The Cost of Abating CO2 Emissions by Renewable Energy Incentives in Germany

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(1) Overview

Incentives for the development of renewable energy (RE) have increasingly become an instrument of climate policy, that is, as a means to reduce GHG emissions.[1] This research analyzes the German experience in promoting RE over the past decade to identify the *ex-post* cost of reducing CO2 emissions through the promotion of RE, specifically, wind and solar. To this propose, we calculated the *annual CO2 abatement cost* for the years 2006-2010 as the ratio of the net cost over the CO2 emission reductions resulting from the use of RE. The quantity of CO2 abated as a result of injections of wind and solar energy for the years 2006-2010 was estimated by Weigt et al. (2012) using a deterministic unit commitment model of the German electricity system. This paper is devoted to estimate the net costs associated with the development of wind and solar energy. The *net cost* is given by the sum of the *costs* and *cost savings* due to the injection of renewable energy into the electric power system. Other benefits -whether they are expressed as energy security, innovation, jobs, non-CO2 emissions, etc.- are not included, nor are costs associated with transmission and distribution. The costs are: the *remuneration to RE generators* (which depends on the RE incentives), the *additional cycling costs* of conventional thermal generation and the *additional balancing cost* (Pérez-Arriaga and Batlle, 2012). Additional cycling costs and additional balancing cost are due to the intermittency of wind and solar energy. The cost savings are: the *fuel cost saving*, the *carbon cost saving* and the *capacity saving*. Priority access to the grid and near-zero variable costs of RE generation means that when available renewable generation nearly always displaces conventional fossil fuel generation, typically either coal or natural gas. The fuel cost saving is the saving in the cost of the fossil fuel required to generate the electricity thus displaced, and the carbon cost saving is the saving in the cost to acquire the carbon allowances in the EU ETS for the CO2 emissions displaced. Increasing renewable generation means also increasing generation capacity in the system. Even if, because of intermittency, 1MW of nominal wind(solar) capacity it is not equivalent to 1MW of conventional generation, however wind(solar) capacity can substitute an amount of conventional capacity as much as the wind(solar) *capacity credit*, without exposing the system to additional risks. Thus we could reduce part of the conventional capacity: the capacity saving is the saving in the cost of keeping that capacity available.

A number of studies have analyzed the costs and benefits of renewable generation on different electric power systems, (eg., Dale (2004), DENA (2005), Denny (2007)). All of these studies take an ex-ante approach. To our knowledge, this is the first paper to estimate the CO2 abatement cost of RE incentives from an ex-post point of view.

(2) Methods

Remuneration to generators. The relevant law in Germany provides producers of RE a 20-year guaranteed fixed FIT. Since the level of the FIT diminishes in value over time both in nominal and real terms, taking the amount paid for the FIT in a given year would make wind energy appear more expensive in the first years of activities, when the payments are relatively generous, and cheaper in the following years. Consequently, the structure of payments over time requires some equalization to avoid over- and understating cost in the early and later years of the facilities life. We do so in the following way for all capacity installed in a given year. First, we assume a 25-year lifetime for all solar and wind power plants and estimate remuneration for each vintage based on observed wind or solar generation in each year through 2010 assuming equal annual capacity factors for each in-service vintage and based on an assumed capacity factor for the remaining years of activity of that vintage. Then, that stream of payments is discounted at the fixed rate of 7% and summed to get an initial Net Present Value (NPV) of all the remunerations. The *equalized remuneration* for all turbines in a given year consists of the sum of the equalized payments to each vintage of capacity in service that year.

Fuels cost saving and carbon cost saving and additional start-up cost. For the estimation of the fuel cost saving and carbon cost saving we make use of the model of Weigt et al. (2012). The model is a deterministic unit commitment model of the German electricity market for the period 2006-2010. It was developed to estimate the CO2 emission abatement due to RE, which is calculated as the difference in total CO2 emissions in the observable (*OBS*) scenario, which corresponds to the historical scenario, and the counterfactual scenarios wherein no energy would have been produced by the relevant form of RE (eg., *No Wind* or *No Solar*). Likewise the fuel cost saving and carbon cost saving are calculated by taking the values of the fuel costs and carbon cost in the *No Wind* and *No Solar* scenarios and subtracting those in the *OBS* scenario. Regarding cycling costs, the model of Weigt et al (2012) considers only start-up costs, which is the cost of the additional fuel needed to start-up the plant. They are calculated similarly to the fuel cost saving.

Wind capacity saving. We make an estimation of the capacity benefit and additional balancing cost for wind only, based on results from existing literature and on simple and transparent assumptions. Our goal is not so much an accurate

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calculation of these costs and cost savings as it is an estimation of its order of magnitude in comparison with other costs and cost savings. For solar energy, even if we do not calculate the capacity benefit and additional balancing cost nevertheless we are able to show that the magnitudes concerning solar energy are such that the capacity credit and the additional balancing cost have little bearing on the final abatement cost. In order to estimate the capacity benefit we must estimate how much, when and which kind of conventional capacity is displaced because of the additional wind generation. We simply assume that the capacity installed up to 2010 would provide a credit of 7%. We assume that these cost savings from all wind capacity built before 2010 are realized in 2015 and we suppose that the wind capacity credit will substitute 70% of coal and 30% of gas. The wind capacity saving is the economic benefit from the savings in capital cost and fixed O&M cost of the conventional plants displaced by the wind capacity credit.

Additional balancing cost for wind. A number of studies have examined the additional balancing cost due to wind energy. Estimations are in the order of €1-4/MWh of wind energy at wind penetrations of up to 20% (Holttinen, 2008). We consider a value of €2/MWh (Meibom et al., 2006).

(3) Results

Three main results can be drawn. (1) There is a large disparity among different costs and cost savings. Equalized remuneration to generators is by far the largest cost; the additional start-up cost and the balancing cost represent just a few percentage of it. Fuel cost saving is the largest savings while carbon cost saving and the capacity saving are much lower although not irrelevant. (2) There is a large difference between the abatement costs of wind and solar energy. While the average value CO2 abatement costs in the period 2006-1010 for wind is of the order of €44/tCO2 the average abatement costs for solar is €537/tCO2. Under several sensitivity analyses, CO2 abatement costs always remain of the order of few tens €/tCO2 for wind energy, while for solar energy are always above €500/tCO2. Comparing these results with the historical annual average EU ETS carbon price, the CO2 abatement costs of wind tend to be higher than EUA prices but of the same order of magnitude (the price of allowances reached levels of €30/tCO2 in April 2006). On the other hand, abatement costs for solar are always much above any possible realistic prices for the EUA. (3) CO2 abatement cost can change considerably from year to year, particularly for wind where variations by a factor of two can be observed. These changes in net cost mostly reflect changes in annual fuel cost saving and carbon cost saving, which are correlated with variations of fossil fuel prices and the carbon price. The year 2008 is the one with the lowest CO2 abatement cost for wind (€20/tCO2) due to a combination of high fossil fuel prices and, with regard to wind energy, a high annual capacity factor.

(4) Conclusions

Our study suggests that if we look at RE only as a climate instrument, and at renewable incentives only as a policy to abate CO2 emissions, the German support for wind energy has induced a reduction of CO2 emissions at a carbon price generally higher than the historically observed EUA price but on the same order of magnitude. On the contrary, supporting solar energy through deployment incentives has proven to be a very expensive way of reducing CO2 emissions.

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