The Merit Order Effect of Wind Generation on the Irish Electricity Market

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Abstract:

This paper considers the cost savings arising from wind generation through the merit order effect in gross pool electricity markets, using the Irish electricity market as a case study. The Irish electricity market makes for a good testing ground due to the fact that it is a single market with very little interconnection to other markets, allowing impacts of wind to be more clearly identified than on a more interconnected system. Ireland also has extremely ambitious renewable energy targets, resulting in a high penetration of wind generation. The authors estimate the historic cost savings arising from wind generation in the Irish electricity market using an hourly time series OLS regression model for 2009. We find that the value of wind to the market dispatch has resulted in savings of €141 million to the market dispatch. We find that the total costs to the market would have been in the region of 12% higher over the course of the year had no wind output been available. These savings are significantly greater than the subsidy received for wind-generated electricity over this time period, and as a result it can be seen that the positive externalities derived from wind generated electricity outweigh the cost of the subsidy; particularly when one considers the CO_2 saving to the market and accepts that all forms of generation impose integration costs to electricity systems.

Keywords: Electricity Markets; Renewable Energy; Merit Order Effect

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1. Introduction

As energy consumption has risen steadily over the past century, so too have emissions, contributing to climate change. This, alongside dwindling fossil fuel resources has resulted in increasing global interest in renewable generation, which allows for lower carbon emissions from electricity generation and contributes to policy targets such as the Kyoto Protocol (1992), US cap and trade programs such as the Clean Air Act (2008) and the Regional Greenhouse Gas Initiative, and the EU Emissions Trading Scheme (European Commission 2009). A key challenge internationally is the design of future electricity systems which will bring about emissions savings and fuel security at least cost.

Due to the recent crisis in Japan, many nuclear programs have been put on hold, with other nations undergoing re-examination of their nuclear facilities post Fukushima (Schneider, Froggatt et al. 2011). This will have implications for renewable energy resources, as they are consequently considered a viable alternative to conventional generation with zero or lower emissions. Of the renewable technologies currently available for electricity generation, wind is one of the most developed and as a result gaining significant market shares internationally. This has resulted in greater focus on the impact of wind on the electricity system, as until quite recently no system had faced the challenges associated with high penetrations of wind – namely the need for greater flexibility and reserve due to the increase in volatility (NERC 2008; NREL 2011).

The benefits associated with wind generation include a reduction in fossil fuel consumption for electricity generation, environmental benefits, diversity of supply, reduced reliance on international fuel price fluctuations, and the meeting of national and international policy targets. Holttinen et al. (2009) observe that as wind replaces fossil fuels for electricity generation, total operational costs and emissions are reduced. It is noted by Clifford and Clancy (2011) that wind generation acts as a hedge against high fuel costs by depressing the wholesale cost of electricity.

Much of the literature surrounding the increased penetration of renewables focuses on the additional costs associated with renewable generation, and, in the case of wind, increased levels of variability and unpredictability (Troy, Denny et al. 2010) rather than on the associated benefits. Smith et al. (2007) found that integrating high levels of wind can affect both transmission and generation through utility system planning and operations. They found that this is driven primarily through increased load-following and unit commitment costs. Dale et al. (2004) establish that, as the level of wind generation increases in an electricity market, extra balancing costs are incurred in the form of additional reserve and frequency response. They also indicate that as wind farms tend to be located in rural and often remote areas, wind generation tends to have a significant effect on transmission costs. The extra reserve costs are also observed in Denny and O'Malley (2007), as wind is shown to increase uncertainty in the system as it is reasonably unpredictable and non-dispatchable. Holttinen et al. (2009) found that adding wind to an electricity system results in added integration costs, which relate to the extra investment and operational costs associated with the non-wind generating units. Wind generation has also been shown to result in the increased cycling of existing units (Troy, Denny et al. 2010). This relates to start-ups, ramping and operation at part load which is caused by adding more variability to a power system (Denny and O'Malley 2009; Troy, Denny et al. 2010). Milligan et al. (2011) also found that systems with significant levels of variable and uncertain primary energy sources require different operation than electricity systems based exclusively on conventional resources. However, they point out that integration costs to power systems are imposed by all forms of generators – such as gas scheduling restrictions and hydro generators with dissolved gas limitations – yet these costs are not allocated to the generators in question. Denny and O'Malley (2006) demonstrate that while wind can reduce the emissions of an electricity market, it is dependent on the method of system operation.

Costs savings have been examined based on the above benefits, however very little has been done from the price reduction perspective. Various studies to date have shown that increased wind power in the generation mix would lead to reductions in the Spot Market Price (Moesgaard and Morthorst 2008; Sensfuß, Ragwitz et al. 2008; Pöyry 2010), however these have largely involved simulated wind production and prices as opposed to historical data. Results from Moesgaard and Morthorst (2008) illustrate that wind power benefits the consumer through economic as well as environmental benefits, yet that the price reducing effect could be higher than the studies estimate, while Sensfuß et al. (2008) indicate that the cost for renewable support paid by consumers is not as high as is generally expected when the merit order effect is taken into account. The All Island Grid Study (DCENR 2008) found that "at higher proportions of renewable capacity installed, less conventional capacity is required to run and thus the operational cost decreases". In reality, markets will differ from results seen by models assumed in such studies as they are based on the assumption that a well functioning market will optimise costs, and so total cost savings will be different for these compared to market savings which we identify.

This paper aims to consider the historic cost savings arising from wind generation in 2009 in the Irish electricity market. The Irish electricity market makes for a good testing ground due to the fact that it is a single market with very little interconnection to other markets, which would enable it to better manage variability and uncertainty. Ireland also has extremely ambitious renewable energy targets, resulting in a high penetration of wind generation. We use a time series OLS regression model in order to consider the magnitude of the impact of wind on an hourly basis over the course of 2009. This study will not attempt to estimate the costs incurred as a result of wind integration, valuing only the savings to the market, which are often overlooked within the literature. Once the average hourly effect has been calculated, we can estimate the cost of electricity over the course of the year had no wind been available.

Wind generation typically receives a subsidy in order to compensate it for its positive external benefits, which include the reduction in fossil fuel consumption for electricity generation, environmental benefits, supply diversification, reduced susceptibility to international fuel price fluctuations, and the meeting of national and international policy targets. We endeavour to quantify these positive externalities. This will then be compared to the subsidy for wind generated electricity over this time period and the cost of carbon in order to observe whether the financial benefits of wind outweigh the costs and therefore whether the subsidies currently received by wind are justified.

The remainder of this paper is structured as follows; Section 2 outlines the theoretical framework and merit order effect of wind on supply and demand, and Section 3 introduces the Irish electricity market as the case system. Section 4 details the model and data used and the results, discussion and conclusion are presented in Sections 5, and 6 respectively.

2. Theoretical Framework

Electricity is a homogenous good, to which suppliers are indifferent between generators, as there is no product differentiation[2]. The market is capacity constrained; with each generator limited in their supply by the maximum output they are capable of producing. As a result, we can describe the generation of electricity as a Cournot oligopoly model, whereby generators are able to choose their level of supply but not the price which they receive for the electricity that they generate. The price of electricity is therefore determined by market demand; $P = a - bQ$. Generators still have market power, as each firm's output decision affects the price of electricity, and their rival's output level.

In a simple 2 firm example, we assume that demand is fixed and supply is split between the two firms; $Q = q_1 + q_2$. Each firm must take into account its rival's behaviour, and will maximise its own profit level and output given that of its rival, which is considered to be a fixed amount, $q_{1,2} = \bar{q}_{1,2}$. Both firms are assumed in this example to initially have identical costs, $c_1 = c_2$. Supply of electricity is split between both firms equally.

As Firm 1 begins to generate a portion of its electricity portfolio output through wind generation, it can now supply electricity at a lower average marginal cost (MC) (since wind has a MC = 0) than previously. Firm 1 will benefit from this change in costs in two ways; firstly due to the fact that the quantities of electricity produced from competing firms are strategic substitutes, meaning that as wind output increases, rival generators will produces less as demand is held constant, and secondly because the Cournot-Nash outcome of a firm depends on the costs of its rival.

Price in a Cournot oligopoly is determined by market demand, with $p = a - b\bar{q}_2 - b\bar{q}_1$. This shows p to be equal to a constant, a, less each firm's output, $\bar{q}_{1,2}$, by a given value.

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[2] This is not necessarily the case in markets with certain renewables schemes such as ROC in the UK, which is designed to incentivise renewable generation into the electricity generation market by placing an obligation on all UK suppliers of electricity to source an increasing proportion of their electricity from renewable sources OFGEM (2011). "Renewables Obligation." However, for the purposes of the theoretical model, this homogenous assumption is justified.

This means that if Firm 1's costs fall below those of Firm 2 ($c_1 < c_2$), then the reaction function of Firm 1 is determined by $q_1 = \frac{a - c_1 - (c_2 - c_1)}{3b}$. Industry output will remain constant as the shift is taking place between firms only, and demand is in no way affected by this change in supply. Theoretically both firms could continue to increase the proportion of wind in their portfolio up to 100%, which would result in the same proportion of electricity being produced, but at a MC = 0. This however is not feasible in practice as it does not consider the fixed cost element of a generators portfolio.

Wind generation affects the intersection of the merit order (supply curve) with the demand curve; Figure 2 demonstrates that it essentially shifts the demand curve for conventional generation to the left as it can be considered as the demand for electricity less the amount of wind generated, resulting in the demand for conventional supply. Wind can be considered as negative demand due to its zero marginal cost, and the fact that it has priority dispatch – meaning that all electricity produced by wind in Europe must be given priority access to the grid by the transmission system operator (European Commission 2001). This is because once the supply curve is defined and it is compared to demand, the System Marginal Price is set to the bid price of the most expensive plant required to meet demand (CER 2007; Devitt, Diffney et al. 2008; Clifford and Clancy 2011). This is known as the Merit Order Effect (MOE), which arises from the fact that, all else equal, adding wind power to the system should replace higher marginal cost plant on the system, and this in turn is likely to lower wholesale electricity prices (Indecon 2008; Felder 2011).

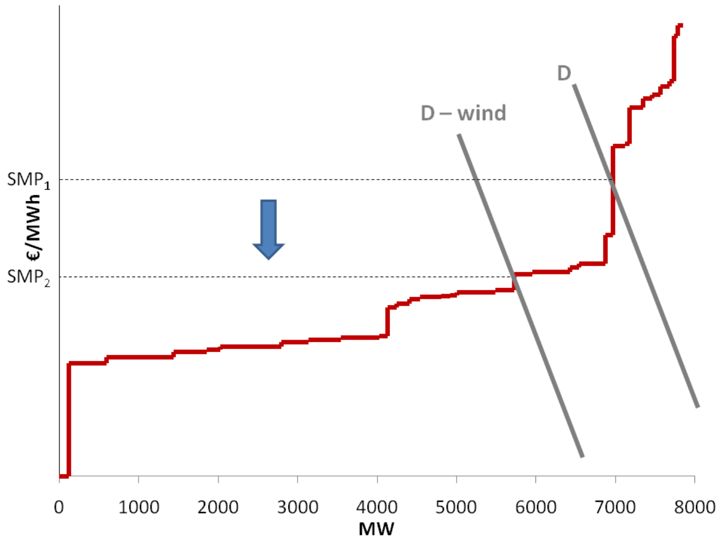

Figure 1 Sample Merit Order Effect

As wind generated electricity comes online, it reduces the amount of conventional generation required to meet demand. Electricity is a homogenous good therefore less expensive generation will be consumed first, and wind has a marginal cost = 0. This shifts the demand for conventional generation to the left, resulting in a fall in the system marginal price from

SMP_1 to SMP_2 shown in Figure 2. Depending on the amount of wind available and the level of demand in a given time period, this price reduction will vary significantly.

3. Irish Electricity System

The Irish gross pool electricity market is an ideal test case for identifying the merit order effect of wind generation, as it is a small, isolated system with little existing interconnection to other systems - at present there is only one interconnector between Great Britain and Northern Ireland which operates at 400MW, with another of 500 MW capacity expected to be online by 2012 (Valeri 2009). Ireland is also highly dependent on fuel imports, in 2007 Ireland imported 88.3% of its energy needs – one of the highest levels of energy imports in the EU, after only Luxembourg (97.5%), Malta (100%) and Cyprus (95.9%) (Eurostat 2011). As a result, Ireland is very susceptible to shocks in energy prices and needs to encourage as diverse a fuel mix as possible in order to protect its security of supply.

In Ireland, wind accounted for 68% of the renewable energy used for electricity generation and over 10% of all electricity generated in 2009, and by June 2011 had reached an installed capacity of 1459MW (SEAI 2009; SEAI 2010; Eirgrid 2011). The substitution of conventional energy sources with renewable energy sources such as wind energy offers considerable potential for reducing a nation's carbon emissions and meeting national and international policy targets (DCENR 2007; European Commission 2009). Since the 2009 European Directive, all EU countries are required to increase their renewable proportion so that 20% renewable energy is achieved on average across member states by 2020 (European Commission 2009). With regards to Ireland this target is set at 16% renewables of total final consumption – which incorporates the use of renewables in electricity, transport and heat sectors. Within the electricity sector specifically, Ireland has a target of 40% from renewable sources to be achieved by 2020, of which wind promises to be a major contributor (Government of Ireland 2008).

4. Methods

In this study we generate a times series multiple regression model. Controls are included for each hour of the day, day of the week, month and public holidays, as all of these have an effect on the demand for electricity, the availability of wind for generation, and the scheduled maintenance of conventional plant which has an effect on the fuel mix. Murray (2009) highlights that while the price is very closely linked to the demand level in power markets; it tends to be stratified as it reflects the different types of plant which are brought into service on a merit order basis.

Irish hourly data for 2009 from the Single Electricity Market (SEM) is used to identify the main drivers of the shadow price[3] through an OLS regression model. It is expected for the

[3] It should be noted that this price is not a shadow price in the economic sense, in that it is not is the value of the Lagrange multiplier at the optimal solution. However, the Irish market documentation refers to the shadow price (essentially SMP in Figure1) so for consistency we will continue to use this terminology here.

Irish system that the most accurate predictors of the shadow price would be the fuel input prices of oil, gas, coal and carbon price from the day prior to bidding (when bids must be made), and demand and marginal capacity of the day in question. The Shadow Price in a given period is set at the marginal cost of the most expensive unit required to meet demand in the same period. This is consistent with the guidelines for bidding set out in the Irish electricity market (CER 2007; SEM-O 2010), and is described in the following equation:

$$\begin{aligned} ShadowPrice_t = \alpha + \beta_1 NetDemandk_t \\ + \beta_2 NetDemandk_t^2 + \beta_3 Wind + \beta_4 Wind^2 + \beta_5 MarCap_t + \beta_6 Gas_{t-24} + \beta_7 Oil_{t-24} \\ + \beta_8 Coal_{t-24} + \beta_9 Carbon_{t-24} + \varepsilon_t \end{aligned}$$

Net demand refers to total system demand less demand that is met through peat output and imports at time t[4], which is measured on an hourly basis. *Gas Coal, Oil and Carbon* relate to the daily spot prices of these fuels on the global exchange, as the Irish Regulator requires units to bid their fuel costs in this manner. These are set and bid into the market on the day ahead in practice, and therefore are lagged by 24 periods.

As demand increases towards total possible supply available, one would expect prices to increase dramatically due to a scarcity premium. In order to see if this is taking place, we include a marginal capacity (“MarCap”) variable in the model, which can be described as MWOffline / Demand - the number of megawatts which are unavailable for generation as reported by each individual generating unit. This is essentially the difference between the maximum rated number of megawatts a unit is able to supply and their actual availability in a given hour. This is included in the model in order to identify whether a scarcity premium is found to be significant, with a fall in availability resulting in an increase in the price of electricity.

The following table provides summary statistics for all observations of variables included within this study:

Table 1 Summary Statistics

Variable	Units	Obs	Mean	Std. Dev.	Min	Max
ShadowPrice	€	8682	36.044	12.438	14.485	146.570
Net Demand	MW	8682	3380.589	820.180	1469.879	5862.166
Wind	MW	8682	426.933	318.007	0.890	1322.626
MarCap	MW	8682	4.313	3.196	0.991	24.701
Oil	€	8682	44.366	6.874	28.157	54.316
Gas	€	8682	34.635	13.274	15.505	77.094
Coal	€	8682	51.173	5.463	44.120	65.040
Carbon	€	8682	13.353	1.542	8.200	15.900

[4] As peat and imports do not bid into the Irish electricity pool.

5. Results

Table 2 presents the results of the main drivers of shadow price using the fuel prices lagged by 24 hours with robust standard errors. Observations with electricity prices exceeding €150 have been omitted from the model, as prices of this level can be attributed to technical failure rather than normal operation; observations missing values for load have also be omitted. Multicollinearity was tested for, and rejected, by analysing the correlations of the estimated coefficients as opposed to the variables of the independent variables. Serial correlation was not detected.

All independent variables are found to be statistically significant at the 99% level with the exception of the price of coal; as coal serves as a baseload fuel it tends not to set the price of electricity and therefore will not directly affect the shadow price of electricity. Gas and oil do however set the price at varying points along the demand curve, and are therefore highly significant in driving the cost of electricity. The coefficient on gas (0.5607) is around 5 times greater than that of oil (0.1016); this is most likely explained by the fact that just under 60% of Ireland's installed conventional capacity uses natural gas (SEAI 2009). The marginal capacity ("MarCap") variable identifies that there is a statistically significant scarcity premium with regards to the availability of generation; a 1MW increase in the ratio of unavailable plant divided by total demand (the load) results in a price reduction of €0.26/MWh.

Table 2 Regression Output

VARIABLES	(1) Shadow
Demandk	-15.3778***
	(1.256)
Demandk^2	2.7562***
	(0.204)
Wind	-0.0099***
	(0.001)
Wind^2	0.0000***
	(0.000)
MarCap	-0.2575***
	(0.042)
GasLag	0.5607***
	(0.018)
OilLag	0.1016***
	(0.039)
CoalLag	-0.0452
	(0.064)
CarbonLag	0.2679***
	(0.100)
Constant	36.2638***
	(5.196)
Observations	8,664
R-squared	0.8133

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The net demand has a positive effect on the price, as an increase in net demand causes a movement up the merit curve to more expensive generating units, causing the price to increase. This relationship is not linear as both net demand and its square are found to be statistically significant at the 99% level. Irish demand can be seen to be highly cyclical and predictable, as are the prices over time. Figure 3 below represents Demand and Price in the first eight days of June 2011.

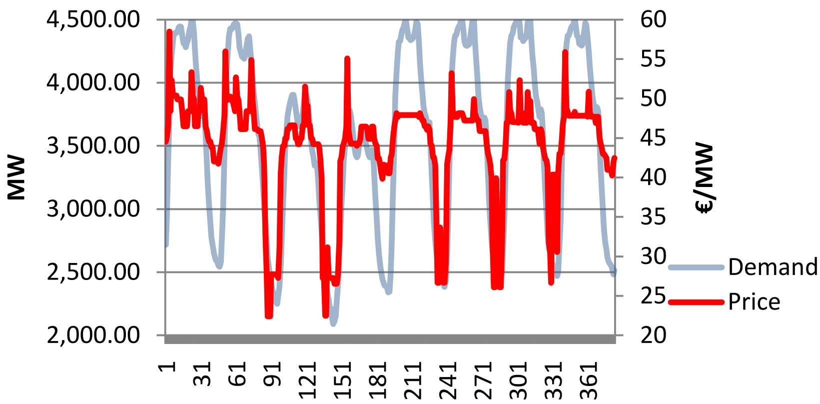

Figure 2 Load & Pool Price end of June 2011

The squared output of wind, while significant, is equal to €/MWh 0.0000 and therefore we can assume that the relationship between the shadow price of electricity and the output of wind to be a linear one. The coefficient on wind is -0.0099, meaning that an increase of one MW of wind on the Irish system led, on average over the course of 2009, to a fall in the shadow price of €0.0099/MWh. In isolation, this may not seem to be a significant amount, particularly given that the mean Shadow Price is €36.044, therefore we will re-estimate our model on an hourly level in order to find the value of the coefficient on wind at each hour in order to value the total saving to the system from having wind more accurately. As wind reduces the demand for generation with higher marginal costs, its value will depend on the demand at the time and the cost of the units it displaces. As a result, using the hourly coefficient should give a reasonable indication of the true shadow price saving on an hourly level; Figure 3 below presents the hourly coefficients on wind.

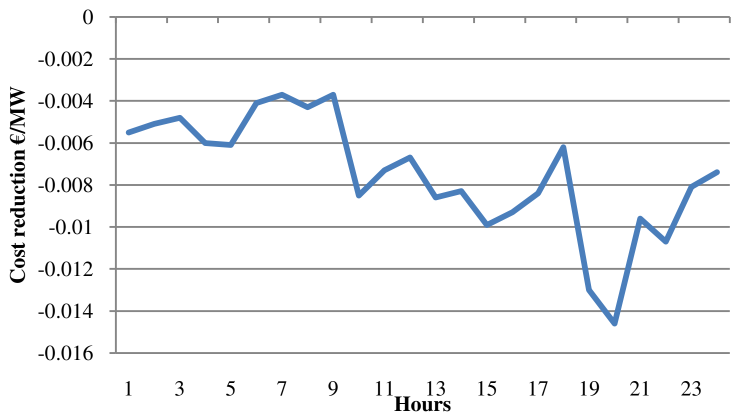

Figure 3 Wind Coefficient

The results show what the value of wind was to the Irish system in 2009, controlling for day of the week and month in question. As expected, the greatest saving to the market coincides with both peak demand and prices, as wind generation at 7pm represents the greatest saving along the merit curve. The value of wind is directly related to the units which it displaces, which is why the value of -0.0189 seen at 7pm is more than double the coefficient seen at 7am (-0.0046).

In order to quantify the price benefit, these coefficients are then multiplied by the historical wind outputs and system demand at each hour of 2009, as shown equation 2 below. The Shadow price of electricity is set by at the marginal cost of the most expensive generator required to meet demand in a given period. As a result, each MW generated receives the same shadow price; a reduction in this price due to wind reduces the price paid to each generator for each unit of electricity that they produce. This allows us to calculate the total saving at each hour of the day which is attributable to wind.

$$\sum Saving_t = \sum Coeff_t * Wind_t * Load_t$$

The results show that the value of wind to the market dispatch has resulted in savings of €141 million in 2009. Ireland's highest daily levels of wind coincide with peak demand, resulting in a significant saving; countries that experience highest wind levels during the night, or periods of low demand may not see the same level of cost savings. The total market dispatch amounted to € 1,284 million over the course of 2009, meaning that if wind output had not been available, the total costs would have been approximately 12% higher than actual values seen. Over this time period the total subsidy received by renewables in the Irish electricity market amounted to €48 million. This relates to the PSO levy in relation to the REFIT and AER schemes, net of administration costs and any interest. The PSO is a levy charged to all electricity customers in Ireland which is designed to recoup the additional costs incurred by purchasing electricity from specified sources, including sustainable, renewable and indigenous sources (CER 2006). This means that the total PSO in 2009 (which is not exclusive to wind generated electricity) is almost three times less than the estimated savings of wind to the dispatch market.

Using the SEAI (2009) average emissions for the Irish electricity market, we can estimate the carbon savings arising from the displaced fossil fuel generation. This value of 0.582 kg/MWh CO_2 is multiplied by the wind output at each hour and the daily carbon price for the same time period lagged by 24 hours, as shown in equation 3. This aggregates to a saving of €29.3 million over the course of 2009. This saving is assumed to be accounted for in our regression model. EPA (2009) values of SO_2 and NO_x for electricity generation are used to assess the savings of this emissions arising from wind generation. These are estimated at €0.5 million and €7.9 million respectively.

As demonstrated in the analysis, this result is heavily dependent on both the level of wind output and total demand at each point in time, and therefore predicting future cost savings will be highly dependent on the assumptions surrounding these parameters. It should also be noted that results are exclusive to the test system, and further study would be needed if attempting to calculate the benefits to other systems.

6. Conclusions

This paper estimates the historic cost savings arising from wind generation in the Irish electricity market using a time series OLS regression model in 2009. This allows us to calculate the extent of the value of wind on an hourly basis over the period analysed. Once the average hourly effect is calculated, we aggregate the total and find that the value of wind to the market dispatch has resulted in savings are of €141 million to the market dispatch. We find that the total costs to the market would have been in the region of 12% higher over the course of the year had no wind output been available. These savings are significantly greater than the subsidy received for wind-generated electricity over this time period, and as a result it can be seen that the positive externalities derived from wind generated electricity outweigh the cost of the subsidy; particularly when one considers the CO_2 saving to the market and accepts that all forms of generation impose integration costs to electricity systems.

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