The market value of increased solar power production in winter

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Overview

Global and regional climate commitments such as the Paris agreement call for a decarbonization of the energy system by 2050. The electricity sector will play a leading role in these decarboniation efforts. First through the expansion of renewable generation capacities within the electricity sector and second through the electrification of other sectors. Solar PV generation is expexted to be one of the major drivers of the global expansion of renewable capacities in the comming decades (IAE 2020). This is the case because investment costs for solar PV panels have been falling rapidly and are expected to decrease further (Xiao et al. 2021). In fact, solar power is now cheaper than coal and gas in most major countries (IAE 2020).

However, at high levels of solar penetration, there is a mismatch between electricity demand and production, within the day and between seasons. Within days, solar generation is highest during the middle of the day, whereas demand peaks are often observed in the afternoon. Such daily variations can easily be addressed by short-term storage options such as battery storage.Seasonal mismatches between high demand in the colder and darker winter months[1]. and high solar generation in summer would require seasonal storage options, grid expansions or additional wind power capacity to increase production during winter months when wind speeds are higher. However, the technical potential for seasonal storage or wind energy might be low or the social acceptability of extending grid or generation capacities might be a problem in some countries. Kahl et al. (2018) have suggested a different approach. They put forward the idea of placing solar PV in locations that have a different seasonal profile with a much higher level of winter production.

Kahl et al. (2018) show that PV panels placed at higher elevations can take advantage of higher winter irradiance, ground-reflected radiation from snow, and greater tilt angles to improve winter yield, all resulting in more electricity generation during the peak winter demand season in Switzerland. At these optimal placements and geometries, more winter demand can be met, thus reducing dependence on imports and nuclear power. These results are exciting for mid-latitude regions; but, it remains to be seen whether there is an economic case for such placements.

In this study, we now want to assess the market value of such innovative solar placements and geometries. To this end, we take Switzerland as a case study.

Methods

To calculate the market value of PV placement strategies, we couple two models: OREES (Optimized Renewable Energy by Evolution Strategy), the optimization scheme for PV deployment described in (Dujardin et al. 2021) using at its core the DC power flow model from (Bartlett et al. 2018); and Swissmod (Abrell et al. 2019), an economic dispatch model of the Swiss electricity market taking into account interactions with neighbouring countries and within Europe. We couple the models to leverage the strengths of each and iterate one with the other until the prices and placements converge to an equilibrium (Fig. 1).

We organize our analysis by comparing two main optimization scenarios: restricted placement and mountain placement optimizing for winter production. Both scenarios begin with the same initial conditions (step 1 in Fig.1): time series of observed market prices. Those time series are fed into the objective function of OREES that explores the feasible space of PV locations in Switzerland and identifies the placements that generates the most revenue while complying with the grid infrastructure (step 2),. This optimization is either including or excluding mountain locations, to create the two scenarios. For each scenario, when the optimal PV placements are found, the corresponding power generation time series are used by Swissmod to compute resulting electricity prices as well as other market related indicators while considering the European market framework (step 3). The new market prices are then used by OREES to optimize the PV placements. We repeat this process until the models converge: The PV placement and corresponding revenues reach an equilibrium and do not change anymore between iterations. We run the process with the electricity system expected for 2025, with the load profiles and weather conditions of the years 2013 to 2015. We also use 2 different CO2 price scenarios for sensitivity analysis (not shown in results of abstract).

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[1] This is the case for example in mid-latitude countries such as Germany, France or Switzerland. However, countries such as Italy or Spain have their peak in Summer due to increased cooling demand.

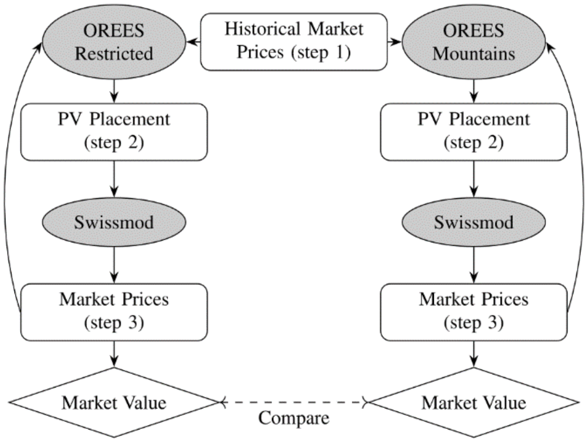

Figure 1: Model iteration process

Results

Table 1 shows the market value results after model convergence for all three years. In comparison to a Business as usual scenario (BAU) with traditional solar panel placements, a small increase can be observed for an optimised placement that excludes mountain areas. This increase in market value is even more pronounced for the mountain scenario. Due to a better alignment of solar power generation with daily and seasonal demand patterns, the market value of energy produced by solar PV panels increases by between 2 and 5 % in comparison to the business as usual scenario when allowing for alpine placements. The observed increases of 15 to 26**%** in market value of panel capacity comes from a higher yield of the panels located in alpine areas. Accordingly, the generation of the targeted 25 TWh in 2015 requires 120.21 km^2 of PV panel area (considering an efficiency of 15 **%**) or 18.03 GW$_{peak}$ under the BAU scenario and 103.83 km^2 or 15.57 GW$_{peak}$ under the Mountain scenario.

Table 1: Market value of energy and capacit for solar PV panels and changes in comparison to Business as usual scenario

Year	*Placement scenario*	*Market value of energy [EUR/MWh]*	*Market value of panel capacity [EUR/kW/yr]*	*Change in market value of energy compared to BAU [%]*	*Change in market value of panel capacity compared to BAU [%]*
2015	BAU	43.55	60.37		
	No-Mountain	44.08	64.43	1%	7%
	Mountain	44.87	72.03	3%	19%
2014	BAU	43.01	56.01		
	No-Mountain	43.14	58.63	0%	5%
	Mountain	43.93	64.25	2%	15%
2013	BAU	44.63	56.41		
	No-Mountain	45.46	60.3	2%	6%
	Mountain	46.91	70.85	5%	26%

Average monthly electricity prices in Switzerland also change substantially. Winter prices are decreased in the mountain placement scenario compared to BAU and the no-mountain scenario. This reflects the change in the generation pattern induced by mountainous placement, with higher winter production and lower summer production. This corresponds to a better fit to demand and thereby a production pattern that produces more at times when electricity is relatively more scarce. With more production at these moments, and thus a relaxation of the winter scarcity of the overall system, the price drops in these hours. The magnitude of the price changes is surprisingly large, given that Switzerland is embedded in the European electricity system (and thereby also its electricity prices are heavily dominated by European patterns) and accounts for only a small share of central European production.

Conclusions

Our study analyses the market value of innovative solar panel placement in mountain areas to better align demand and supply in mid-latitude countries. Even though we have not considered the added installation cost of such panel placement, our estimates of their revenues give an approximation of the range of added costs for which such placements would be profitable.

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