***Designing renewable electricity auctions: what is the trade-off between direct and indirect costs of electricity generation?***

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## Overview

Auctions have become the main instrument of choice to support renewable electricity around the world. This is probably due to their alleged advantages in terms of cost-efficiency and minimization of support costs. In turn, the integration of variable renewable electricity in electricity markets is an issue of increasing concern, especially in countries with high shares of variable electricity. The optimization of social welfare requires that the total system costs of renewable electricity generation are minimized. These costs are made up of direct costs, which include investment and O&M costs and indirect costs, which include grid costs (congestion and connection costs).

Although some auctions for renewable electricity around the world have included locational signals in their design in order to facilitate such integration, most auctions are still geographically-neutral, i.e., they are mostly focused on the minimization of the direct costs and not the system costs. However, it is possible that those two cost components trade-off with each other regarding their location, i.e., a concentration of renewable electricity projects in locations with very good renewable energy resources will probably minimize direct costs but at the expense of increasing the indirect (grid) costs. Conversely, a high dispersion of renewable electricity installations in the territory will likely bring less saturation to grid nodes, i.e., minimize the grid costs at the expense of higher direct generation costs. This has an undeniable energy policy relevance: if the integration costs are considerable (indirect costs) with respect to the direct costs (in terms of LCOE), then auctions should not be designed in order to minimise the direct costs, but design elements such as geographical adjustments or site-specific auctions should be included in the auction in order to mimimise the total system costs.

The aim of this paper is to identify whether a trade-off between direct and indirect costs exist, the extent of the trade off and its implications for the design of future RES auctions. Although those questions are answered using the Spanish case, and policy implications for the design of auctions are derived based on it, the novel approximation and methods employed in this paper are easily applicable to explore these issues in other electricity systems. This is a timely issue with a considerable policy relevance. Identifying this trade-off is important from a social welfare perspective, since it indicates policy makers which are the best options from a system cost perspective and the cost implications of not following this least cost approach. Our detailed simulations with real grid-costs provide insightful information on how to choose and design policy measures aimed at increasing the deployment of RES. In particular, it contributes to an emerging literature on the design of RES auctions to integrate variable RES (IRENA 2019), i.e. on how to improve the design of RES auctions in order to encourage the location of new RES to minimise the total system costs. Only recently has there been some discussion on how to design renewable electricity auctions which minimize the integration costs of RES (see IRENA 2019), due to the acknowledging that with increasing variable RES penetration the share of intermittent costs increases and the fact that some countries are including these design elements in their design.

While the addition of the direct and indirect costs of generation should be minimized, currently designed geographically-neutral auctions usually encourage that only the projects with the lowest direct generation costs (LCOE) are awarded. This is so unless the design is adapted to include hourly or geographical adjustments. Price-only, geographically-neutral auctions naturally lead to an incentive for bidders to reduce their LCOE since this allows them to be competitive in the auction and have more chances of being awarded. In turn, this leads them to choose the best locations in terms of renewable energy resources, i.e., those places with the best wind or irradiation conditions. Therefore, projects can be expected to concentrate in those locations. However, this concentration of projects would lead to strong pressure on the grid in those places which, in turn, would result in higher grid costs (indirect costs). Therefore, a trade-off between both types of costs can be expected and the following hypothesis is proposed:

Hypothesis 1: There is a trade-off between direct and indirect costs: The higher the concentration level, the lower the direct costs and the higher the indirect costs.

However, the relevant cost chapter from a social point of view is the net effect on system costs, which are the addition of direct and indirect costs. With higher levels of variable renewable energy integration, the indirect costs can be expected to increase substantially, whereas the trend in the generation costs is exactly the opposite, given the reduction in the technology costs of RETs, which have advanced along their learning curve (as shown in IRENA 2019) and have the potential to continue to do so in the future. Thus, a higher concentration level can be expected to increase the system costs, since the increase of the indirect costs would offset the reduction of the direct costs. Therefore, the following hypothesis is put forward:

Hypothesis 2: The higher the concentration level, the higher the system costs.

## Methods

As baseline, we use the actual transmission flows with geographical information from generation plants and main consumption areas to simulate how flows change when new renewables are connected in different locations. We define different *scenarios* corresponding to the location of new RES installations delineated in the Spanish National Energy and Climate Plan (NECP), to calculate both, the direct generation costs and the indirect grid-related costs (including grid-investments and electricity losses). Using the maximum LCOE, all NUTS2 regions for wind and solar are sorted in ascending order, and six scenarios are simulated for regions with similar LCOE. In addition, three different *allocation types* for the deployment of new RES capacity are employed: a) new wind and solar capacity are proportionally allocated considering the regional capacity in 2017, b) new wind and solar capacity are equally allocated regardless the regional capacity in 2017, and c) new wind and solar capacity are allocated until all regions achieve the same density in MW/km2. For the calculation of the grid-related cost we, as baseline for our simulations, we use the actual daily generation mix and electricity flows in transmission between 2015 and 2017. We calculate resultant flows between regions and congestions for the baseline and for the scenarios and allocations types. Comparing flows and the growth in congestions, the grid-congestion and the electricity losses costs are calculated. Then we calculate the total grid-connection costs which are necessary to allocate the future connection points for new RES plants, along with the auction’s costs (proxy by the total cost of RES subsidies in each scenario).

## Results

Our results show that, in fact, there is a trade-off between the direct and indirect costs of generation, which move in opposite direction with a greater concentration or dispersion of the project location. We find that total indirect (grid) costs are the highest when new RES are concentrated only in two regions and decrease when new RES are allocated across all the country. Both grid-congestion and grid-connection costs follow the same pattern. However, not much difference can be observed in the total indirect costs considered in this paper when we move from an scenario in which the new wind and solar capacity is proportionally allocated considering the regional capacity in 2017 to another in which it is equally allocated regardless of the regional capacity in 2017.

Regarding auctions, our results indicate that subsidies costs increase as we move from the more concentrated scenarios to the more scattered ones. A higher geographical dispersion would increase the direct costs (LCOE) and, thus, the support that should be provided by the auction in order to cover those costs and lead to the deployment of RES capacity. The profits are higher when RES is proportionally allocated than with equal allocation (if constant wholesale price are assumed). There is a higher amount of RES installed in the most optimal regions (i.e. the capacity deployed in 2017 would be more efficient in terms of resource use than one stemming from an equal allocation across regions). Our results on RES promotion costs indicates than these are extremely dependent on the changes of the wholesale prices, but the differences between the concentrated and dispersed scenarios are lower (in relative terms) with greater reductions in wholesale prices.

From the above results we conclude that a trade-off between direct costs and indirect costs exist. Regarding the extent of this trade-off, it is relevant to highlight that the total aggregated costs would be reduced when moving from more concentrated to more dispersed scenarios.

## Conclusions

This paper shows that the grid-related costs of RES deployment decrease with a more dispersed location of RES projects, whereas the direct costs and, then, the auction costs, increase. Therefore, a trade-off between those costs exist, with the total aggregated costs being lower in scenarios in which RES plants are more scattered across the territory. Our finding has implications for the design of renewable electricity auctions. A potential option it would be including design elements which change a purely price-only auction to another one which encourages a geographical dispersion of the deployment of projects in the territory seems justified. Among the different alternatives explored we have site-specific auctions, locational signals in merit order, locational signal in remuneration, site-specific volumes, prequalifications, and technology-specific auctions.