Energy and Climate Change Committee Call for Evidence: Economics of wind power

Response from the Centre for Energy Policy and Technology, Imperial College London (ICEPT)

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Covering note

This submission has been prepared in the following format: A two page summary – pages 2 and 3 – provide key points/issues. Additional detail is provided in pages 4 through 8, the technical annex.

ICEPT is an interdisciplinary research centre focused upon the interaction of technology and policy. From its base at Imperial College, the centre is uniquely placed to gather insights into technological and scientific developments relevant to contemporary debates in energy policy. ICEPT is funded by a wide range of bodies, including UK research councils, industry, the EU, and NGOs. It is independent and does not exist to promulgate any particular agenda related to wind, renewables or energy policy more widely. The centre also has policy analysis expertise, drawing upon a wide range of system modelling, scenario and technology assessment techniques. ICEPT runs the Technology and Policy Assessment function of the UK Energy Research Centre (www.ukerc.ac.uk). The reports it produces have been widely cited by select committees and in policy documents.

This submission draws upon UKERC reports on the costs and impacts of intermittent generation, investment decisions in electricity generation, and the costs of offshore wind in UK waters. It draws also upon forthcoming UKERC research, which is undertaking a thorough meta-analysis of estimates of the costs of wind, gas, nuclear, solar and CCS. This project also explores the means by which we make judgements on the future costs of power generation. The submission draws upon expertise developed by the authors into the relative costs/performance of various technologies through a wide range of research projects going back to the early 2000s.

The authors experience in meta-analysis indicates the importance of scrutinising methodology carefully, particularly when estimates are outliers emanating from special interest groups. There is considerable agreement around issues, methods and approaches in the international literature from peer reviewed, government and other reputable sources. This note seeks to present this evidence.

2 Page Summary: Key Issues

1. What do cost benefit analyses tell us about onshore and offshore wind compared with other measures to cut carbon? Accounting for the full costs and benefits of different technologies is complex. Complicating factors include potential for cost reduction through deployment (learning by doing), wider industrial or regional benefits, or environmental costs. German cost benefit analyses have been very positive, see point 7 below. Generally speaking decarbonising power generation is more costly than measures to cut demand. However many analyses of long term decarbonisation point to the importance of decarbonising power, with wind a proven and relatively low cost option for doing so. Costs of nuclear and CCS are uncertain, but higher than onshore wind. Offshore wind costs and the costs of first of a kind nuclear/CCS appear similar. In the UK wind also offers a large potential resource. The Annex provides more detail.

2. What do the latest assessments tell us about the costs of generating electricity from wind power compared to other methods of generating electricity? Onshore wind is among the cheapest of the non-fossil options. Wind costs fell steadily during the 1990s until the mid-2000s. Absolute costs for *all* sources have risen recently due to global commodity prices and market factors, but wind costs relative to other generation options have declined, see Table 1 in the Annex. By the mid 2020s the range of forecast costs for onshore wind and gas-fired generation (CCGT) show an overlapping range. Gas prices are uncertain and the cost of wind lies in a range due to varying wind speeds/sites. Figure 1 in the Annex shows the results of a meta-analysis of cost estimates from around the world. Onshore wind is currently about 10-15% more costly than gas in a UK context, and cheaper than estimates for new nuclear.

3. How do the costs of onshore wind compare to offshore wind? Figure 1 and Table 1 in the Annex show that onshore wind costs are substantially below offshore wind, with onshore currently costing around 40% less per unit of electricity. What Figure 1 also shows is that most analyses suggest that the scope for cost reduction in offshore wind is considerably greater than the scope for cost reductions onshore, since the onshore wind industry is relatively mature, and the opportunities for continued cost reductions offshore are more substantial. Details on the sources of cost reduction offshore are provided in the Annex.

4. What are the costs of building new transmission links to wind farms in remote areas and how are these accounted for in cost assessments of wind power? Transmission requirements associated with the government's plans for renewable energy have been assessed in great detail by network operators, utilities, experts, DECC and Ofgem. This Electricity Network Strategy Group (ENSG) first reported on the transmission costs of the 2020 targets in 2009[1]. The estimates were updated in February 2012[2]. The ENSG estimate from 2009 was that around £4.7 billion in total investment in transmission upgrades would be needed to accommodate a mix of onshore and offshore wind, together with other changes to the generation mix.

4.1 A 2011 report from the CCC[3] annualised the ENSG expenditure estimate of £4.7 billion, and distributed it over anticipated electricity demand[4]. The resulting 0.1 p/kWh on bills is reported in the CCC note on bills[5]. The annualised cost amounts to £275 million per year from 2020 on. If we assume 29 million households in 2020, with households accounting for around 30% of demand, the annual cost is around £3.20 per household per year. The latest ENSG capital cost estimate is rather higher at £8.8 billion. Very approximately therefore the estimated transmission cost per household should be increased to around £5.70 per year. These costs are not attributed to individual wind farms.

4.2 Offshore network costs *are* paid for by generators, are borne directly by offshore wind farms and hence already show up in analyses of the costs of the RO, outlined below.

5. What are the costs associated with providing back up capacity for when the wind isn't blowing, and how are these accounted for in cost assessments of wind power? The costs and impacts of the 'intermittent' nature of wind any other renewables has been comprehensively studied by academics, utilities and consultancies from around the world. A thorough systematic review and meta-analysis by the authors in 2006, with input from a wide spectrum of leading experts, indicated that the cost of intermittency amounted to around 0.5 to 0.8 pence per kWh of wind generation, should intermittent generation reach around 20% to 25% electricity supplied in Britain[6]. This work needs updating to reflect 2012 costs, which will be higher, since electricity costs have risen. But more recent analysis by Poyry for the Committee on Climate Change, combined with the ENSG data, provides an indication that the 0.8 p/kWh figure is broadly consistent with contemporary analysis[7]. 0.8 p/kWh of wind is equivalent to annual expenditure of approximately £600 million, at 20% renewables, or £740 million for 25% renewables. Assuming the domestic sector bears 30% of this, the cost per household for intermittency in 2020 is around £6 to £8 per year[8].

6. How much support does wind power receive compared with other forms of renewable energy? Is it possible to estimate how much consumers pay towards supporting wind power in the UK? (i.e. separating out from other renewables) Ofgem produce an annual report on the Renewables Obligation (RO) which identifies the total value of the support provided and the share for each technology. For the most recent data (2010/2011)[9], the total annual value of support for all renewables through the RO was £1.28billion, with onshore wind accounting for 30.9% (£395million) and offshore wind accounting for 20.2% (£258million)[10]. Assuming the domestic sector bears 30% of this across 29 million households, then this translates to around £6.75 per household for onshore and offshore wind combined, compared to around £6.50 for all other renewables. Renewables can exert downward pressure on wholesale electricity market prices. This can partially offset the costs of the RO. By 2020 DECC estimate that the effect on wholesale prices will amount to a bill *reduction* of £20 per household/yr. More details in the Annex.

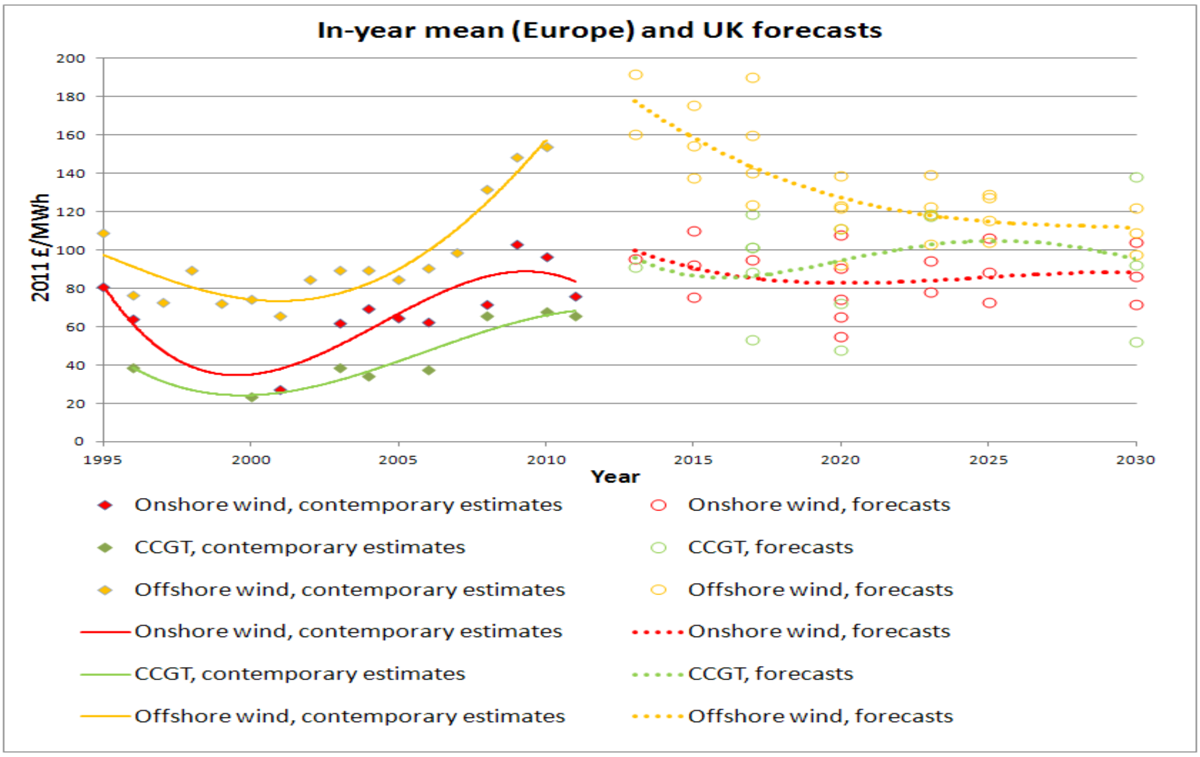
7. What lessons can be learned from other countries? The evidence suggests that stable and investable policies – in particular fixed Feed in Tariffs, FiTs, bring down costs, create industries, allow consumers to invest and generally maximise social benefits. The evidence that more competitive schemes do more to reduce costs is questionable. Indeed the academic evidence suggests that the UK NFFO in the 1990s, an auction based scheme, favoured the big utilities, was antagonistic to domestic manufacturers, created a perceived 'rush' for the best locations, often also the most scenic, and led to disappointing levels of delivery. By contrast, the fixed FiTs in our near neighbours provided a simple and stable system that allowed large levels of local/community ownership and lots of new entrants. This was assisted in some instances through favourable loan schemes from community or state backed banks[11]. Germany has assessed costs and benefits associated with its FiTs and found a strongly positive economic benefit[12]. However the international experience is mixed. Alongside positive experiences are examples of things going wrong; tariffs, planning, grid management[13].

8. What methods could be used to make onshore wind more acceptable to communities that host them? Evidence from countries where wind has already been developed on a much larger scale (e.g. Denmark and Germany) suggests that there is a direct relationship between the extent to which local people can take a meaningful stake in a wind farm, and the extent to which local people object to wind development[14]. The potential for community ownership is further enhanced if financial vehicles exist to facilitate it, as noted above. In the UK context the most straightforward way to encourage greater community/local owned schemes would be to extend the micro-generation FiT for wind from 5 MW to perhaps 50 MW, so that smaller wind farms could benefit from the simplicity and revenue stability that the FiT can provide relative to the RO, and proposed CfD[15].

Relative costs of wind and other technologies

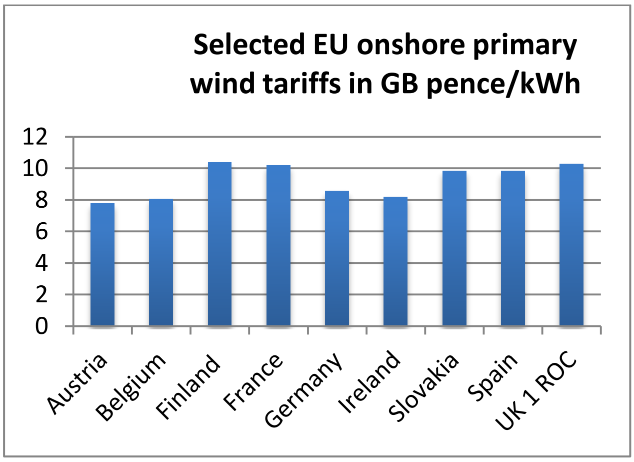
Figure 1 is based upon ongoing UKERC research, which is undertaking a thorough meta-analysis of estimates of the costs of electricity generation technologies, examining how those estimates are arrived at, and assessing what lessons can be drawn from the accuracy or otherwise of past estimates and projections. The left hand half of the diagram shows the historical trajectory of the average (mean) of Europe-wide estimates for electricity generation costs for onshore wind, offshore wind and gas-fired plant. The wide range of UK forecasts, shown on the right hand half of the diagram, result from differing assumptions that studies have adopted for key cost drivers such as capital and operating costs, plant load factors, fuel costs (in the case of gas plant), and discount rates. These estimates do not take into account intermittency/network costs, which tend to increase system costs, or 'merit order effects' (see below) which tend to decrease system costs.

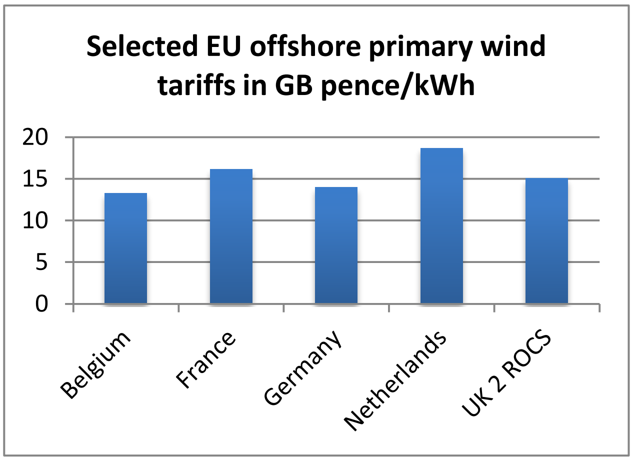
Figure 1 Comparative costs of electricity from CCGT, onshore and offshore wind[16]



Support for wind in other countries – Feed in Tariff rates in the EU

Figures 2 and 3 show FiT rates for selected European countries, for onshore and offshore. This indicates that the UK (assuming 1 ROC for onshore) is towards the upper end of payment levels for onshore wind. UK offshore wind tariffs look around average in comparison to other EU country tariffs. However, both The Netherlands and Germany use a range of tariff rates; an average of the rate is given in Figure 3. The German tariff is dependant on the duration of payment and scheme chosen by system operator, whilst The Netherlands uses four stages of subsidy level that is allocated on a first come first serve basis. It is important to note that both The Netherlands and Germany have much higher rates than the UK at, 23.37 and 23.62 GBP pence/kWh respectively. When, where and how these rates are employed will determine how attractive these countries offshore tariffs are in relation to other country tariffs. UK figures assume £48/MWh for ROCs (2011 ERoc average), and wholesale price of £55/MWh. The latter figure is obviously quite variable, having reached £80/MWh in 2008 and varying between £38 and £58 during 2010 and 2011[17].





Onshore tariffs; *currency conversion to GBP as of 28/06/12, EUR = 1.243 GBP. All rates valid for 2012. Austria rate for 2012-2013; Belgium rate set in 2006, set as a minimum price of certificates; Finland current price valid until end of 2015; France current price set in 2008; Germany price set in 2012, range of rates (average presented in graph); Ireland current price for 2012; Slovakia price set in 2009 valid for 3 years, finishing in 2012; Spain set in 2007 current price.*

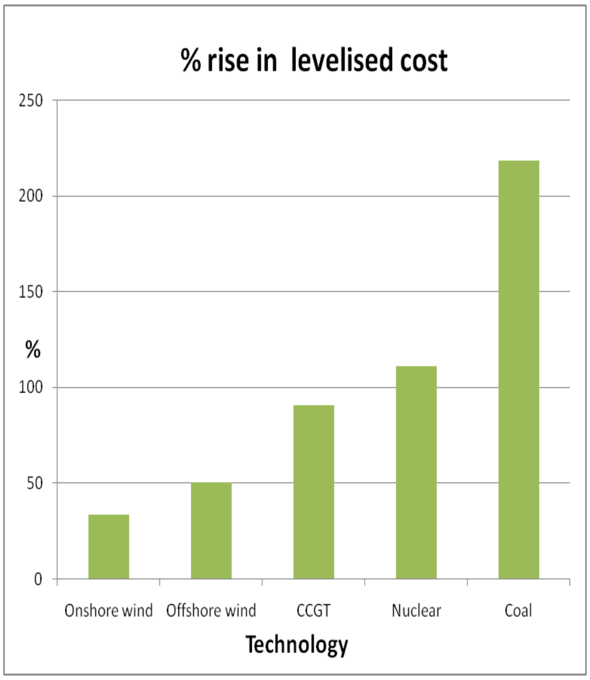
Offshore tariffs; *currency conversion to GBP as of 28/06/12, EUR = 1.243 GBP. All rates valid for 2012. Germany and Netherlands rates are averages of a range of rates provided. Netherlands; 14.05 - 23.37. Germany; 4.35 - 23.62*

Figures 2 and 3 wind tariffs in selected countries[18]

Sources of cost reduction offshore

Whilst onshore wind is a comparatively mature industry with relatively limited scope for major cost reductions (especially since cost savings through increased unit size are limited by physical constraints on handling very large components such as the turbine blades on land), the scope for cost reductions in offshore wind is significant. Major areas of potential cost reduction include increasing turbine size, the introduction of turbines designed specifically for offshore (rather than adapted from onshore designs), improvements in installation techniques, and enhanced reliability through design and optimised maintenance regimes to maximise plant availability and therefore load factor (a key driver of generation costs for wind plant). In addition, the increasing size of the offshore wind market is attracting new entrants, improving competiveness and building confidence and resilience in the supply chain[19].

Table 1 Cost rises by technology[20]



	2006 £/MWh	2009 £/MWh
CCGT	£42	£80
Coal	£32	£102
Nuclear	£46	£97
Onshore wind	£66	£88
Offshore wind	£99	£149

Costs per tonne of carbon saved

Cost per tonne of carbon saved will depend upon a range of factors, these include the cost and financing assumptions made about the wind farm, nature of plant displaced, any wider impacts such as emissions in wind farm construction or from back up plant. There is widespread agreement that the lifecycle emissions associated with wind are small, of the order of 10g/kWh (compared to 380g/kWh for gas plant). Analyses of the impacts of intermittency reviewed by the authors also indicate that any emissions from back plant or extra spinning reserve amount to a few percent at most of the emissions savings from wind that result from reduced use of fossil fuel plant[21].

One of the simplest representations of abatement cost is the so called 'MAC' or Marginal Abatement Cost curve. Over reliance upon them has been criticised for failing to recognise dynamic effects and cost reduction over time, and interactions between choices of technologies and between sectors[22]. It also does not account for the volume of abatement possible over time. Nevertheless most assessments show wind to be a 'mid range' contender, more expensive than energy efficiency but cheaper than many other 'supply side' options.

Wind and wholesale price formation (the 'merit order effect')[23]

Wind power is generated at near zero marginal cost and is therefore generally dispatched when it is available. In the short-term, where the rest of the generating capacity remains unchanged, wind power therefore pushes high marginal cost plant out of the generating mix and wholesale spot prices become depressed, especially at times when wind output is high. This 'displacement' effect is illustrated in Figure 1 where wind is characterized as reducing residual demand because it is always dispatched (subject to transmission constraints). During periods of very high wind (and low demand), where wind output exceeds demand, prices in the GB market could go negative since wind operators would still be willing to trade in the market so long as the price they 'pay' is less than the value of a Renewable Obligation Certificate. This will be exacerbated if thermal capacity is kept running to avoid cycling costs.

Similar conditions occur in other markets, since the Feed in Tariffs common in other countries also insulate wind generators from wholesale price movements. Indeed in many instances renewables are given priority access by system operators. Studies from overseas are therefore relevant to the British situation and numerous modelling and empirical studies have attempted to estimate the impact of renewables on electricity markets. These studies all conclude that wind will depress prices. For example:

- Sensfuss et al (2008) use a simulation model to estimate the impact of renewables (mainly wind) on spot market prices in Germany. They estimate that a wind penetration of around 10% in 2006 (52 TWh) results in a reduction of average spot price of €7.83 / MWh (approximately 15%), compared to a counterfactual with no wind. Neubarth et al (2006) conduct a statistical analysis of time-series data in Germany in 2004/5 when wind penetration was around 5%, concluding that wind power reduces the average daily spot market price by €1.89/MWh for every GW of average available wind energy. They estimate that the 18.4 GW of installed capacity resulted in an overall average price reduction of €6.08/MWh (approximately 12%).

- A modelling study by the regulatory authorities in Ireland (CER and UREGW, 2009) looked at the effect of wind on wholesale prices under a range of scenarios with wind penetrations ranging from 16% to 42% and with different mixtures of conventional generation. For most of the scenarios prices were significantly depressed (by between 9 and 21%). However, the exception was a scenario which assumed a high proportion of Open Cycle Gas Turbines (OCGTs), where prices were 10% higher than the counterfactual.

- Moesgaard and Morthorst (2007) statistically analyse spot prices between 2004 and 2007 in Western Denmark and concluded that they were reduced by 5-15% as a result of wind power. During this period the penetration of wind was approximately 20-25%.

In summary, these studies generally conclude that wind has a negative impact on average spot prices of the order of 1% for every 1% of additional wind penetration. Price effects may be more extreme under similar wind penetrations in GB because it has relatively low supply-side flexibility - interconnection and hydropower capacity - to balance fluctuations in wind output, compared to some of the countries studied above (DECC, 2009b).

In the long term, where the make-up of the conventional generation mix can change more radically (through closures and new build), it is more difficult to predict the impact of wind on electricity prices. The lower load factors experienced by plants with relatively high capital costs (and low marginal costs) means they may be replaced by peaking plants with low capital cost and higher marginal costs, such as OCGTs (Nicolosi and Fursch, 2009; Saenz de Miera et al, 2008). This would push up average prices (see Figure 4).

Figure 4: The long-term impact of wind on electricity prices (Author's illustration)

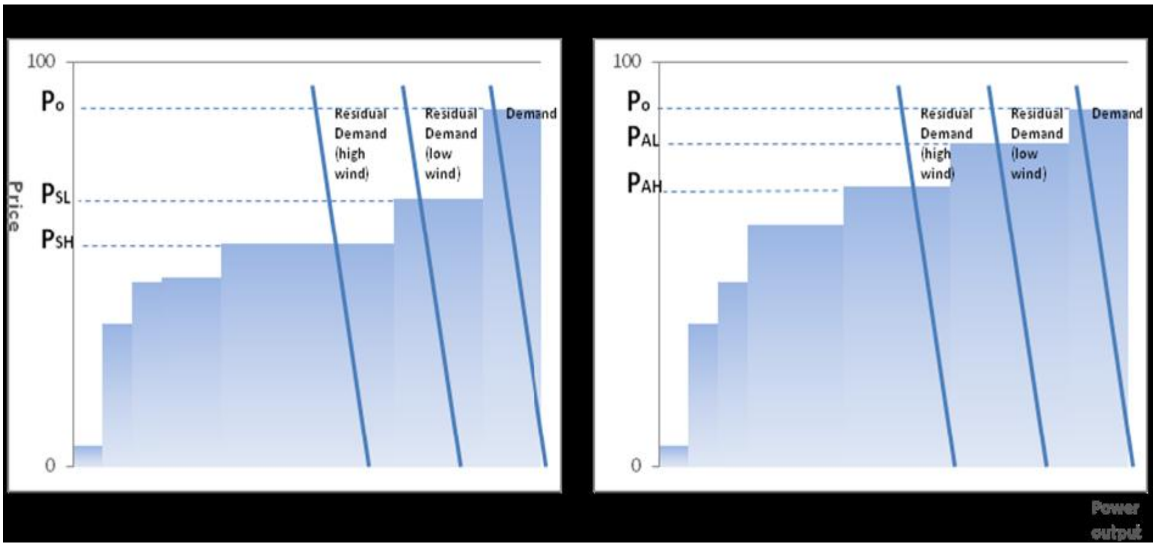


Figure 1 is an illustrative representation of equilibrium prices in two peak demand scenarios: (i) where the conventional generation mix order remains dominated by CCGTs and coal stations and (ii) where the conventional generation mix is adapted to a high wind penetration with higher proportion of higher marginal cost plants (such as OCGTs). Under a standard generation mix, the market clears at PSL and PSH under high and low wind conditions respectively. Under a 'wind-adapted' generation mix, the corresponding prices are higher, at PAL and PAH. In this way, the dynamics of the conventional generation mix as a response to wind could work to push up electricity prices in the long-term. This could partially offset or even exceed the 'displacement' effect of wind.

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[1] http://webarchive.nationalarchives.gov.uk/20100919181607/http://www.ensg.gov.uk/assets/ensg_transmission_pwg_full_report_final_issue_1.pdf

[2] http://www.decc.gov.uk/en/content/cms/meeting_energy/network/ensg/ensg.aspx

[3] http://www.theccc.org.uk/reports/household-energy-bills

[4] 320 TWh - Personal Communication with the CCC secretariat, Feb 2012

[5] http://www.theccc.org.uk/reports/household-energy-bills

[6] See http://www.ukerc.ac.uk/support/Intermittency and Gross R, Heptonstall P, 2008, *The costs and impacts of intermittency: An ongoing debate*, Energy Policy (36) Pages: 4005-4007; Skea J, Anderson D, Green T, Leach, M, 2008, *Intermittent renewable generation and maintaining power system reliability*, IET Generation, Transmission & Distribution, (2) Pages: 82-89; , 2007, *Renewables and the grid: understanding intermittency*, Proceedings of ICE Energy (161) Pages 31-41

[7] The CCC's 2011 total figure is 1 p/kWh for intermittency and transmission combined, and as noted above, the transmission cost element is around 0.1 p/kWh of intermittent renewables.

[8] Assumes 29 million households and electricity sales of 370 TWh, households 30% of sales. The UKERC work also notes that cost estimates lie in a range, which depends upon the nature of the system (extent of interconnection, availability of demand response, mix of fossil/nuclear plant) mix of renewables and operational rules for the System Operator.

[9] See *Renewables Obligation Annual Report 2010-2011*, Ofgem, London, available from http://www.ofgem.gov.uk/Pages/MoreInformation.aspx?docid=278&refer=Sustainability/Environment/RenewablObl

[10] Landfill gas accounted for 20.1% (£257million), biomass including co-firing 19.4% (£248million), hydro power 7.5% (£96million), with the remainder including sewage gas and PV accounting for around 2% (£26million)

[11] See Gross R, Heptonstall P, 2010, *Liberalised Energy Markets: an obstacle to Renewables?* In Rutledge I, Wright P (eds.), *UK energy policy and the end of market fundamentalism*, Oxford University Press, Oxford

[12] German data is presented in http://www.dbcca.com/dbcca/EN/_media/Paying_for_Renewable_Energy_TLC_at_the_Right_Price.pdf

[13] Deutsche Bank retains a wide ranging library of international review papers http://www.dbcca.com/dbcca/EN/investment_research.jsp
[14] As 11.
[15] The proposed CfD should offer revenue stability overall, but this will be subject to securing a PPA and achieving the reference price for power output. At the time of writing the micro-gen FiT apears far simpler.
[16] This graphic appeared in the Guardian and is based on data collected by the authors for UK Energy Research Centre project: http://www.ukerc.ac.uk/support/tiki-index.php?page=Cost+Methodologies
[17] http://www.decc.gov.uk/assets/decc/11/about-us/economics-social-research/3593-estimated-impacts-of-our-policies-on-energy-prices.pdf
[18] http://www.e-roc.co.uk/trackrecord.htm
http://www.consumerfocus.org.uk/policy-research/energy/paying-for-energy/wholesale-retail-prices
http://www.decc.gov.uk/assets/decc/11/about-us/economics-social-research/3593-estimated-impacts-of-our-policies-on-energy-prices.pdf
http://www.res-legal.de/en/search-for-countries.html
[19] Greenacre P, Gross G, Heptonstall P, 2010, *Great Expectations: The cost of offshore wind in UK waters*, UK Energy Research Centre, London, http://www.ukerc.ac.uk/support/tiki-index.php?page=Great+Expectations:+The+cost+of+offshore+wind+in+UK+waters
[20] Adapted from: Heptonstall P, Gross R, Greenacre P, Cockerill T, 2012, *The cost of offshore wind: Understanding the past and projecting the future*, Energy Policy (41) Pages 815-821
[21] http://www.ukerc.ac.uk/support/Intermittency
[22] http://www.whoseolympics.org/bartlett/energy/news/documents/ei-news-290611-macc.pdf
[23] Excerpt from Steggals W, Gross R, Heptonstall P, *Winds of change: How high wind penetrations will affect investment incentives in the GB electricity sector*, Energy Policy, 2011, Vol:39, Pages:1389-1396