Application of portfolio theory to the wind-solar energy mix in Spain: climate-related risks and opportunities

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Non-hydroelectric renewable energy sources (RES) are the fastest growing energy generation technologies in terms of new capacity and their penetration is expected to double in the next 20 years. More than half of this growth is expected to come from wind power. However, given the variable nature of RES production linked to climate variability and the need for a constant supplydemand balance, increasing penetration of renewables raises structural, technological and economical issues. In Spain, the correlation of solar and wind climate potential with the fluctuation of electricity consumption, associated mostly with tourism activity, allows for some ambitious renewable penetration scenarios. This work aims at identifying optimal energy mix scenarios that maximize RES penetration while minimizing distribution risk, using the Markowitz modern portfolio theory as a starting point. We apply the e4clim model to the Spanish electricity system, using reanalysis and electricity data in order to produce scenarios for optimal geographical and technological distribution of RES installed capacity. We conduct a mean-risk analysis and discuss the geographical distribution for the most relevant optimal scenarios. We also provide an interpretation of the optimal RES penetration results in terms of the regional climatic characteristics of Spain. Beyond the large potential of the regional climates of Spain to exploit RES technologies, optimal scenario results reveal interesting regional differences with respect to the current installed capacities, which can be linked to economic and regulatory regional contexts.

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Introduction

Europe is undergoing an energy transition towards a less polluting, more renewable and more efficient energy mix. In this scenario, the inherently intermitent nature of Renewable Energy Sources (RES) presents structural, technological and economical challenges.

Given the importance of RES integration, we explore the climatic energy potential of Spain and propose optimal alternatives to the current installed capacity distribution.

Our main objective is to be able to study the most efficient approaches towards using the whole climatic potential of Spain for energy generation.

The main questions being addressed are:

- How far could the Spanish RES penetration go without assuming higher risks?

- What changes should we make to the spatial distribution of technologies to achieve that?

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Methodology

Data used

Climate data: MERRA-2 reanalysis

Resolution: 0.625º lon, 0.5º lat; hourly

Variables
- Surface air temperature
- Air density at surface
- 10-meter eastward wind
- 10-meter northward wind
- Surface incoming shortwave flux

Electricity data: Red Eléctrica Española (REE)

Resolution: Autonomous Community; monthly
National data; hourly

Variables
- National hourly demand
- Regional yearly and monthly demand
- Regional yearly and monthly generation (PV and wind onshore)
- Regional installed capacity

Model used

We use the *e4clim* model (Tantet et al., 2019). This model allows one to compute a mean-variance analysis, where a bi-objective optimization takes place: the mean of the RES penetration is being maximized while the variance (proxy of risk) is being minimized. This is subject to the constraints that no negative capacity can be installed and total capacity can not exceed current installed capacity.

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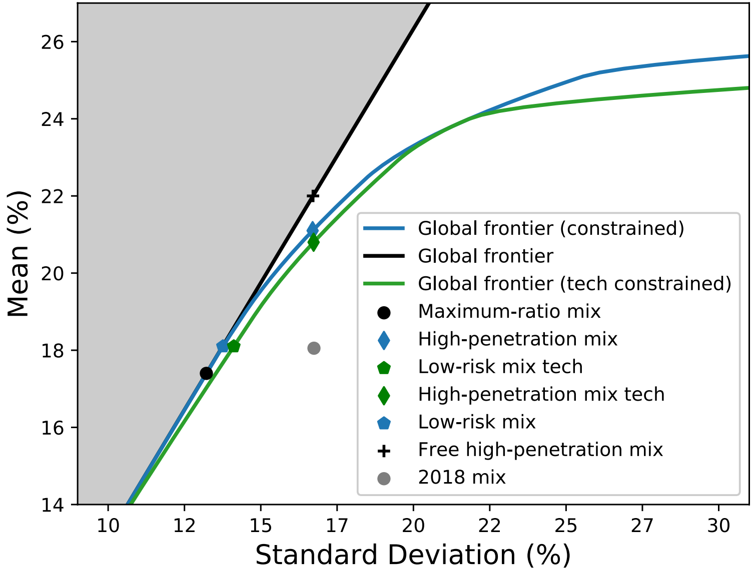
Results: The mean-risk front

The solution to the bi-optimization problem is not a point, but a Pareto frontier (blue line), where all points are optimal. Points to the left of the frontier are unachievable when all constraints are considered and Points to the right of the frontier are suboptimal. All points along the frontier are optimal, therefore an additional criterium can be applied to fulfill external requirements.

Mean-variance analysis resulting front for Spain



- **Black line**: optimal frontier without constraint on the total installed capacity (unconstrained)
- Blue line: optimal frontier with total capacity constrained to current installed capacity (constrained)
- Green line: optimal frontier with constrained capacity for each technology independently (tech-constrained)
- Grey circle: position of current mix
- Diamonds: optimal mixes with current risk
- Pentagons: optimal mixes with current penetration
- **Black cross**: optimal unconstrained total capacity mix with current risk
- **Black circle**: maximum mean-risk ratio optimal scenario

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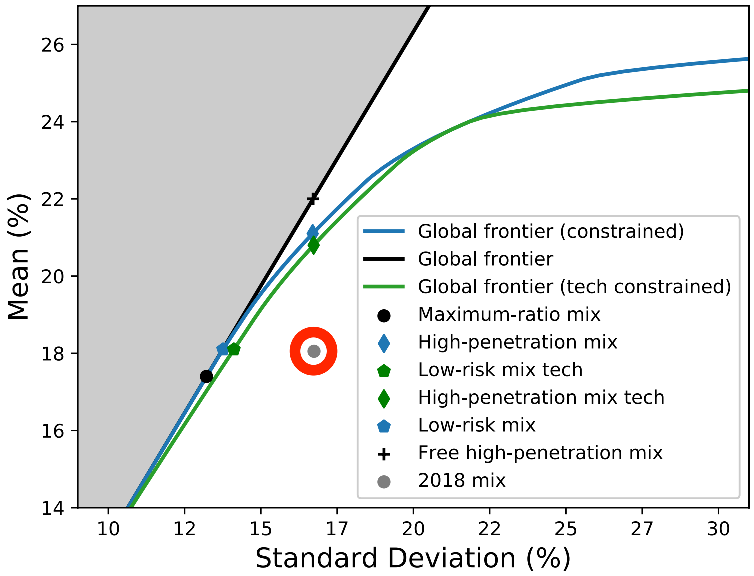
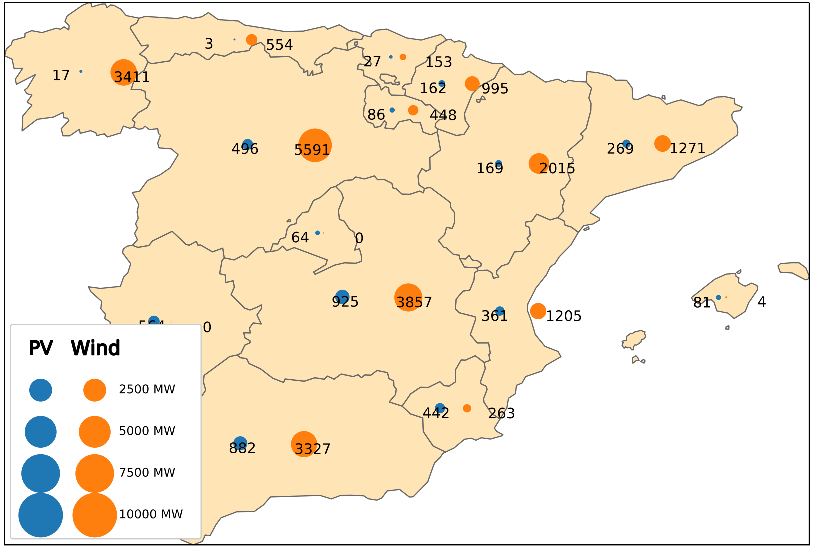
Results: Current mix in the front

The solution to the bi-optimization problem is not a point, but a Pareto frontier (blue line), where all points are optimal. Points to the left of the frontier are unachievable when all constraints are considered and Points to the right of the frontier are suboptimal. All points along the frontier are optimal, therefore an additional criterium can be applied to fulfill external requirements. The current mix is clearly a suboptimal scenario in terms of its penetration and risk



Mean-variance analysis resulting front for Spain



The current (2018) Spanish electricity mix.
Data source: *Red Eléctrica Española*

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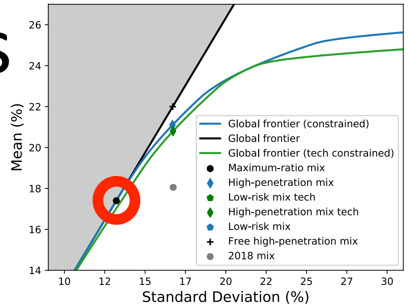
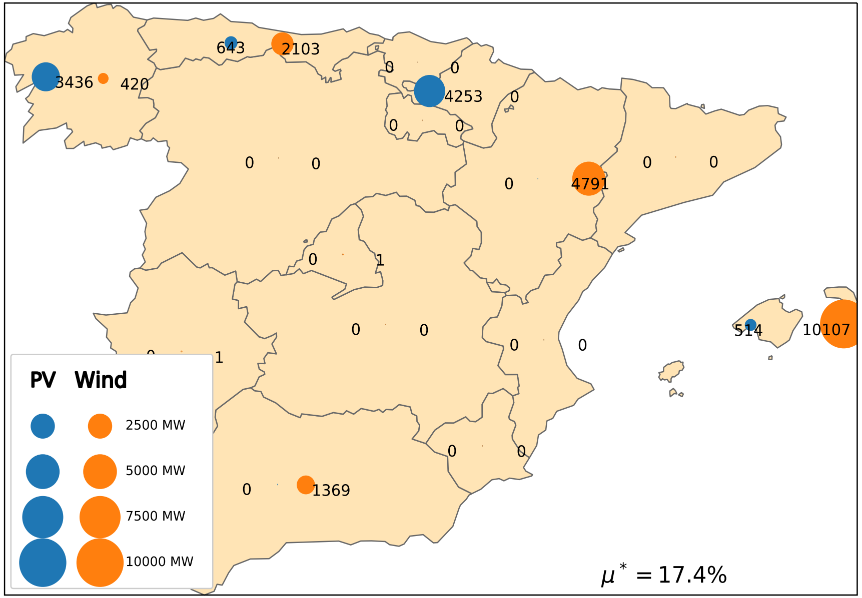
Results: some relevant scenarios

The first analyzed mix is the maximum-ratio mix, which indicates the scenario with higher penetration where the constrained and the unconstrained mixes match.



The location of this mix towards the left of the curve can be interpreted as the priorization of low risk over high penetration scenarios. This mix clearly favors PV installations towards the northern side of the Iberian Peninsula, where the variance of the climatic PV is small. Similarly, a lot of wind energy is located in coastal regions, specially the Balearics, where the maritime effect can be more intense. Besides, Aragon shows a very strong wind installation, being the region with the strongest, although highly variable, wind in part due to the presence of the Pyrenees.



Maximum-ratio mix map

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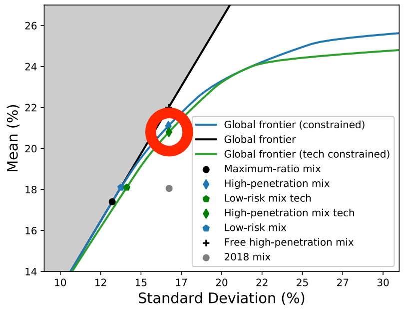
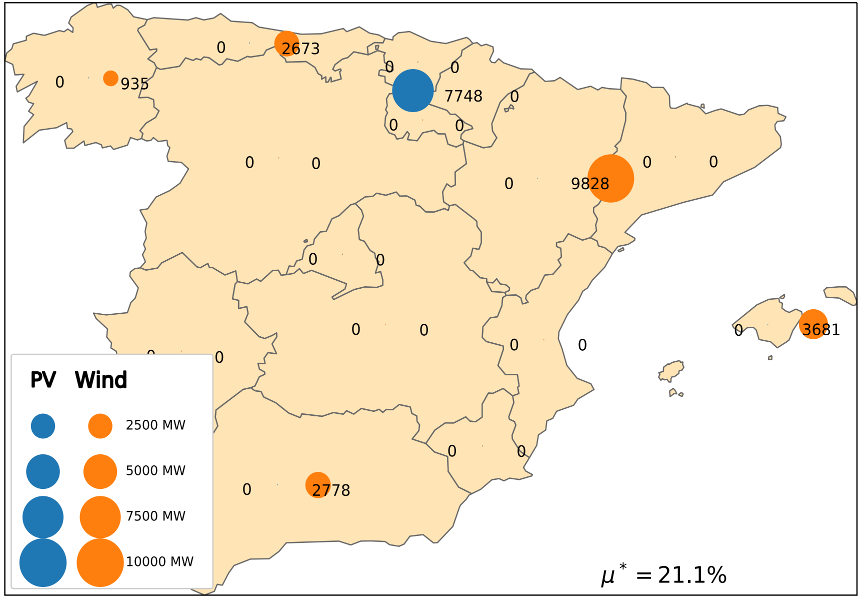
Results: some relevant scenarios



The second analyzed mix is the high-penetration mix. This mix represents the penetration of RES that could have been achieved with the current installed capacity if it had been distributed geographically and technologically in the most optimal way, assuming exactly the same risk as the current mix.



High-penetration mix map

This mix is representative of an optimal state where a high penetration mean is being chased. In this case, the majority of the installed capacity is going towards the wind energy in Aragon and the PV in Navarra. These two regions are favored by the optimization problem because of their high mean/risk ratio. Note that other coastal regions show the presence of wind installation. In the case of the Balearics, Galicia, and Asturias and Cantabria, there is a strong influence of wind from the north, being a strong driver of their wind energy potential.

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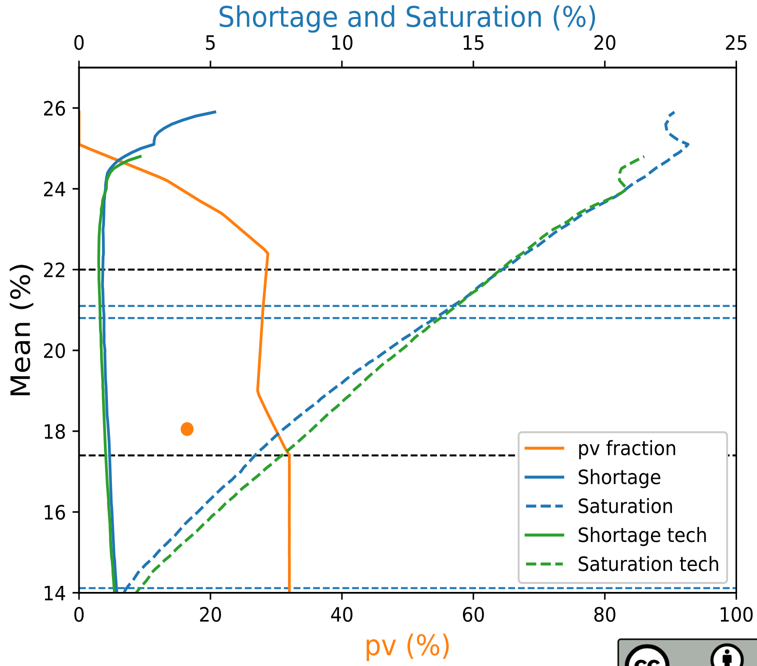
Results: pv-fraction, shortage and saturation

When dealing with a specific energy mix, there are two important factors to consider: the saturation and shortage frequency. Conventional energy sources are assumed to cover up to 80% of the modeled demand maximum and must produce a minimum of 60% of the instantaneous demand. When RES generation can not fulfill these requirements, shortage or saturation occur. Each mix can be identified by a PV fraction, which is the fraction of RES covered by PV.

The represented lines follow the Pareto frontiers represented in the mean-risk plot. The analysis of the PV fraction shows that higher penetrations require a larger investment in wind technology. On the other hand, the shortage frequency becomes lower as the penetration increases, which is expectable, but then experiences a rise at the highest penetrations considered. Similarly, the saturation frequency goes up as the penetration does and shows a drop and rise for the highest possible penetrations. Again, the current PV fraction (orange point) is not optimal, as a higher share would result in more beneficial scenarios.



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Conclusions

- We have proposed the application of the *e4clim* model to Spain and obtain some mixes that benefit Spanish energy system in terms of increasing the penetration and diminishing the risk of RES.

- We have seen how the optimal mixes compare to the current mix and have studied how only reorganization of the already installed capacity could bring multiple benefits to the overall behavior of the RES deployment.

- We have analyzed the specific geographic distribution of the RES installed capacity in two specific scenarios and have seen the regions that are generally more important in this set of optimal scenarios.

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