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Is renewable energy a cost-effective mitigation resource? An application to the Spanish electricity market

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ABSTRACT

This paper evaluates the net effect of renewable energy policy in Spain from 2002 to 2017 and calculates its cost-effectiveness in terms of CO_2 emission reductions in the production of electricity. Our conclusions indicate that although the phasing out of Feed-in Tariffs reduced the regulatory costs, it also limited renewable participation in the electricity market, leading to an increased electricity price and higher emissions. According to our results, the joint effect of *(i)* the value of avoided emissions due to renewable energy participation and *(ii)* the merit order effect was able to compensate for the regulatory costs (subsidies) up until 2010, while the sign of the net effect was reversed from 2011 to 2017. Finally, we find that the economic implications of emission reductions are highly dependent on how the social cost of carbon is measured.

1. Introduction

The international community recognizes climate change as one of the most important risks for humanity and encourages efforts to limit global temperature rise to 2 °C above pre-industrial levels [1]. Greenhouse gas (GHG, hereafter) emissions have proven to be directly linked to global warming and breaking current emission trends (i.e. mitigation) in the short term is thus key to ensuring temperature stabilization [2]. In this context, the role of the energy sector becomes crucial for the climate change mitigation process. In fact, the source of 65% of worldwide emissions is the use of energy (through fossil fuel combustion) and around 40% of the global electricity supply derives from coal-fired stations, the top air pollutant source in the power sector [3]. Some of the behavioural changes needed to mitigate this problem include measures such as shifting towards lower-emitting fuels, increasing energy efficiency -both in generation and demand-, reducing deforestation and pursuing the carbon capture and storage technologies [4]. Therefore, given their non-emitting and non-depletable nature, Renewable Energy Sources (RES, hereafter) represent an important element in the transition towards a low carbon economy.

In particular, the Electricity from RES (RES-E, hereafter) has been developed in many countries thanks to government support, justified by its positive socioeconomic and environmental impacts, with the cost of subsidies generally transferred to electricity consumers. In this paper, we perform a regulatory impact assessment by analyzing the *net social cost* (or benefit) of Renewable Energy (RE, hereafter) promotion, and considering not only the economic but also the environmental effects of RES-E. To compute the net social cost, we first calculate the net effect of RES-E regulation on the monetary costs for consumers (*net monetary cost*), considering that they pay the market price for electricity and also the incentives to green energy, which are included in the bill. Second, we evaluate the environmental benefit of avoided emissions and add up the result to the monetary cost to obtain the net social cost of RES promotion.

The application to RES in Spain is of special interest, given that Spain is one of the leading countries in RES promotion worldwide; according to the International Energy Agency, the share of solar in total primary energy supply[1] is the highest among the International Energy Agency countries, while the wind share is the third-highest behind Denmark and Portugal [5]. Additionally, the important growth of RES-E in Spain has been supported by a combined system of Feed in Tariffs (FIT, hereafter) and Premiums (FIP, hereafter) from 2008 to 2012 and accompanied by an important increase in the regulatory cost of the electricity system. This FIT-FIP system was phased out in the electricity reform passed in 2013, in an attempt to tackle the growing deficit of the electricity system. For the period prior to the reform, 2008–2012, Ciarreta, Espinosa and Pizarro-Irizar [6] obtained the net monetary costs of RES promotion, but no consideration was given to its environmental benefits. Finally, Spain/the Iberian peninsula is (close to) an energy island (i.e. there are very few interconnections with some

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[1] Total primary energy supply considers: production + imports − exports − international marine bunkers − international aviation bunkers +/− stock changes.

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other countries and, as a consequence, imports/exports are limited), a fact that makes the Spanish case sort of interesting for the proposed research study.

Concerning the environmental effects, RE reduces the use of conventional sources (i.e. coal, oil or natural gas), since it acts as a substitute for fossil technologies in electricity production. This helps to mitigate the GHG emissions produced in the electricity sector, which is responsible for 28% of carbon dioxide (CO_2, hereafter) emissions in Spain, only surpassed by the transport sector with 34% [5]. We assess the economic benefits derived from the substitution of conventional sources by converting those emission reductions into monetary terms. We follow two different approaches to perform this environmental impact assessment: *(i)* a market-based approach, based on the actual price of the EU's Emission Trading System (EU ETS, hereafter); and *(ii)* the Social Cost of Carbon (SCC, hereafter) approach based on the marginal cost of emitting one extra ton of CO_2. If SCC estimates and market emission allowances were perfect signals, both approaches would be equivalent. However, this is not the case and annual average prices for emissions allowances in Europe, for instance, were even below the lowest SCC mean value in 2013.[2] Therefore, since carbon markets are not efficient, a carbon value that takes social costs into account needs to be constructed. In fact, SCC estimates are hotly debated in the literature, and surely will remain so in the foreseeable future (for instance, two polar examples can be found in [9,10]), which makes this research interesting from a policy perspective.

The goal of our paper is twofold. First, we assess the net cost of the RES-E deployment in the Spanish electricity system in a timeframe (2002–2017) that allows us to analyze the market when renewable participation was still low (2002–2007), when renewable greatest expansion took place (2008–2012) and the effect of the phasing out of the incentive system from 2012 onwards. Second, we quantify the environmental impact derived from the displacement of conventional sources of energy by RES-E. The avoided emissions assessment is carried out by comparing market and SCC approaches, including emissions from both CO_2 and other air pollutants (nitrous oxide-NO_x, sulfur dioxide-SO_2 and particulate matter-PM).[3] The results are relevant to the debate over the financial burden of the RES-E implementation and the discussion about the instruments and mechanisms for climate change mitigation at the lowest cost.

The rest of the paper is structured as follows. Section 2 reviews previous literature regarding the effect of RES-E deployment and carbon prices. Section 3 then describes the data and the methods applied, and Section 4 discusses the main results. Finally, Section 5 presents the conclusions and policy implications.

2. Beyond the merit order effect

The presence of RES-E in power markets affects the two components of the market price in different ways: *(i)* the regulated component, which increases prices due to the payment of the FITs by the electricity consumers; and *(ii)* the market component, which modifies prices due to the presence of the RES-E in the energy mix. This latter effect is known as the merit order effect (MOE) and the combination of these two opposite forces determines the net effect of RES-E on consumer prices.

The MOE is one of the most studied phenomena regarding the deployment of RES-E. From a theoretical standpoint, Jensen and Skytte [12,13] were among the first to point out that the integration of RES-E into the generation mix reduces the electricity market price. This is due to several reasons. First, before the reform in 2014 Spanish regulation made it compulsory for RES-E to bid at zero prices. RES-E obtained their revenue from FIT irrespective of the market price and therefore their bid did not affect profits so that bidding zero was compatible with their incentives. Second, after the reform bidding at zero is not compulsory, but RES-E bids reflect their lower variable costs compared to conventional fuel electricity sources; since RES-E uses inputs that cannot be accumulated (e.g. wind or sun), the opportunity cost for non-dispatchable energy sources is zero. Consequently, RES-E producers, unlike conventional fuel generators, would have the incentive to sell the electricity generated at very low prices, displacing conventional fuel electricity sources and reducing the market electricity price [14].

Additionally, when the MOE is computed as the difference between actual electricity prices and counterfactual prices in absence of RES-E (ceteris paribus), it also controls for other factors that could be affecting prices, such as demand changes, supply changes, fossil fuel price changes and carbon price changes. It could be argued that without incentives to renewable energy, investors would have launched other projects in different technologies. However, this is unlikely for Spain, given that the electricity market exhibits high reserve margins even excluding renewable sources [6]. Another criticism to this methodology could be that other technologies' supply curves could be affected in the long run by RES-E presence (given the intermittency of some sources). Ciarreta, Espinosa and Pizarro-Irizar [15] explored the shape of Spanish supply curves before and after the introduction of renewable sources and concluded that only combined cycle plants (11% of the electricity mix in 2015) experienced a change in the slope of their supply curves as a consequence of RES-E.

The MOE has been widely analyzed in the empirical literature for energy policy analysis. Sensfuß, Ragwitz, and Genoese [16] and Sáenz de Miera, del Río González, and Vizcaíno [17] were among the first authors conducting empirical analysis on this effect for Germany and Spain, respectively. Similarly, other authors have also focused on this approach: Weight [18] and Cludius et al. [19] for Germany; Munksgaard and Morthorst [20] for Denmark; Forrest and MacGill [21] and Cutler et al. [22] for Australia; and, Gelabert et al. [23], Gil et al. [24], Azofra et al. [25] and Ciarreta et al. [6] for Spain, among others.

However, when assessing the economic impact of RES-E, other environmental implications should also be taken into account. In this regard, the emission reduction due to RES-E has already been quantified in the empirical literature. For Europe,[4] van den Bergh et al. [26] showed that total annual CO_2 displacement due to RES-E deployment was over 100 $MtCO_2$/year for the period 2007–2010. According to Rathmann [27], Germany was able to reduce CO_2 emissions by 25.7 $MtCO_2$/year from 2000–2002 to 2005–2007 due to the public support devoted to RES-E. For Spain, Ortega et al. [28] calculated that the total avoided emissions for Spain during 2002–2011 ranged between 122.5 and 168.3 $MtCO_2$, peaking at 27.9 $MtCO_2$/year in 2011.

There are two main approaches to translate this RES abatement potential into economic terms. First, if emission allowance markets were efficient, actual market prices should provide the marginal cost/benefit of reducing emissions. However, actual market prices may not reflect the marginal costs and benefits of reducing emissions and usually they are highly volatile. Second, the approaches based on the SCC predict the potential future damage caused by emissions, although they involve a large uncertainty in the estimates.

Using historical carbon prices, and looking at renewable incentives only as a policy to abate CO_2 emissions, Marcantonini and Ellerman [29] found that German support for wind energy induced reductions of CO_2 emissions at a carbon price higher but of the same order of magnitude than the historically observed EU ETS price, but incentives to solar power led to abatement costs above EUR500/tCO_2. The literature

[2] Annual average prices in the European Emission Trading system in 2013 were 4.45 EUR/tCO_2 [7] and the mean SCC estimate in the studies analyzed by [8] is 49 EUR/tCO_2. The lowest mean SCC estimate (considering a 3% rate of time preference) is 5 EUR/tCO_2.

[3] Environmental externalities of renewable energy production can be divided into two categories that distinguish emissions of pollutants with global impacts (i.e. GHG) from those with local and/or regional impacts (i.e. pollutants other than GHG) [11].

[4] More precisely, they included 12 EU Member States plus Switzerland.