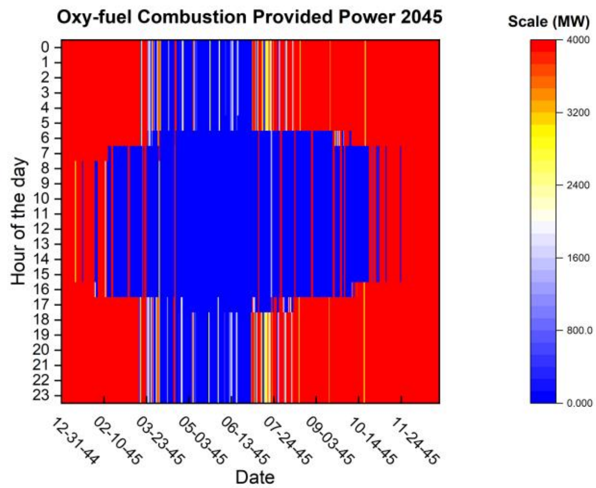

Fig. 5. Hourly dispatch of oxy-fuel combustion resource for 2045.

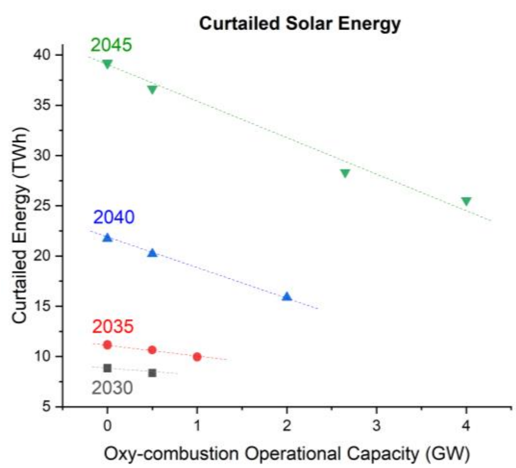

Fig. 6. Curtailed solar energy as a function of oxy-combustion operational capacity for 2030, 2035, 2040 and 2045.

As winter is the most challenging season in terms of renewable generation supply in California [11], having a fixed generation resource reduces the need of additional solar and batteries for supplying the demand. Reducing these resources helps to decrease the negative economic impact of overproduction during summer, in some cases leading to curtailment (Fig. 6). For 2045, 4 GW of oxy-combustion could reduce solar energy curtailment by 35%.

IV. Conclusions

In this study, the impact of oxy-fuel combustion on California's future grid was evaluated.

Even though there is high uncertainty regarding its ability to scale up in the state and in the speed of cost reduction in the short-term, the results indicated that even limited amounts of this technology will have an impact on solar PV and storage operational capacities.

Even with these reductions, the opportunity for solar growth is huge. However, bigger challenges need to be addressed to maintain the renewable electricity value as share of VRE increases.

Oxy-fuel combustion reduces solar energy curtailment, which helps retain the economic and environmental benefits of solar electricity generation. Moreover, reducing the need in the short-term for batteries and solar, helps to ease the current pressure on the supply chain for raw materials allowing for a more sustainable development. Effectively, assuming that the oxy-combustion can be dispatchable to complement solar, it reduces the need for storage, providing an excellent complement to solar.

In conclusion, oxy-fuel combustion technology is not considered today in a position to grow at levels that could threaten solar development. In fact, the complement with solar electricity generation could be considered an opportunity for addressing the additional challenges of increased solar penetration.

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